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Highlights

- Evaluation of Obudu Beeswax Fireclays Blended with Zircon
- Determination of Safety Level Performance Evaluation of Refractory

Discovering Thoughts, Inventing Future

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Evaluation of Obudu Beeswax for Lost-Wax Casting Process

By Ochieze B. Q., Ochieze U. P., Anyakwo C. C., Undiandeye J. U. & Ochieze, I. A.

Federal University of Technology

Abstract- Beeswax from Obudu, Nigeria, was evaluated to assess its suitability for the lost-wax casting process. Modulated differential scanning calorimeter showed a melting point of 66.31oC and melting enthalpy165.5J/g. Compression test specimens were subjected to various cooling media in the air, refrigeration (-4°C) and liquid nitrogen (-197°C) to ascertain which condition will provide the best result and most appropriate for processing the wax. Results showed that naturally air-cooled samples had the highest compressive strength of 577.7 kPa and a density of 0.941g/cm^3. However, the samples cooled in liquid nitrogen fumes were fast to solidify in 0.5 minutes as compared to 90 minutes for air cooling. These samples were also the easiest to remove from the mold due to very high shrinkage but showed the lowest compression strength of 471.5 kPa. The prototype beeswax 'Q6' pattern adhered tenaciously to the refractory slurry, melted at a low temperature, left no remnant residue upon melting out, maintained dimensional accuracy and good replication of intricate details due to the good compressive strength.

Keywords: beeswax modulated differential scanning calorimeter, melting point, compressive strength, and beeswax pattern.

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Evaluation of Obudu Beeswax for Lost-Wax Casting Process

Ochieze B. Q. [α], Ochieze U. P. [σ], Anyakwo C. C. [ρ], Undiandeye J. U. [ω] & Ochieze, I. A. [¥]

Abstract- Beeswax from Obudu, Nigeria, was evaluated to assess its suitability for the lost-wax casting process. Modulated differential scanning calorimeter showed a melting point of 66.31ºC and melting enthalpy165.5J/g. Compression test specimens were subjected to various cooling media in the air, refrigeration (-4ºC) and liquid nitrogen (-197ºC) to ascertain which condition will provide the best result and most appropriate for processing the wax. Results showed that naturally air-cooled samples had the highest compressive strength of 577.7 kPa and a density of 0.941g/cm^3. However, the samples cooled in liquid nitrogen fumes were fast to solidify in 0.5 minutes as compared to 90 minutes for air cooling. These samples were also the easiest to remove from the mold due to very high shrinkage but showed the lowest compression strength of 471.5 kPa. The prototype beeswax 'Q6' pattern adhered tenaciously to the refractory slurry, melted at a low temperature, left no remnant residue upon melting out, maintained dimensional accuracy and good replication of intricate details due to the good compressive strength. It gave a very smooth mold surface finish after drying as a result of its waterproofing nature. The combined effect of all these made the beeswax remarkably suitable for the lost-wax molding process.

Keywords: beeswax modulated differential scanning calorimeter, melting point, compressive strength, and beeswax pattern.

I. Introduction

As defined by Encyclopedia Britannica, beeswax is a commercially useful animal wax secreted by the worker bee to make the cell walls of the honeycomb. The honeycomb is generally discarded as waste in the open field thus polluting the environment. Also, this dump site attracts bees and consequently posing severe health and safety concern to the people. Beeswax are used in various applications which include; candle making (religious ordinances often specify its use for ceremonial church candles), artificial fruit and flowers, modeling wax, manufacture of furniture and floor waxes, leather dressings, waxed paper, lithographic inks, cosmetics, and ointments.

There are no known references that deal with the physical and mechanical properties of Obudu beeswax as well as its use for casting activities. The corresponding literature review vindicates this.

Graig et al., 1967, studied the use of beeswax in dentistry at the University of Michigan and reported that the strength properties are particularly important when significant expansion takes place in the investment for dental applications.

Kissi in 2011, evaluated casting of hollow artifacts produced by Ghanaian traditional metals miths and suggested that the use of molten wax to produce hollow wax patterns in P.O.P molds should be employed to ensure direct duplication of the original object without creating parting lines in the inner walls of the model.

Hossain et al., 2009, studied the physical and mechanical properties of paraffin and beeswax to simulate the rocking behavior for water jet drilling and concluded that natural beeswax could be a good substitute for reservoir rocks.

Giuseppe et al., in 2015 studied the thermal and mechanical properties of halloysite nanotubes (HNT)/beeswax composites at various compositions and stated that a slight loss of beeswax crystallinity occurred upon HNT addition.

Zhang et al., 2011, investigated the thermal behavior of four insect waxes and obtaineda melting point of 70.34°C and melting enthalpy of 168.1J/g for beeswax.

In 2000, Dong-Joo et al. studied the effect of mold temperature and cooling rate on mechanical properties of press consolidated thermoplastic composite and the results show that crystallinity decreased with increasing cooling rate with the slow cooled specimen having high fracture toughness.

The characteristic properties of Obudu beeswax will be of interest from an academic viewpoint as well as in the industry since these properties are novel. The knowledge of the characteristics of Obudu beeswax is also important since it is locally available and has no known engineering, medical and other applications. Mechanical and thermal properties are therefore imperative for foundry and related applications since the wax is subjected to forces that arose during investment and setting of molds and to temperature changes resulting from curing reactions, especially during the water glass molding process. In situations where shrinkage takes place, as it is always the case during the setting of the investment, a lot of stresses are applied to the wax pattern which they should be able to

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withstand and maintain dimensional accuracy of the mold and its various intricate regions.

This work, therefore, investigated the suitability of Obudu beeswax for lost-wax molding by determining its melting point, compressive strength and mold surface finish.

II. Materials and Methods

a) Materials

The scrap honeycomb, which contains beeswax, was obtained from beekeepers in Obudu, Cross River State, Nigeria.

b) Methods

i. *Rendering*

This is the removal of foreign materials such as dead bees, dirt, and twigs embedded in the honeycomb. Figure 1 show the sorted scrap honeycombs which were melted with large quantity of water and then filtering through qualitative filter paper. During melting, the temperature of the water was constantly below 100°C (boiling point of water). Below the boiling point of water, there was no spillover of the molten beeswax, which is flammable, into the heating source, thereby preventing violent fire outbreak. Water and wax passed through the filter paper, leaving behind some residues. The clean beeswax which solidified as a hard-yellow mass upon cooling floated on top of the water. It was then removed for test sample preparation and pattern making. Figure 2 shows rendered beeswax.

Figure 1: Sorted out honeycomb containing beeswax

Figure 2: Rendered beeswax

ii. *MDSC Analysis*

Modulated Differential Scanning Calorimeter, MDSC 2920, manufactured by TA Instruments was used for the analysis. Samples of 20mg each cut with stainless steel scissors and tweezers were weighed on Sartorius BP410 digital laboratory balance. Figure 3 shows the weighing of sample and aluminum hermetic sample pan with lid, TA Instruments 900793.901.

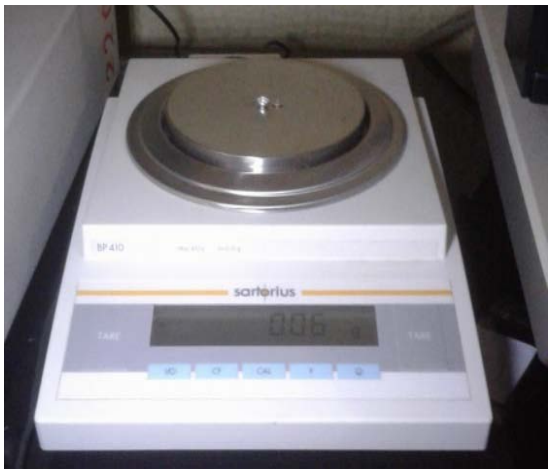

Figure 3: Weighing of the sample with hermetic aluminum sample pan with the lid on Sartorius BP410 digital laboratory balance

Selection of Aluminum pans with lids for both the sample and empty reference pans and placement in their respective positions in the heating cell.

Experimental parameters (sample and instrument information) were keyed in through the TA universal controller 2000. The ramp rate of 5°C/min and an end temperature of 300°C were selected. By pressing the START key on the instrument Control program, the instrument automatically ran the experiment to completion. Figures 4 and 5 show the MDSC 2920 and the experimental parameters respectively. A real-time plot was generated simultaneously. Both the

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experimental considerations and the real-time plot automatically saved in the system for subsequent recall and analysis. Figure 6 shows the thermo gram of the experimental result.

Figure 4: TA Instruments, MDSC 2920

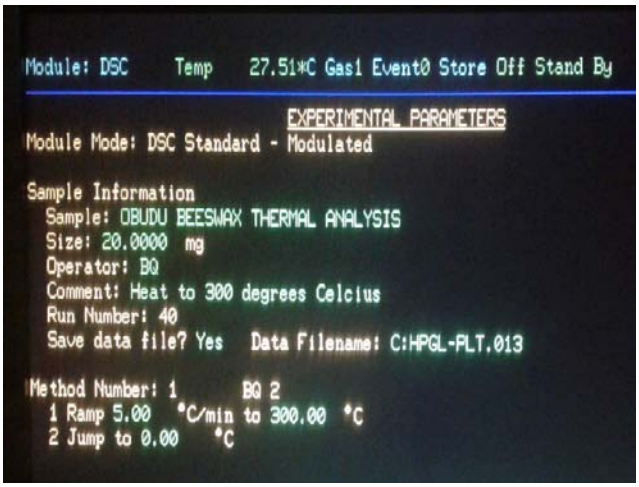

Figure 5: MDSC experimental parameter of Obudu beeswax

Figure 6: Thermogram of Obudu beeswax

iii. *Density evaluation*

The density of the beeswax was determined by using the relationship between mass which was 25.92 gand volume. The metrological dimensions of the sample, diameter 24.16mm and a length of 60.12mm were measured using Mitutoyo Absolute Digimatic vernier caliper and gave a volume of 27.55cm^3. A density of 0.941g/cm^{3}was derived using the following expression;

$$Density = \frac{Mass}{Volume} \quad (1)$$

iv. *Mechanical properties evaluation*

The compression specimens were prepared by re-melting the rendered beeswax and pouring it into preheated split stainless-steel molds. Figure 7 shows the samples cooled in various media; air, liquid nitrogen, and refrigerator.

Figure 7: Beeswax samples cooled in various media; air, liquid nitrogen, and refrigerator.

Uniaxial compression tests were performed on the beeswax samples using a retrofitted Ametek EZ 250 tension/compression tester, Figure 7. The dimensions of the specimens were diameter 24.16mm and 60.12mm length. The length-to-diameter ratio was about 2.5. The force applied was at a travel rate of 15mm/minute. Figure 8 shows the beeswax samples in the tension/compression strength test machine with digital readout of linear travel and applied force. The compressive strength calculated by dividing the measured peak force value by the cross-sectional area of the sample according to the stress equation:

$$\sigma = \frac{\text{Peak Force}}{\text{Cross} - \text{sectional Area}} \quad (2)$$

Figure 8: Beeswax samples on tension/ compression tester

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Table 1: Compressive Strengths at various cooling media

SN	Cooling medium	Compressive Strength (kPa)
1	Liquid Nitrogen	471.5
2	Refrigerator	541.9
3	Natural Air	577.7

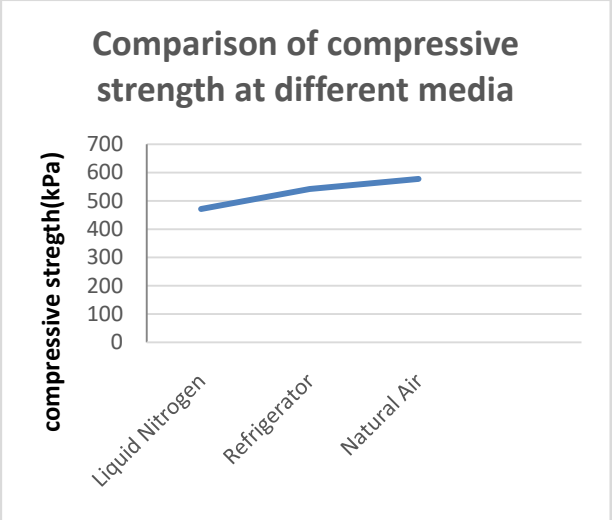

Figure 9: Compressive Strengths at various cooling media

III. Results and Discussions

a) MDSC Analysis

The results of the modulated differential scanning calorimetry showed a melting point of 66.31°C which is in agreement with works of Royal Bees, 2018, who obtained a range of 62 to 72°C. The melting enthalpy was 165.5J/g, which is close to values obtained by Zhang et al., 2011. From the the rmogram, we can see that the wax was stably liquid from the melting point to 172°C, after which a decrease in heat flow occurred. This effect is suggestive of some exothermic reaction and possible vaporization of the beeswax. Therefore, all wax must have been lost from the mold before this temperature is reached provided here is an adequate channel for its exit.

b) Density measurement

The experimentally calculated density is 0.941g/cm^{3}was close to 0.947 - 0.985g/cm^{3}obtained by Charles et al., 1940 and 0.96g/cm^3 by Khamdaeng et al., 2016. It notes that properties of beeswax vary by location and method by which the honey was cultured (Charles et al., 1940). The density value which was less than 1g/cm^3, the density of water, was responsible for the floating of the beeswax on water.

c) Compressive strength

The compressive strength depends on the rate of cooling. The experiment shows that fast cooling has a negative effect on compressive strength, i.e., the slower the cooling rate, the higher the compressive strength. Thus, the naturally air-cooled samples had the highest value of 577.7kPa, followed by samples cooled in the refrigerator, 541.9kPa and lastly in liquid nitrogen fumes, 471.5kPa. This behavior is in line with the behavior of polymers. Slowly cooled polymer specimen had high fracture toughness than fast cooled ones (Dong-Joo et al., 2000).

Natural air-cooling offered the best alternative regarding yielding good compressive strength, reduced cost as no additional facilities were required, especially in safe handling liquid nitrogen.

d) Prototype beeswax pattern and mold

The prototype mold was made by first making a beeswax pattern. Letter Q and number 6 were drawn on cardboard paper and traced on the solid beeswax. They were subsequently carved out with sculptor's scrapper and smoothened. See Figure 10. Refractory slurry made of Plaster of Paris molded on the pattern contained in a metal flask. After setting and curing, the mold was gradually heated to a temperature of 120°C at a rate of 2°C/minute for 60 minutes to lose the wax. Figure 11 shows the revealing mold cavities.

Figure 10: Beeswax pattern

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Figure 11: Dried mold revealing the mold cavities

IV. Conclusions

Evaluation of Obudu beeswax for lost-wax casting process was successful.

The melting point of 66.31°C, which is considerably low, lends itself to ease of beeswax use.

The long-range liquid phase, from 66.31 to 172°C, makes it possible to lose all wax from the mold provided there is an adequate channel for its exit.

The air-cooled samples had the highest compressive strength of 577.7kPa, which was responsible for achieving the high dimensional accuracy and good replication of intricate details.

The prototype sample mold made from beeswax 'Q6' pattern showed excellent surface finish, good replication of intricate details as well as good dimensional accuracy.

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Development of Boundary Element Method in Polar Coordinate System for Elasticity Problems

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Keywords: polar coordinates; elasticity problem; boundary element method; fictitious load method; boundary value problem.

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Abstract- The article presents an exact version of the boundary element method, in particular, the fictitious load method used to solve boundary value and boundary-contact problems of elasticity. The method is developed in the polar coordinate system. The circular boundary of the area limited with the coordinate axes of this system is divided not into small segments like in case of a standard boundary element method (BEM), but into small arcs, while the linear part of the boundary divides into small segments. In such a case, the considered area can be described more accurately than when it divides into small segments, and as a result, a more accurate solution of the problem is obtained. Two test boundary-contact problems were solved by using a boundary element method developed in the polar coordinate system (PCSBEM), and the obtained numerical values are presented as tables and graphs.

Keywords: polar coordinates; elasticity problem; boundary element method; fictitious load method; boundary value problem.

I. Introduction

The boundary element method [1, 2] is a helpful tool to solve the problems of computational mechanics. Many researchers and scientists use standard BEM, with the boundary approximation done by using linear segments (boundary elements), or standard BEM is improved by considering the conditions of a given problem [1-19]. The advantage of using linear boundary elements is the opportunity to analytically calculate the integrals, while with curvilinear elements generally, it is possible to do numerical integration [20].

The boundary element method, in particular, the fictitious load method formulated to solve the boundary value and boundary-contact problems of elasticity for a circular ring and its parts are improved in the present paper if considering that the circular segment of the boundary is divided into arcs instead of linear segments. This allows to describe the considered area more accurately and to arrive at a more accurate solution of the problem. So, when the considered area is limited with circles or their parts, i.e., with the coordinate axes of the polar coordinate system, then by dividing the circle into small arcs, we can formulate BEM in the polar coordinate system with all integrals solved analytically. In particular, a fictitious load method is considered in the polar coordinate system, whereas it was described in a Cartesian coordinate system by Crouch and Star field [1].

The article gives a fundamental solution written down in polar coordinate systems serving as a basis to obtain a numerical solution, and a problem of constant forces distributed along the arc is considered. A numerical procedure is presented and boundary coefficients of influence are written out.

Two test boundary-contact problems are solved:

1. Elastic equilibrium of an infinite area with a circular hole is studied when a circular ring inserts near the hole; normal constant stress is given on the internal surface of the ring, the body is free from stresses in the infinity, and the conditions of continuity of displacements and stresses are given on the contact line. Numerical values are obtained by using: a) analytical solution, b) standard BEM, i.e., when a circular boundary divides into linear segments, and c) PCSBEM, i.e., when the boundary divides into arcs, and the results obtained in all three cases are compared to one another.
2. A boundary-contact problem is solved for a double-layer circular ring when the internal circular boundary is loaded with a normal variable force, the outer boundary is not loaded, and conditions of a rigid contact are given for the contact line. The numerical results are obtained by using standard BEM and PCSBEM and are compared to one another. MATLAB software was used to obtain the relevant numerical values and graphs for both problems.

II. The Fundamental Solution in the Cartesian Coordinate System

Let us consider the problem shown in Fig. one known as Kelvin's problem of plane deformation [1].

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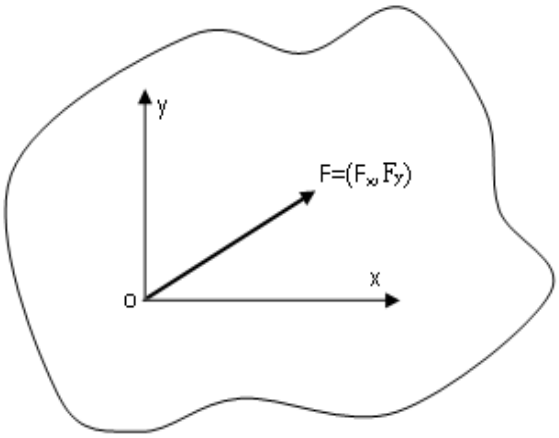

Figure 1: Kelvin's problem for plane deformation

$F=(F_x,F_y)$ forces in Fig. 1 are a line of the point force applied along axis z in the infinite elastic plane.

The solution to this problem is given by the following function [1]:

$$g(x,y)=-\frac{1}{4\pi(1-\nu)}\ln\sqrt{(x^2+y^2)}\ , \tag{1}$$

where ν is the Poisson's ratio.

The displacements will be written down as follows:

$$u_x(x,y)=\frac{F_x}{2G}\left[(3-4\nu)g-xg_{,x}\right]+\frac{F_y}{2G}\left(-yg_{,x}\right),$$
$$u_y(x,y)=\frac{F_x}{2G}\left(-xg_{,y}\right)+\frac{F_y}{2G}\left[(3-4\nu)g-yg_{,y}\right], \tag{2}$$

where $G=\frac{E}{2(1+\nu)}$ is shear modulus, and E is Young's modulus.

For the plane deformation, the stresses for Kelvin's problem will be written down as follows:

$$\sigma_{xx}(x,y)=F_x\left[2(1-\nu)g_{,x}-xg_{,xx}\right]+F_y\left(2\nu g_{,y}-yg_{,xx}\right),$$
$$\sigma_{yy}=F_x\left(2\nu g_{,x}-xg_{,yy}\right)+F_y\left[2(1-\nu)g_{,y}-yg_{,yy}\right] \tag{3}$$
$$\sigma_{xy}(x,y)=F_x\left[(1-2\nu)g_{,y}-xg_{,xx}\right]+F_y\left[(1-2\nu)g_{,x}-yg_{,xy}\right]$$

As it can be seen from (1), (3), the stress at point $x=0,\quad y=0$ has the singularity. It can be shown that these stresses correspond to the point force at the origin of coordinates [21].

For the sake of simplicity, we mean that $F_i=(F_x,F_y)$ force is applied to the origin of coordinates.

III. The Fundamental Solution in the Polar Coordinate System

Let us write down formulae (1), (2) and (3) in polar coordinate system $r,\vartheta\ (0\le r<\infty,0\le\vartheta<2\pi)$

$$\tilde{u}_x(r,\vartheta)=\frac{F_x}{2G}\left[(3-4\nu)g_1-r\cos\vartheta g_{1,x}\right]+\frac{F_y}{2G}\left(-r\sin\vartheta g_{1,x}\right),$$
$$\tilde{u}_y(r,\vartheta)=\frac{F_x}{2G}\left(-r\cos\vartheta g_{1,y}\right)+\frac{F_y}{2G}\left[(3-4\nu)g_1-r\sin\vartheta g_{1,y}\right] \tag{4}$$

and for the components of the stress tensor we will obtain:

$$\tilde{\sigma}_{xx}(r,\vartheta)=F_x\left[2(1-\nu)g_{1,x}-r\cos\vartheta g_{1,xx}\right]+F_y\left(2\nu g_{1,y}-r\sin\vartheta g_{1,xx}\right),$$
$$\tilde{\sigma}_{yy}(r,\vartheta)=F_x\left(2\nu g_{1,x}-r\cos\vartheta g_{1,yy}\right)+F_y\left[2(1-\nu)g_{1,y}-r\sin\vartheta g_{1,yy}\right], \tag{5}$$
$$\tilde{\sigma}_{xy}(r,\vartheta)=F_x\left[(1-2\nu)g_{1,y}-r\cos\vartheta g_{1,xx}\right]+F_y\left[(1-2\nu)g_{1,x}-r\sin\vartheta g_{1,xy}\right],$$

[22]. Following certain algebraic transformations, we obtain the following expression for the function $g(x,y)$:

$$g(x,y)\equiv g_1(r,\vartheta)=-\frac{1}{4\pi(1-\nu)}\ln r.$$

For the components of a displacement vector, we will obtain the following equations:

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where $g_{1,x}$, $g_{1,y}$, $g_{1,xx}$, $g_{1,yy}$, $g_{1,xy}$ in the polar coordinate system have following form:

$$g_{1,x} = -\frac{1}{4\pi(1-\nu)}\frac{\cos\vartheta}{r}, \quad g_{1,y} = -\frac{1}{4\pi(1-\nu)}\frac{\sin\vartheta}{r},$$

$$g_{1,xx} = \frac{1}{4\pi(1-\nu)}\frac{\cos(2\vartheta)}{r^2}, \quad g_{1,yy} = -\frac{1}{4\pi(1-\nu)}\frac{\cos(2\vartheta)}{r^2},$$

$$g_{1,xy} = \frac{1}{4\pi(1-\nu)}\frac{\sin(2\vartheta)}{r^2}.$$

By using the superposition principle, we can solve the problem for an infinite elastic body, with a set of point forces acting at any of its points. If distributing such forces continuously along some line of the plane, we will obtain a problem with the forces given along this line.

IV. Constant Forces Distributed Along the Curve

Let us consider the following problem: constant $t_r = P_r$ and $t_\vartheta = P_\vartheta$ forces are applied to the $\vartheta_1 \le \vartheta \le \vartheta_2$ arc of a circle with radius r in an infinite body. This problem can be solved by integrating a fundamental solution.

Let us divide arc MN into the elements with a length of $d\xi$ (See Fig. 2). Then, the sum of the forces acting on the arc element with its center at the point (r,ξ), equals $F_i(\xi) = P_i \cdot r d\xi$, where index i denotes r or ϑ. To solve this problem, let us insert the expressions of $F_r(\xi)$ and $F_\vartheta(\xi)$ forces in (4) and (5), change ϑ with $\vartheta - \xi$ and integrate the obtained expressions with ξ from ϑ_1 to ϑ_2. The following formulae are obtained for displacements:

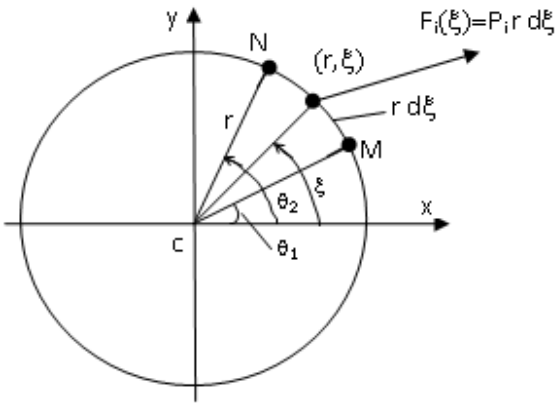

Figure 2: Integration of a fundamental solution

$$\begin{aligned}
\bar{u}_x = \frac{r^2}{8G\pi(1-\nu)}\{&P_\vartheta[(3-4\nu)(\vartheta_1-\vartheta_2)\ln r + 0.5(\vartheta_1-\vartheta_2) \\
&+ 0.5(\sin(2(\vartheta-\vartheta_1)) + \sin(2(\vartheta-\vartheta_2)))] \\
&- 0.25P_r\cos(2(\vartheta-\vartheta_1)) - \cos(2(\vartheta-\vartheta_2))\}, \\
\bar{u}_y = -\frac{r^2}{8G\pi(1-\nu)}\{&0.25P_\vartheta(\cos(2(\vartheta-\vartheta_1)) - \cos(2(\vartheta-\vartheta_2))) \\
&+ P_r[-(3-4\nu)(\vartheta_1-\vartheta_2)\ln r + 0.5(\vartheta_1-\vartheta_2) \\
&+ 0.25(\sin(2(\vartheta-\vartheta_1)) - \sin(2(\vartheta-\vartheta_2)))]\},
\end{aligned} \tag{6}$$

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and the following formulae are obtained for stresses:

$$\begin{aligned}
\bar{\sigma}_{yy} = -\frac{r}{8\pi(1-\nu)}\{&P_\vartheta\left[(4\nu-1)(\sin(\vartheta-\vartheta_1)-\sin(\vartheta-\vartheta_2))\right.\\
&\left.-\frac{1}{3}(\sin(3(\vartheta-\vartheta_1))-\sin(3(\vartheta-\vartheta_2)))\right]\\
&-P_r\left[(5-4\nu)(\cos(\vartheta-\vartheta_1)-\cos(\vartheta-\vartheta_2))\right.\\
&\left.-\frac{1}{3}(\cos(3(\vartheta-\vartheta_1))-\cos(3(\vartheta-\vartheta_2)))\right]\},\\
\bar{\sigma}_{xx} = -\frac{r}{8\pi(1-\nu)}\{&P_\vartheta\left[(5-2\nu)(\sin(\vartheta-\vartheta_1)-\sin(\vartheta-\vartheta_2))\right.\\
&\left.+\frac{1}{3}(\sin(3(\vartheta-\vartheta_1))-\sin(3(\vartheta-\vartheta_2)))\right]\\
&-P_r\left[(4\nu-1)(\cos(\vartheta-\vartheta_1)-\cos(\vartheta-\vartheta_2))\right.\\
&\left.+\frac{1}{3}(\cos(3(\vartheta-\vartheta_1))-\cos(3(\vartheta-\vartheta_2)))\right]\},\\
\bar{\sigma}_{xy} = -\frac{r}{8\pi(1-\nu)}&P_\vartheta\left[(4\nu-3)(\cos(\vartheta-\vartheta_1)-\cos(\vartheta-\vartheta_2))\right.\\
&\left.+\frac{1}{3}(\cos(3(\vartheta-\vartheta_1))-\cos(3(\vartheta-\vartheta_2)))\right]\\
&+P_r\left[(5-4\nu)(\sin(\vartheta-\vartheta_1)-\sin(\vartheta-\vartheta_2))\right.\\
&\left.-\frac{1}{3}(\sin(3(\vartheta-\vartheta_1))-\sin(3(\vartheta-\vartheta_2)))\right]\}.
\end{aligned} \tag{7}$$

Equations (6) and (7) are displacements and stresses in an infinite elastic body when constant $t_r = P_r$ and $t_\vartheta = P_\vartheta$ forces are applied to $\vartheta_1 \le \vartheta \le \vartheta_2$ arc of a circle with the radius r. These equations are the basis for the boundary element method considered later. The following peculiarity of the analytical solution given above is worth mentioning.

Displacements from the origin of coordinates to the infinitely distanced points are not limited because of the logarithm included in them. Therefore, equations (6) show only relative displacements. In any concrete case, we must choose a reference point and determine the displacement in respect of such a point.

V. Numerical Procedure

The analytical solution obtained above is the basis for the boundary element method used to obtain a numerical solution of the boundary value problem of the theory of elasticity. Let us explain the physical aspect of this method by using a specific example. Let us consider a boundary value problem for an infinite body with a hole (with a circular hole in our case). We will consider a plane deformation. Let us denote the boundary of the cut, which is a circle in our case, by C (See Fig. 3). At any point of the C curve, local s and n coordinates have the direction of a tangent and its perpendicular. Therefore, they change at different points along the border. We take these coordinates so that the direction of n should coincide with the direction of an outer normal at the same point as the border and s should coincide with the direction of the boundary line. In this case, the direction of the boundary line is anticlockwise. Let us assume that the same normal stress ($\sigma_n = -p$) acts at all points of the hole wall (i.e., there is compression) and tangential stress $\sigma_s = 0$. Let us calculate the displacements and stresses in the body caused by such a load of the boundary.

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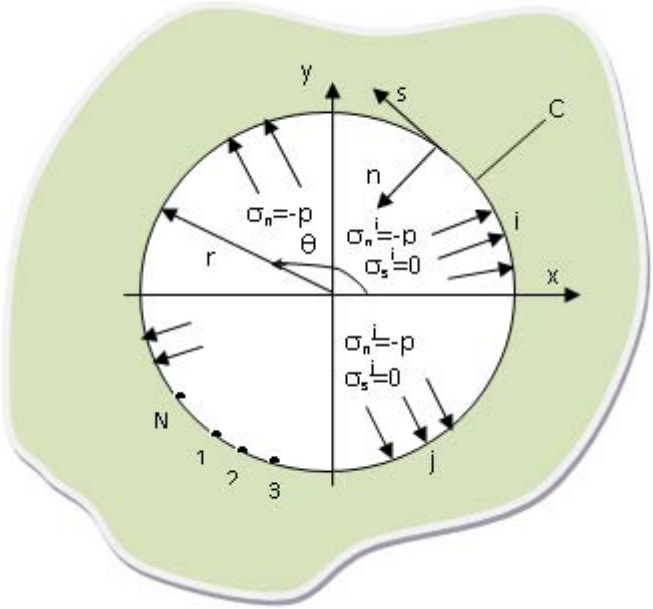

Figure 3: Illustration of the problem statement

The numerical solution of this problem can be obtained as follows: first, let us divide circle *C* into N small arcs (elements). As these elements are small, we can consider that normal $\sigma_n = -p$ stress acts along the whole length of every element, and the tangent is free from stress. In this case, the boundary conditions will be as follows:

$$\sigma_n^i = -p, \qquad \sigma_s^i = 0, \qquad (i = 1, \ldots N).$$

Let us imagine that constant normal and tangent stresses act on every element of the circle, e.g., let us denote the normal and tangent stresses acting on the element j by P_n^j and P_s^j, respectively.

It should be noted that the real normal and tangent tresses acting on the element j do not equal to P_n^j and P_s^j, if stresses act on other elements, too. Therefore, there are two different kinds of stresses for every element. For example, for the element j, we have applied stresses P_n^j and P_s^j and real stresses σ_n^j and σ_s^j caused by the action of the stresses applied to all N elements.

By using (6) and (7), we can calculate real σ_n^i and σ_s^i stresses, $i = 1, \ldots, N$ in the middle point of each element with the following formula:

$$\sigma_s^i = \sum_{j=1}^{N} \left(A_{ss}^{ij} P_s^j + A_{sn}^{ij} P_n^j \right),$$
$$\sigma_n^i = \sum_{j=1}^{N} \left(A_{ns}^{ij} P_s^j + A_{nn}^{ij} P_n^j \right), \quad i = 1, \ldots, N, \tag{8}$$

where $A_{ss}^{ij}, \ldots$ are the boundary coefficients of the influence of the stresses for the considered problem. For example, A_{sn}^{ij} is the real tangent stress in the center of the element i caused by the constant normal unit load ($P_n^j = 1$) applied to the element j.

By considering the boundary conditions, we will obtain the following equations:

$$\left.\begin{aligned} 0 &= \sum_{j=1}^{N} \left(A_{ss}^{ij} P_s^j + A_{sn}^{ij} P_n^j \right), \\ -p &= \sum_{j=1}^{N} \left(A_{ns}^{ij} P_s^j + A_{nn}^{ij} P_n^j \right), \end{aligned}\right\}, \quad i = 1, \ldots, N, \tag{9}$$

which is a system of $2N$ linear algebraic equations with $2N$ P_n^j and P_s^j ($j = 1, \ldots, N$) unknown values.

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It should be noted that P_n^j and P_s^j stresses in these equations are fictitious values. They are introduced as an intermediate quantity to obtain the numerical value of the problem, and they have no physical essence. However, a linear combination of a fictitious load presented with formulae (8) has a physical essence in the considered problem, and is the basis to obtain a system of algebraic equations (9). After solving this system, we can express displacements and stresses at any point in a body with another combination of P_n^j and P_s^j, ($j = 1,\dots N$) fictitious load.

The above-described boundary element method is called a fictitious load method [1].

VI. Influence Coefficients

Let us write down the expressions of the tangent and normal displacements and stresses in the middle point of the i-th element caused by fictitious loads P_n^j and P_s^j, $j = 1,\dots N$ applied to the j-th element. For the displacements, we will have:

$$
\begin{aligned}
u_s^i = P_s^j \Bigg\{ & \frac{\bar{r}^2}{8G\pi(1-\nu)} \Big[(3-4\nu)(\vartheta_1 - \vartheta_2)\ln\bar{r} + 0.5(\vartheta_1 - \vartheta_2) \\
& + 0.25\sin\big(2(\bar{\vartheta} - \vartheta_1)\big) - \sin\big(2(\bar{\vartheta} - \vartheta_2)\big) \Big] \Bigg\} \\
& + P_n^j \Bigg\{ \frac{-\bar{r}^2}{32G\pi(1-\nu)} \Big[\cos\big(2(\bar{\vartheta} - \vartheta_1)\big) - \cos\big(2(\bar{\vartheta} - \vartheta_2)\big) \Big] \Bigg\}, \\
u_n^i = P_s^j \Bigg\{ & -\frac{\bar{r}^2}{G\pi(-\nu)} \Big[\cos\big(2(\bar{\vartheta} - \vartheta_1)\big) - \cos\big(2(\bar{\vartheta} - \vartheta_2)\big) \Big] \Bigg\} \\
& + P_n^j \Bigg\{ \frac{\bar{r}^2}{8G\pi(1-\nu)} \Big[(3-4\nu)(\vartheta_1 - \vartheta_2)\ln\bar{r} - 0.5(\vartheta_1 - \vartheta_2) \\
& - 0.25\big(\sin\big(2(\bar{\vartheta} - \vartheta_1)\big) - \sin\big(2(\bar{\vartheta} - \vartheta_2)\big)\big) \Big] \Bigg\},
\end{aligned}
\tag{10}
$$

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and for the stresses, the expressions will be as follows:

$$\begin{aligned}
\sigma_n^i &= P_s^j\left\{\frac{-\bar{r}}{8\pi(1-\nu)}\left[(4\nu-1)(\sin(\bar{\vartheta}-\vartheta_1)-\sin(\bar{\vartheta}-\vartheta_2))\right.\right.\\
&\quad\left.\left.-\frac{1}{3}(\sin(3(\bar{\vartheta}-\vartheta_1))-\sin(3(\bar{\vartheta}-\vartheta_2)))\right]\right\}\\
&\quad+P_n^j\left\{\frac{\bar{r}}{8\pi(1-\nu)}\left[(5-4\nu)(\cos(\bar{\vartheta}-\vartheta_1)-\cos(\bar{\vartheta}-\vartheta_2))\right.\right.\\
&\quad\left.\left.-\frac{1}{3}(\cos(3(\bar{\vartheta}-\vartheta_1))-\cos(3(\bar{\vartheta}-\vartheta_2)))\right]\right\},\\
\sigma_s^i &= P_s^j\left\{\frac{-\bar{r}}{8\pi(1-\nu)}\left[(4\nu-3)(\cos(\bar{\vartheta}-\vartheta_1)-\cos(\bar{\vartheta}-\vartheta_2))\right.\right.\\
&\quad\left.\left.+\frac{1}{3}(\cos(3(\bar{\vartheta}-\vartheta_1))-co(3(\bar{\vartheta}-\vartheta_2)))\right]\right\}\\
&\quad+P_n^j\left\{\frac{-\bar{r}}{8\pi(1-\nu)}\left[(3-4\nu)(\sin(\bar{\vartheta}-\vartheta_1)-\sin(\bar{\vartheta}-\vartheta_2))\right.\right.\\
&\quad\left.\left.-\frac{1}{3}(\sin(3(\bar{\vartheta}-\vartheta_1))-\sin(3(\bar{\vartheta}-\vartheta_2)))\right]\right\},\\
\sigma_t^i &= P_s^j\left\{\frac{-\bar{r}}{\pi(\ -\nu)}\left[(5-2\nu)(\sin(\bar{\vartheta}-\vartheta_1)-\sin(\bar{\vartheta}-\vartheta_2))\right.\right.\\
&\quad\left.\left.+\frac{1}{3}(\sin(3(\bar{\vartheta}-\vartheta_1))-\sin(3(\bar{\vartheta}-\vartheta_2)))\right]\right\}\\
&\quad+P_n^j\left\{\frac{\bar{r}}{8\pi(1-\nu)}\left[(4\nu-1)(\cos(\bar{\vartheta}-\vartheta_1)-\cos(\bar{\vartheta}-\vartheta_2))\right.\right.\\
&\quad\left.\left.+\frac{1}{3}(\cos(3(\bar{\vartheta}-\vartheta_1))-\cos(3(\bar{\vartheta}-\vartheta_2)))\right]\right\},
\end{aligned}\tag{11}$$

where $\bar{r}$ and $\bar{\vartheta}$ are coordinates in the local coordinate system, with its center coinciding with the middle point of the i-th element. Generally, the displacements and stresses in the i-th element are functions of the P_s^j and P_n^j fictitious load on all N elements. So, by (10) and (11), we can write down:

$$u_s^i = \sum_{j=1}^{N}\left(B_{ss}^{ij}P_s^j + B_{sn}^{ij}P_n^j\right),$$

$$u_n^i = \sum_{j=1}^{N}\left(B_{ns}^{ij}P_s^j + B_{nn}^{ij}P_n^j\right),$$

$$\sigma_s^i = \sum_{j=1}^{N}\left(A_{ss}^{ij}P_s^j + A_{sn}^{ij}P_n^j\right),$$

$$\sigma_n^i = \sum_{j=1}^{N}\left(A_{ns}^{ij}P_s^j + A_{nn}^{ij}P_n^j\right).$$

In these equations, boundary influence $B_{ss}^{ij},\ldots$ and $A_{ss}^{ij},\ldots$ coefficients are calculated with the expressions in the curly braces of equations (10) and (11). For example, the A_{sn}^{ij} coefficient is calculated with the expression given in curly braces at P_n^j of the first equation of (10).

VII. Numerical Examples and Discussion

There are two test problems of using a fictitious load method given below. We have an exact solution to one problem. Therefore, in the case of dividing the boundary into segments and arcs, the numerical results obtained by using the boundary element method will be compared to the exact values. Another problem will compare the numerical values obtained by using the fictitious load method to one another in case of dividing the boundary into segments on the one hand and into arcs on the other hand.

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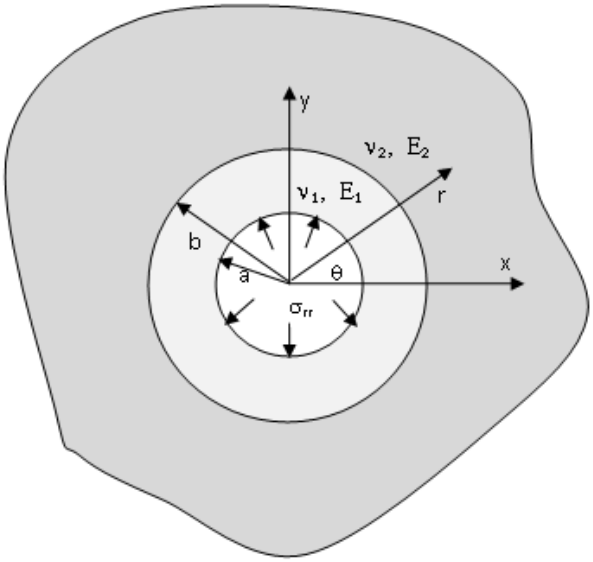

Figure 4: A circular ring in an infinite plate with a hole

a) Ring in an infinite plate with a circular hole

The study area consists of the $a \le r \le b$ ring with ν_1 and E_1 as its elastic characteristics and infinite area with a circular hole with $r = b$ radius, with ν_2 and E_2 as its elastic characteristics (See Fig. 4). $\sigma_{rr} = -p$ normal stress is given on the internal surface of the ring, while in the infinity, the body is free from stresses, and the continuity conditions of displacements and stresses are given on $r = b$ contact surface. So, we will have the following boundary conditions:

$$r = a: \ \sigma_{rr}^{(1)} = -p, \qquad \sigma_{r\vartheta}^{(1)} = 0,$$

$$r \to \infty: \ \sigma_{rr}^{(2)} = 0, \qquad \sigma_{r\vartheta}^{(2)} = 0,$$

and contact conditions:

$$r = b: \ \sigma_{rr}^{(1)} = \sigma_{rr}^{(2)}, \ \ \sigma_{r\vartheta}^{(1)} = \sigma_{r\vartheta}^{(2)}, \ \ u_r^{(1)} = -u_r^{(2)}, \ \ u_\vartheta^{(1)} = -u_\vartheta^{(2)}.$$

The solution to this problem is obtained from standard formulae [23, 24] for a thick-wall cylinder. In particular, the radial and tangential stresses are calculated with the following formulae [1]:

$$\left.\begin{aligned} \sigma_{rr} &= \frac{1}{1-\frac{a^2}{b^2}}\left[\left(p\frac{a^2}{b^2}-p'\right)-(p-p')\frac{a^2}{r^2}\right] \\ \sigma_{\vartheta\vartheta} &= \frac{1}{1-\frac{a^2}{b^2}}\left[\left(p\frac{a^2}{b^2}-p'\right)+(p-p')\frac{a^2}{r^2}\right] \end{aligned}\right\} \quad \text{when} \quad a \le r \le b,$$

$$\left.\begin{aligned} \sigma_{rr} &= -p'\frac{b^2}{r^2} \\ \sigma_{\vartheta\vartheta} &= p'\frac{b^2}{r^2} \end{aligned}\right\} \quad \text{when} \quad r \ge b.$$

A numerical solution of this problem is obtained with a fictitious load method for the following parameter values: $\frac{a}{b} = \frac{1}{2}$, $\nu_1 = \nu_2 = 0.25$, $\frac{E_1}{E_2} = 2$, $\frac{p}{E_2} = 10^{-3}$. Because of the symmetry of the problem, one-fourth of the area, in particular, the space between $\vartheta = 0$ and $\vartheta = \frac{\pi}{2}$ is considered. Within this range, the $r = a$ boundary surface and both sides of the $r = b$ contact surface are divided into n=90 elements each, and the obtained visual and numerical results are presented in Fig. 5, Fig. 6, Table 1 and Table 2, while in cases shown in Fig. 7, Fig. 8, Table 3 and Table 4, they are divided into 180 elements each.

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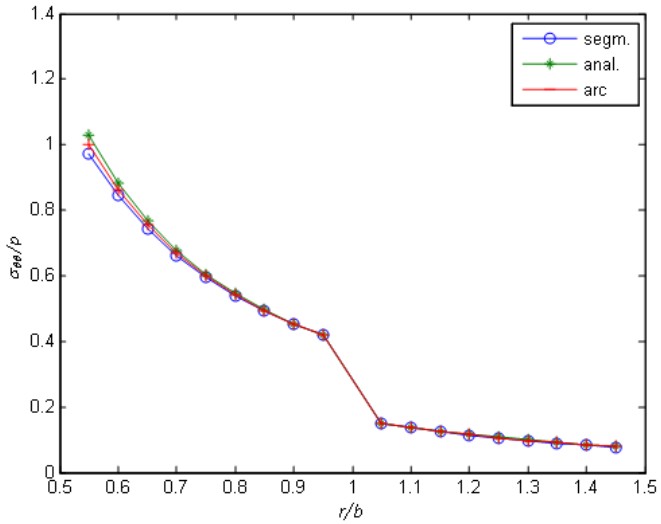

Figure 5: Shearing stress $\sigma_{\vartheta\vartheta} / p$ in the ring $0.5 \le \frac{r}{b} \le 1$ and infinite body $\frac{r}{b} \ge 1$ (n=90)

Table 1: Shearing stress $\sigma_{\vartheta\vartheta} / p$ in the ring $0.5 \le \frac{r}{b} \le 1$ and infinite body $\frac{r}{b} \ge 1$ (n=90)

No.	r/b	Exact solution	Approximate solution		Relative error, percent	
			In case of the division into segments	In case of the division into arcs	Segments	Arcs
1	0.5500	1.0294	0.9726	1.0010	5.5160	2.7574
2	0.6000	0.8827	0.8446	0.8637	4.3169	2.1543
3	0.6500	0.7686	0.7437	0.7561	3.2348	1.6174
4	0.7000	0.6780	0.6621	0.6701	2.3412	1.1706
5	0.7500	0.6049	0.5950	0.6000	1.6392	0.8196
6	0.8000	0.5451	0.5392	0.5422	1.0956	0.5478
7	08500	0.4956	0.4923	0.4939	0.6601	0.3300
8	0.9000	0.4540	0.4528	0.4534	0.2769	0.1395
9	0.9500	0.4189	0.4194	0.4191	0.1096	0.0548
10	1.0500	0.1512	0.1507	0.1509	0.3242	0.1621
11	1.1000	0.1377	0.1370	0.1374	0.5607	0.2803
12	1.1500	0.1260	0.1250	0.1255	0.7963	0.3981
13	1.2000	0.1157	0.1146	0.1151	1.0238	0.5119
14	1.2500	0.1067	0.1053	0.1060	1.2381	0.6192
15	1.3000	0.0986	0.0972	0.0979	1.4361	0.7181
16	1.3500	0.0914	0.0900	0.0907	1.6165	0.8083
17	1.4000	0.0850	0.0835	0.0843	1.7787	0.8894
18	1.4500	0.0793	0.0777	0.0785	1.9234	0.9714
Average					1.6605	0.8306

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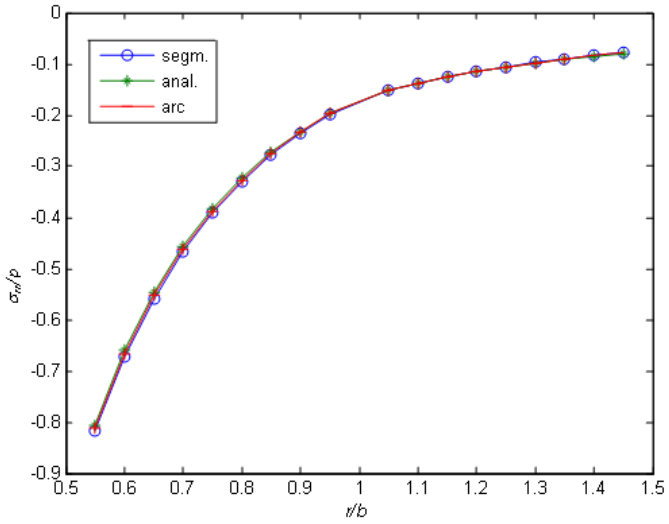

Figure 6: Normal stress σ_{rr} / p in the ring $0.5 \le \frac{r}{b} \le 1$ and infinite body $\frac{r}{b} \ge 1$ (n=90)

Table 2: Normal stress σ_{rr} / p in the ring $0.5 \le \frac{r}{b} \le 1$ and infinite body $\frac{r}{b} \ge 1$ (n=90)

No.	r / b	Exact solution	Approximate solution		Relative error, percent	
			In case of the division into segments	In case of the division into arcs	Segments	Arcs
1	0.5500	-0.8072	-0.8160	-0.8116	1.0951	0.5498
2	0.6000	-0.6605	-0.6725	-0.6665	1.8187	0.9093
3	0.6500	-0.5463	-0.5588	-0.5526	2.2884	1.1438
4	0.7000	-0.4558	-0.4671	-0.4615	2.4873	1.2545
5	0.7500	-0.3827	-0.3921	-0.3874	2.4410	1.2239
6	0.8000	-0.3229	-0.3300	-0.3265	2.1918	1.1097
7	08500	-0.2734	-0.2782	-0.2758	1.7851	0.8939
8	0.9000	-0.2318	-0.2347	-0.2333	1.2643	0.6365
9	0.9500	-0.1967	-0.1980	-0.1973	0.6700	0.3173
10	1.0500	-0.1512	-0.1521	-0.1516	0.6113	0.2834
11	1.1000	-0.1377	-0.1379	-0.1378	0.0929	0.1777
12	1.1500	-0.1260	-0.1256	-0.1258	0.3699	0.1777
13	1.2000	-0.1157	-0.1148	-0.1153	0.7785	0.3808
14	1.2500	-0.1067	-0.1055	-0.1061	1.1357	0.5313
15	1.3000	-0.0986	-0.0972	-0.0979	1.4453	0.7294
16	1.3500	-0.0914	-0.0899	-0.0907	1.7117	0.8195
17	1.4000	-0.0850	-0.0834	-0.0842	1.9396	0.9808
18	1.4500	-0.0793	-0.0776	-0.0784	2.1335	1.0984
Average					1.4589	0.7343

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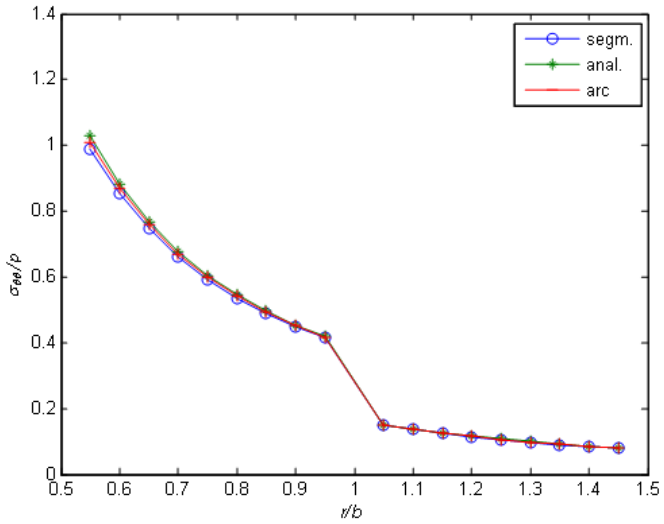

Figure 7: Shearing stress $\sigma_{\vartheta\vartheta} / p$ in the ring $0.5 \le \frac{r}{b} \le 1$ and infinite body $\frac{r}{b} \ge 1$ (n=180)

Table 3: Shearing stress $\sigma_{\vartheta\vartheta} / p$ in the ring $0.5 \le \frac{r}{b} \le 1$ and infinite body $\frac{r}{b} \ge 1$ (n=180)

No.	r / b	Exact solution	Approximate solution		Relative error, percent	
			In case of the division into segments	In case of the division into arcs	Segments	Arcs
1	0.5500	1.0294	0.9895	1.0095	3.8708	1.9317
2	0.6000	0.8827	0.8539	0.8683	3.2648	1.6331
3	0.6500	0.7686	0.7475	0.7580	2.7475	1.3757
4	0.7000	0.6780	0.6622	0.6701	2.3276	1.1659
5	0.7500	0.6049	0.5960	0.6005	1.4713	0.7274
6	0.8000	0.5451	0.5400	0.5445	0.9356	0.1101
7	08500	0.4956	0.4930	0.4940	0.5246	0.3228
8	0.9000	0.4540	0.4531	0.4536	0.1982	0.0881
9	0.9500	0.4189	0.4183	0.4185	0.1432	0.0955
10	1.0500	0.1512	0.1509	0.1510	0.1984	0.1323
11	1.1000	0.1377	0.1372	0.1375	0.3631	0.1452
12	1.1500	0.1260	0.1252	0.1256	0.6349	0.3175
13	1.2000	0.1157	0.1150	0.1154	0.6050	0.2593
14	1.2500	0.1067	0.1058	0.1062	0.8435	0.4686
15	1.3000	0.0986	0.0978	0.0983	0.3043	0.8114
16	1.3500	0.0914	0.0907	0.0912	0.7659	0.2188
17	1.4000	0.0850	0.0844	0.0847	0.7059	0.2353
18	1.4500	0.0793	0.0788	0.0791	0.6305	0.2522
Average					1.1408	0.5717

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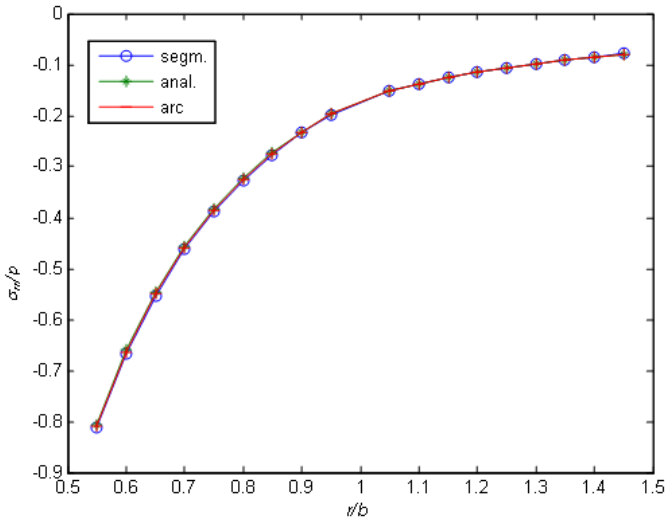

Figure 8: Normal stress σ_{rr} / p in the ring $0.5 \le \frac{r}{b} \le 1$ and infinite body $\frac{r}{b} \ge 1$ (n=180)

Table 4: Normal stress σ_{rr} / p in the ring $0.5 \le \frac{r}{b} \le 1$ and infinite body $\frac{r}{b} \ge 1$ (n=180)

No.	r/b	Exact solution	Approximate solution		Relative error, percent	
			In case of the division into segments	In case of the division into arcs	Segments	Arcs
1	0.5500	-0.8072	-0.8124	-0.8098	0.6519	0.3268
2	0.6000	-0.6605	-0.6675	-0.6640	1.0552	0.5308
3	0.6500	-0.5464	-0.5535	-0.5499	1.3036	0.6496
4	0.7000	-0.4558	-0.4622	-0.4590	1.4077	0.7060
5	0.7500	-0.3827	-0.3880	-0.3854	1.3926	0.7013
6	0.8000	-0.3229	-0.3271	-0.3250	1.2871	0.6452
7	08500	-0.2734	-0.2764	-0.2749	1.1177	0.5647
8	0.9000	-0.2318	-0.2339	-0.2329	0.9077	0.4640
9	0.9500	-0.1967	-0.1980	-0.1973	0.6761	0.3173
10	1.0500	-0.1512	-0.1522	-0.1517	0.6921	0.3496
11	1.1000	-0.1377	-0.1383	-0.1380	0.4447	0.1880
12	1.1500	-0.1260	-0.1263	-0.1262	0.2216	0.1397
13	1.2000	-0.1157	-0.1158	-0.1158	0.0207	0.0512
14	1.2500	-0.1067	-0.1065	-0.1066	0.1600	0.0625
15	1.3000	-0.0986	-0.0983	-0.0985	0.3226	0.1210
16	1.3500	-0.0914	-0.0910	-0.0912	0.4690	0.2728
17	1.4000	-0.0850	-0.08.45	-0.0848	0.6011	0.2752
18	1.4500	-0.0793	-0.0787	-0.0790	0.7203	0.3415
Average					0.7473	0.3726

b) Double-layer circular ring

Let us consider the boundary-contact problem shown in Fig. 9. This problem, too, is symmetrical to both coordinate axes and therefore, we will consider it for a one-fourth of a circular ring. So, the area to be considered is $\Omega = \Omega_1 + \Omega_2$, where

$$\Omega_1 = \left\{ a \le r \le b, \quad 0 \le \vartheta \le \frac{\pi}{2} \right\},$$

$$\Omega_2 = \left\{ b \le r \le c, \quad 0 \le \vartheta \le \frac{\pi}{2} \right\}.$$

The boundary conditions will be written down as follows:

$$r = a: \ \sigma_{rr}^{(1)} = -p \sin^3(2\vartheta), \quad \sigma_{r\vartheta}^{(1)} = 0.$$

$$r = c: \ \sigma_{rr}^{(2)} = 0, \quad \sigma_{r\vartheta}^{(0)} = 0.$$

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The conditions of a rigid contact will be written down as follows:

$$r = b: \quad \sigma_{rr}^{(1)} = \sigma_{rr}^{(2)}, \quad \sigma_{r\vartheta}^{(1)} = \sigma_{r\vartheta}^{(2)}, \quad u_r^{(1)} = -u_r^{(2)}, \quad u_\vartheta^{(1)} = -u_\vartheta^{(2)}.$$

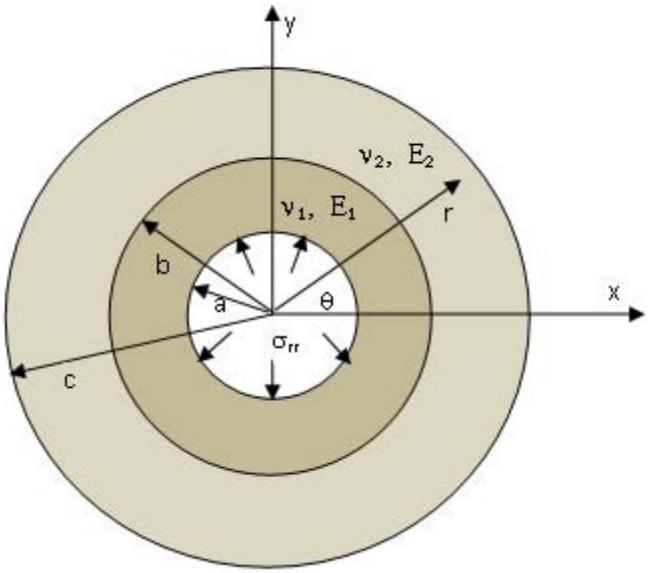

Figure 9: A double-layer circular ring

A numerical solution of the set problem is obtained by the boundary element method for the following data: $E_1 = 2*10^6 kg/cm^2$, , $\nu_1 = 0.3$, $\nu_2 = 0.46$., $a = 1cm$, $b = 1.5cm$, $c = 2cm$, $0 \le \vartheta \le \frac{\pi}{2}$ within the range $r = a$, $r = c$ boundary surfaces and both sides of the $r = b$ boundary surface is divided into n=50 elements each.

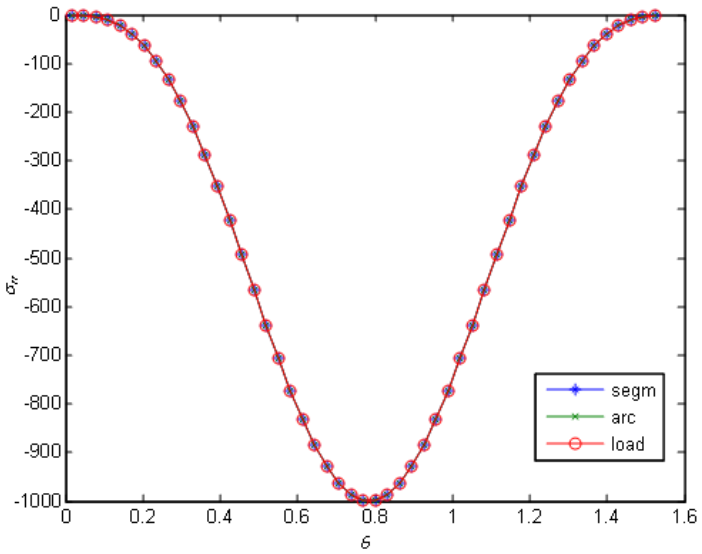

Figure 10: Stress σ_{rr} on the circle $r = a$

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Table 5: Values of stress σ_{rr} on the circle $r = a$

ϑ	In case of the division into segments	In case of the division into arcs	Load	Relative error, percent	
				Segments	Arcs
0.0157	-3.09909783×10^{-2}	-3.09909790×10^{-2}	-3.09909789×10^{-2}	2.253×10^{-6}	2.674×10^{-7}
0.2042	-6.264072573×10	-6.26407257×10	-6.26407257×10	7.184×10^{-10}	2.235×10^{-10}
0.3927	$-3.53553391\times10^{+2}$	$-3.53553391\times10^{+2}$	$-3.53553390\times10^{+2}$	5.656×10^{-11}	1.414e-10
0.6440	$-8.85548231\times10^{+2}$	$-8.85548231\times10^{+2}$	$-8.85548230\times10^{+2}$	1.128×10^{-11}	6.776×10^{-11}
0.7697	$-9.98520411\times10^{+2}$	$-9.98520411\times10^{+2}$	$-9.98520411\times10^{+2}$	1.001×10^{-11}	4.007×10^{-11}
0.8953	$-9.29476324\times10^{+2}$	$-9.29476324\times10^{+2}$	$-9.29476325\times10^{+2}$	1.075×10^{-11}	3.227×10^{-11}
1.1467	$-4.22062458\times10^{+2}$	$-4.22062458\times10^{+2}$	$-4.22062458\times10^{+2}$	2.369×10^{-11}	4.738×10^{-11}
1.3352	-9.35707896×10	-9.35707897×10	-9.35707896×10	7.481×10^{-11}	1.175×10^{-10}
Average				2.818e-07	3.351e-08

c) Discussion

The error of the numerical solutions of the problem considered in paragraph 7.1 obtained by using PCSBEM and BEM, in particular: a) shearing stress $\sigma_{\vartheta\vartheta}/p$ (See Fig. 5, Table 1, when n=90 and Fig.7, Table 3, when n=180) and b) normal stress σ_{rr}/p in ring $0.5\le\frac{r}{b}\le1$ and infinite body $\frac{r}{b}\ge1$ (See Fig. 6, Table 2, when n=90 and Fig.8, Table 4, when n=180), is almost twice as less in terms of percents. It should be noted that in case of dividing the boundary into very small elements, e.g., when n=180, the error is more, as the arithmetic operations with very small numbers results in additional errors (counter error).

Paragraph 7.2 considers the boundary-contact problem for a double-layer circular ring with a normal load of a special kind given on its internal boundary ($\sigma_{rr}^{(1)}=-p\sin^3(2\vartheta)$), while the external boundary is free from loads. Here, the numerical values of σ_{rr} stress on the internal circle by using PCSBEM and BEM and numerical values of the special load are obtained. All three of them are given in Fig. 10 and Table 5, where one can see that they coincide with one another quite exactly.

VIII. Conclusion

The article develops BEM, in particular, the fictitious load method in the polar coordinate system (PCSBEM) to solve the boundary value and boundary-contact problems of the theory of elasticity for the areas limited by the coordinate axes of a polar coordinate system. The bodies relevant to such areas are quite frequent in practice, e.g., in building the underground structures (tunnels), in mechanical engineering, etc. Consequently, the above-described method (PCSBEM) is one of the means to obtain the adjusted solutions of the problems of computational mechanics, as the boundary of the considered area is divided not into small segments, like in case of a standard boundary element method (BEM), but into small arcs. In this case, the boundary of the considered area can be described more accurately, and consequently, the solution to the problem will be more accurate. To illustrate this case, two test boundary-contact problems are solved by using standard BEM and PCSBEM. The obtained numerical results given as tables and graphs are analyzed in paragraph 7.3.

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Versions of Protection for the Human Organism

By K.N. Voinov
ITMO University

Annotation- This paper contains the new information connected with two possible technical decisions, namely: 1) how to stand in the way of the undesirable movement for clot of blood and for sand in the urethra; 2) how to restore the normal function for the injured human organs. These are very important moments to improve the life for many persons. Millions of people suffer from such pains and, unfortunately, from time to time they perish or become as the life invalid.

Keywords: treatment, restoration, injury, nerves, heart, urethra, clot of blood, organs.

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Versions of Protection for the Human Organism

K.N. Voinov

Annotation- This paper contains the new information connected with two possible technical decisions, namely: 1) how to stand in the way of the undesirable movement for clot of blood and for sand in the urethra; 2) how to restore the normal function for the injured human organs. These are very important moments to improve the life for many persons. Millions of people suffer from such pains and, unfortunately, from time to time they perish or become as the life invalid.

Keywords: treatment, restoration, injury, nerves, heart, urethra, clot of blood, organs.

I. Introduction

There are too many reasons which act on a man during his/her life. For example, they can be different traumas, strong contusions, breaks, old age, is predisposed to have anomalous factors or peculiarities in the body/organism. Here they are several examples. Let's suppose that the tree fell on the man hand and broke one finger. After this influence the definite nerve was killed or essentially damaged. In this sad case this finger cannot move at all. Another example which will be joined with urethra. Let's assume that some sands appeared in the kidneys. If rather big sand begins its moving through the urinary vessel, it will be great discomfort for any person. The unbearable pain can take place for persons if they want, for example, to wee-wee. In this case as usually doctors recommend to make the surgical operation. At last, some words about clots of blood which can destroy person at all if they penetrate into the heart or if they hit in our head. In this case, for example, the partial paralysis can take place for the person.

In these described situations we try to restore and to save the health for people. And I don't insist to realize in practice without fail only described below ways. They aren't the dogmatic assertion that's why rightfully a specialist can apply another way how to treat this or other illness.

a) The first situations (clot of blood and sand)

From the very beginning let's depict the situation connected with the human heart and head. Practically, they are the main organs in our body. They must get blood constantly because of in the contrary case the fatal issue will be inevitable. Perhaps, a clot of blood is the basic danger in these cases. If it closes the normal blood stream, the tragedy will not be succeeded.

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The next important question is standing: what's the way or the possibility to prevent this negative situation?

It is common knowledge, that the very small clots of blood usually aren't such dangerous factors. They don't stop the normal working for our heart. But if the size of the clot of blood has rather big measurement, in this case it will be possibly the huge problem for blood to move or for heart mitral valve to work perfectly well.

One of the ways to surmount this problem you can see below (Fig. 1).

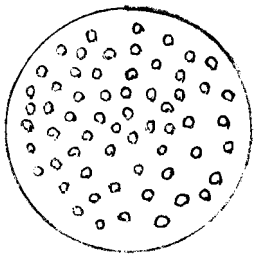

Figure 1: One version to catch the clots of blood

In this case, we must prepare the disk with many small holes in it. The diameter of each opening must have such size which doesn't permit to go through it such dimension of clot of blood which can be dangerous for heart or/and for head. Let's suppose that we have 30 holes in this disk, but for normal movement of blood it will be enough even 20 of them. In this case while more than 10 holes will n't be closed with the clots of blood the blood stream will be normal for the human organs. It takes more time (many years). After the definite period this disk can be changed by surgical operation of course if it will be crammed with clots of blood essentially. The material for this disk must be made in such material which will be suitable for the human organism.

Practically the same way must be applied to protect the movement of sand in the urethra.

And the additional important moment: where must be these disks placed? For our heart they have to set in the main arteries before the entrance for blood into the heart. Analogously, this disk/diaphragm must be put in that cannel where it will allow to avert both the ache and the obstacle for the movement of liquid.

Consequently, evidently, that this way can be applied in practice. As the patent search showed, it seems to me, that this method has advantages before the others ones.

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b) The second situations (if the nerve was damaged essentially)

Unfortunately, there are too many grave damages take place with the different parts/organs in the human body during the life. For example, one eyelid ceased to open left eye though the right eyelid works well. One finger was paralyzed but the others fingers work normally. And so on. What can I recommend to restore the damaged organs if the nerve cannot work at all?

All of us know that even the modern medicine from time to time is incapable to help in such accidents. Below I'll try to suggest the way how we can get over these difficulties.

For treatment damaged organs our doctors usually use two ways, namely: either with tablets and injections or surgical operation. But these ways are not effective in many cases. Moreover, sometimes it is not any possibility to make the surgical operation at all because of the contradictory evidence. There are rather many patents in which authors describe their attempts to treat the mobile neurons. Some damaged zones in brain or in our central nervous system don't permit to restore the health for a person. What a pity, but in this cases the up-to-date medicine is powerless. At the same time the latest achievements in the surgical medicine and in the artificial intellect give the definite hope to get over these problems.

It is common knowledge, that the moving neurons are the nervous cells. Our head brain sends through these sells commands/signals to the muscles in the forms of the electrical impulses. Degeneration for the moving neurons creates the weakness and dystrophy in muscles. These symptoms take place chiefly in our hands and legs. To treat these foes doctors try to use the possibility of the pipe-sells. At last some doctors try to restore the damaged places by means of leading into our body the composition of different medical elements.

In our case we recommend to use the next two ways.

The first version

To join the healthy neuron with the place which it goes round of the damaged point. It can be made using both the natural cells/nervous and artificial connexion. This method can be applied using the nearest healthy element or organ.

The second version

We can apply the special connective suture which must have the same properties as the real nature link in our body or take the additional neuron system. The natural connecting neuron line in our body can have the length to the 1.5 m. In this case we can join the healthy even remote point with the old point which goes round of damaged place. Moreover, this link can be done using the artificial suture which goes both into the body and on the surface of the skin/cutis. In this case, we can get the next possibility to restore the damaged organ. For example, linking the healthy neuron/nerve (let's suppose in the belly) with the healthy neuron/nerve quite near behind of the damaged point we can manage of the behaviour for our damaged finger or eyelid (for example maybe) sending our command straining belly or another part of our body.

II. Conclusion

Several possible ways how to restore damaged organs or part of human body are represented in this article. Of course, it is needed to make natural experiments to confirm suggested ways for restoration different human organs or their parts. But, it seems to me, that in the nearest future we can realize these suggested ways in practice very widely. The main gist of this published information is the next: we try to compel one of the healthy organ (neuron, nervous or muscle) to take for itself the additional function to help for the damaged one.

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A Review for Dynamic Scheduling in Manufacturing

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Abstract- This paper discusses review of literature of dynamic scheduling in manufacturing. First, the problem is defined. The scheduling problems are classified based on the nature of the shop configuration into five classes, i.e., single machine, parallel machines, flow shop, job shop, and open shop. A variety of approaches have been developed to solve the problem of dynamic scheduling. Dynamic scheduling could be classified into four categories, completely reactive scheduling, predictive-reactive scheduling, robust predictive reactive scheduling, and robust pro-active scheduling. It is better to combine together different techniques such as operational research and artificial intelligence to overcome dynamic scheduling problems so as to endow the scheduling system with the required flexibility and robustness, and to suggest various orientations for further work is this area of research.

Keywords: dynamic scheduling, rescheduling, real-time events, operational research, artificial intelligence.

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A Review for Dynamic Scheduling in Manufacturing

Khalid Muhamadin Mohamed Ahmed Bukkur [α], M.I. Shukri [σ] & Osama Mohammed Elmardi [ρ]

Abstract- This paper discusses review of literature of dynamic scheduling in manufacturing. First, the problem is defined. The scheduling problems are classified based on the nature of the shop configuration into five classes, i.e., single machine, parallel machines, flow shop, job shop, and open shop. A variety of approaches have been developed to solve the problem of dynamic scheduling. Dynamic scheduling could be classified into four categories, completely reactive scheduling, predictive-reactive scheduling, robust predictive-reactive scheduling, and robust pro-active scheduling. It is better to combine together different techniques such as operational research and artificial intelligence to overcome dynamic scheduling problems so as to endow the scheduling system with the required flexibility and robustness, and to suggest various orientations for further work is this area of research.

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I. Introduction

Dynamic scheduling is the process of absorbing the effect of real-time events, analyzing the current status of scheduling and automatically modifying the schedule with optimized measures in order to mitigate disruptions (Amer Fahmya, 2014). Also dynamic scheduling which is named rescheduling and it is the process of updating an existing production schedule in response to disruptions or other change (HERRMANN, 2006). Also dynamic scheduling is a direct allocation of tasks to resources, according to given sequencing rules (Kalinowski Krzyszt of 2013). Real-world scheduling problems are combinatorial, dynamic and stochastic (Daria Terekhov, 2010). The goal in such problems is to determine an approach that dictates, at every decision epoch, how the available resources should be allocated among competing job requests in order to optimize the performance of the system (Daria Terekhova, 2014). Real world scheduling requirements are related with complex systems operated in dynamic environments. That make the current schedules easily outdated and unsuitable (A. Madureira, 2014). In a more general way, dynamic changes can be seen as a set of inserted and cancelled constraints (I. Pereira 2013). The dynamic scheduling problems that our work about are characterized by a stream of products that should produce stochastically over time. Each product requires a combination of resources, sequentially and/or in parallel, for different processing times. The overall aim of our work is to show how dynamic scheduling problem was solved and determined the best ways for dealing with this problem.

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II. Dynamic Scheduling Problems

a) Definition of dynamic scheduling problems

A dynamic scheduling problem is generally viewed as a collection of linked static problems (Daria Terekhov, 2010) . Scheduling in manufacturing is an activity of allocating jobs to resources with respect to a time frame that considers critical ratio and considered as N-P hard type of problem (Tarun Kanti Jana, 2013). The main problem in job-shop and flexible job-shop scheduling is that of obtaining the best possible schedules with optimal solutions (Ahmad Shahrizal Muhamad, 2011). There is a need to incorporate these dynamic events into the scheduling process, in order to ensure feasibility of the scheduling plan that the manufacturing system is following (Gomes, 2014). Real-time scheduling theory has traditionally focused upon the development of algorithms for feasibility analysis (determining whether all jobs can complete execution by their deadlines) and run-time scheduling (generating schedules at run-time for systems that are deemed to be feasible) of such systems (Joseph Y-T. Leung"Sanjoy Baruah 2004). The problem of scheduling in the presence of real time events, termed dynamic scheduling. Real-time events have been classified into two categories.

Resource-related: Machine breakdown, operator illness, unavailability or tool failures, loading limits, delay in the arrival or shortage of materials, defective material (material with wrong specification), etc.

Job-related: Rush jobs, job cancellation, due date changes, early or late arrival of jobs, change in job priority, changes in job processing time, etc. (Djamila Ouelhadj, 2008). Also (A. S. Santos, 2014), (Ouelhadj D., 2009) and (Chao Lu, 2017b) agree with that categories.

b) Scheduling problem classifications

Suppose that (m) machines $M_j\left(j=1,...,m\right)$ have to process (n) jobs $J_i\left(i=1,....n\right)$. A schedule for each job is an allocation of one or more time intervals to

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one or more machines (Brucker, 2007). The scheduling problems are classified based on the nature of the shop configuration into five classes, i.e., single machine, parallel machines, flow shop, job shop, and open shop(J.Behnamian 2014)(Eliana María González-Neira, 2017).

c) Optimality criteria (objective functions)

We denote the finishing time of job J_i by C_i, and the associated cost by $f_i(C_i)$. There are essentially two types of total cost functions.

$$f_{\max}(C) := \max\{\langle f_i(C_i) | i = 1,...,n\rangle\}$$

and

$$\sum f_i(C) := \sum_{i\ 1}^{n} f_i(C_i)$$

Called bottleneck objectives and sum objectives, respectively. The scheduling problem is to find a feasible schedule which minimizes the total cost function. If the functions f_i are not specified, we set $\gamma = f_{\max}$ or $\gamma = \sum f_i$. However, in most cases we consider special functions f_i. The most common objective functions are that make span $\max\{C_i \mid i = 1,...,n\}$, total flow time $\sum_{i=1}^{n} C_i$, and weighted (total) flow time $\sum_{i=1}^{n} w_i C_i$. In this case we write $\gamma = C_{\max}, \gamma = \sum C_i, \gamma = \sum w_i C_i$, respectively. Other objective functions depend on due dates d_i which are associated with jobs J_i. We define for each job J_i:

$L_i := C_i - d_i$ lateness

$E_i := \max\{0, d_i - c_i\}$ earliness

$T_i := \max\{0, C_i - d_i\}$ tardiness

$D_i := |C_i - d_i|$ absolute deviation

$S_i := (C_i - d_i)^2$ squared deviation

$U_i := 0 if C_i \le d_i$, 1 otherwise unit penalty.

With each of these functions G_i we get four possible objectives $\gamma = \max G_i, \max w_i G_i, \sum G_i, \sum w_i G_i$. The most important bottleneck objective besides $C_{\max}$ is maximum lateness $L_{\max} := \max L_i$. Other objective functions which are widely used are $\sum T_i, \sum w_i T_i, \sum U_i, \sum w_i U_i, \sum D_i, \sum w_i D_i, \sum S_i, \sum w_i S_i, \sum E_i, \sum w_i E_i$. Linear combinations of these objective functions are also considered. An objective function which is non decreasing with respect to all variables C_i is called regular. Functions involving E_i, D_i, S_i are not regular. The other functions defined so far are regular. A schedule is called active if it is not possible to schedule jobs (operations) earlier without violating some constraint. A schedule is called semi active if no job (operation) can be processed earlier without changing the processing order or violating the constraints(Brucker, 2007).

Practical experience shows that some computational problems are easier to solve than others. Complexity theory provides a mathematical framework in which computational problems are studied so that they can be classified as “easy” or “hard”. One of the main issues of complexity theory is to measure the performance of algorithms with respect to computational time. A problem is called polynomially (P) solvable if there exists a polynomial p such that $T(|x|) \in O(p(|x|))$ for all inputs x for the problem, i.e. if there is a k such that $T(|x|) \in O(|x|^k)$(Jun Zhao, 2014). A commonly faced problem in flow-shop scheduling is that it belongs to the class of NP-hard problems (Florian T. Hecker, 2014). We are dealing with scheduling problems which are not decision problems, but optimization problems. An optimization problem is called NP-hard if the corresponding decision problem is NP-complete. A decision problem P is NP-complete in the strong sense if P belongs to NP and there exists a polynomial q for which Pq is NP-complete (Chuanli Zhao, 2017) . The knowledge that a scheduling problem is NP-hard is little consolation for the algorithm designer who needs to solve the problem. Fortunately, despite theoretical equivalence, not all NP-hard problems are equally hard from a practical perspective. We have seen that some NP-hard problems can be solved pseudo polynomially using dynamic programming. Another possibility is to apply approximation algorithms. One of the most successful methods of attacking hard combinatorial optimization problems is the discrete analog of “hill climbing”, known as local (or neighborhood) search. Any approach without formal guarantee of performance can be considered a “heuristic”. Such approaches are useful in practical situations if no better methods are available (Brucker, 2007).

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III. Current Dynamic Scheduling Approaches

Dynamic scheduling divided into four categories, completely reactive scheduling, predictive-reactive scheduling, robust predictive-reactive scheduling, and robust pro-active scheduling (Ouelhadj D., 2009). In (Amer Fahmya, 2014) and (Djamila Ouelhadj, 2008) there are three main dynamic scheduling categories (or strategies),completely reactive scheduling, robust pro-active scheduling, predictive-reactive scheduling.

a) Completely reactive scheduling

In completely reactive scheduling no firm schedule is generated in advance and decisions are made locally in real-time. A dispatching rule is used to select the next job with highest priority to be processed from a set of jobs awaiting service at a machine that becomes free (Ouelhadj D., 2009). This scheduling type termed as "Dispatching" or "Priority Rule-based Scheduling". This approach was introduced by(Dongjuan, 2010) who proposed a dynamic scheduling established through an aloging connectivity. A new policy proposed for scheduling systems with setups, the Hedging Zone Policy (HZP) policy belongs to what we called the Clearing Cruising (CC) Class, which includes all produce-up-to or base stock policies (Tubilla, 2011). There was another work presented deal with dynamic task allocation mechanism for machine scheduling in a job shop environment following agent based holonic control approach. (Tarun Kanti Jana 2013). A new optimization-based control algorithm was proposed that developed for the buffer management and the production scheduling of a multiple-line production plant (Andrea Cataldo 2015). An approach to dynamically adjust the parameters of a dispatching rule was presented depending on the current system conditions by using machine learning method and demonstrate the capability of their work by reducing the mean tardiness of job (Heger, 2016). There was another article deals with a parallel machine scheduling problem subject to non-interference constraints. The good results presented by the heuristic enable the evaluation of different storage policies for real size instances (Gabriela N. Maschiettoa 2016). A work of a multi- agent-based dynamic scheduling system was introduce for manufacturing flow lines (MFLs) using the Prometheus methodology (PM) considering the dynamic customer demands and internal disturbances. The proposed decision making system supports both static and dynamic scheduling (Ali Vatankhah Barenji, 2016). A complex manufacturing network model CMNBS was proposed for RFID "radio frequency identification" -driven DMS" discrete manufacturing system" modeling, performance analyzing and dynamic scheduling (Jiewu Leng, 2017). There was another work, a simulated annealing and the dispatching rule based complete rescheduling approaches as well as the simulation optimization tools are proposed for dynamic identical parallel machines scheduling problem with a common server (Alper Hamzadayi 2016). There was another work considered the problem of optimizing on-line the production scheduling of a multiple-line production plant (Andrea Cataldo, 2015).

b) Robust pro-active scheduling

This scheduling approach is based on building predictive schedules with studying the main causes of disruptions and integrating them into the schedules. The disruptions are measure based on actual completion measures compared to the originally planned completions; then the mitigation of these disruptions was mitigated through simple adjustment to the activities durations(Ouelhadj D., 2009). An algorithm was developed for the optimal production schedule in a backward dynamic programming approach. It will be applied to the development of an algorithm for production scheduling problems which permit backlogging (C. S. SUNG 1987).

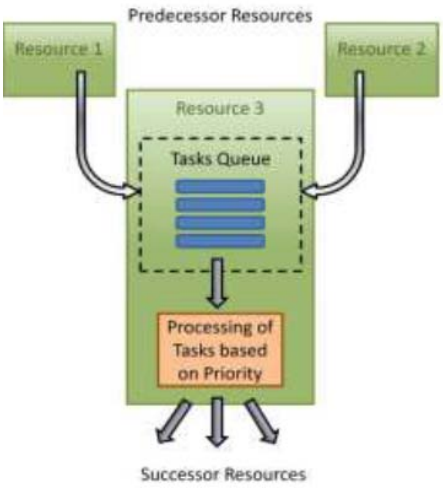

Figure 1: Completely reactive scheduling

There was another work proposed a new neural network approach to solve the single machine mean tardiness scheduling problem and the minimum make spanjob shop scheduling problem. The proposed network combines the characteristics of neural networks and algorithmic approaches (Ihsan Sabuncuoglu 1996).A scheduling approach that uses and compares inductive learning and neural networks was presented to improve the manufacturing system's performance (PAOLO PRIORE, 2001). A scheduling method based on variable neighborhood search (VNS) was proposed for dynamic job shop scheduling problem with random job arrivals and machine breakdowns (M. A.Adibi 2010).A multi-agent based approach is developed in another work to solve the part scheduling problem in

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multiple job shop cells with inter cell moves and flexible routes.A pheromone based approach (PBA) using multi agent is presented in this work, in which various types of pheromone inspired by ant colony optimization (ACO) are adopted as the basis of negotiation among agents (Dongni Li 2013). (Yiping Wen 2014) Proposeda schedulingoptimization algorithm named PACO-TCbyutilizing the theory of ant colony optimization. (Zaki Ahmad Khan, 2017) Also propose dynamic task scheduling algorithm. The comparative simulation study shows that the proposed algorithm gives better performance in terms of task scheduling on various cube based multiprocessor networks.(Zhicheng Cai 2017) This study presenteda bag-based delay scheduling strategy and a single-type based virtual machine interval renting method to decrease the resource renting cost. (Mehdi Abedi, 2017) Proposed a new mathematical modelto study scheduling with simultaneously consideration of aging effects and multi maintenances on un-related parallel machine problem in just in time environment.

c) Predictive-reactive scheduling

Predictive-reactive scheduling is the most common dynamic scheduling approach used in manufacturing systems. Most of the definitions reported in the literature on dynamic scheduling refer to predictive-reactive scheduling.

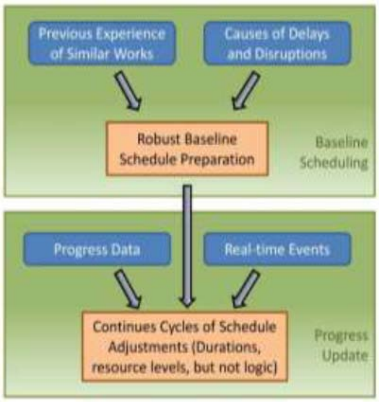

Figure 2: Robust pro-active scheduling

Predictive-reactive scheduling is a scheduling/ rescheduling process in which schedules are revised in response to real-time events. Predictive-reactive scheduling is a two step process. First, a predictive schedule is generated in advance with the objective of optimizing shop performance without considering possible disruptions on the shop floor. This schedule is then modified during execution in response to real-time events(Ouelhadj D., 2009).(Abdallah Elkhyari, 2003) Introduced a new approach for solving dynamic RCPSP "Resource Constrained Project Scheduling Problem" instances. This work is based on new constraint programming techniques. And provided a complete system able to handle both dynamic and over-constrained scheduling problems. (Chuanyu Zhao, 2013) Proposed a novel and rigorous RDHS "real-time dynamic hoist Scheduling " methodology , which takes into account uncertainties of new coming jobs and targets real-time scheduling optimality and applicability. (Bing-hai Zhou, 2013) Proposed a dynamic scheduling method of the photolithography process based on kohonen neural network. It determines the optimal combination of scheduling policies due to the special system status. (Gomes, 2014) Stated that dynamic events must be taken into account, since they may have a major impact on the schedule. They can change the system status and affect performance. Manufacturing systems require immediate response to these dynamic events. (Paolo Priore, 2015) Stated that dispatching rules are usually applied to schedule jobs in Flexible Manufacturing Systems (FMSs) dynamically. A scheduling approach that employs Support Vector Machines (SVMs) and case-based reasoning (CBR) was proposed.(Yuxin Zhai 2017) Proposed adynamic scheduling approach to minimize the electricity cost of a flow shop with a grid-integrated wind turbine. (Chao Lu, 2017b)There was another work developed a high-performance multi-objective predictive-reactive scheduling method for this MODWSP in order to narrow the gap between theoretical research and applicable practice.

d) Robust pro-active scheduling

This scheduling approach is based on building predictive schedules with studying the main causes of disruptions and integrating them into the schedules; which, predictably, can accommodate changes in a dynamic environment. The disruptions are measured based on actual completion measures compared to the originally planned completions.(Amer Fahmya, 2014)

e) Comparison of dynamic scheduling approaches

Dynamic scheduling has been defined under four categories: on-line scheduling (completely reactive approaches), predictive-reactive scheduling, robust predictive-reactive scheduling, and robust pro-active scheduling. In completely reactive scheduling, schedules are easily generated using dispatching rules. However, the solution quality is poor due to the nature of these rules. Predictive-reactive scheduling is the most common approach in dynamic scheduling. Predictive reactive approaches search in a larger solution space, generate high quality schedules, and can generate better system performance to increase productivity and minimize operating costs compared with on-line scheduling and predictive scheduling. Simple schedule adjustments require little effort and are easy to implement. However, they may lead to poor system performance. Generating robust schedules lead to better system performance, even though robustness measures are not easy to define.

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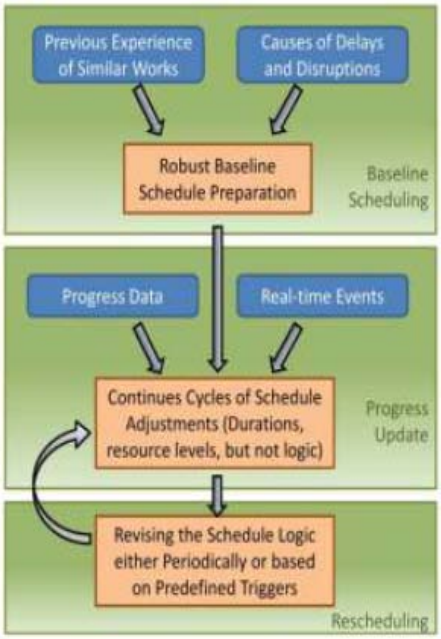

Figure 3: Predictive-reactive scheduling

IV. Dynamic Scheduling Techniques Applied to Manufacturing Systems

There are many techniques that used for solving dynamic scheduling in manufacturing systems and they vary. Here we discuss techniques like "Dispatching rules, Heuristics Techniques, Meta-heuristics Techniques, Hyper-heuristics techniques, Artificial Intelligence Techniques, Multi-agent-based Dynamic Scheduling, The model of network topology technique, Constraint programming technique, Environment driven, function-based technique".

a) Dispatching rules

Dispatching rules have played a significant role within dynamic contexts. (Ouelhadj D., 2009). From the literature reviewed, Dispatching heuristic was able to provide not only a good solution but also the best solutions for the system observed (Kaban, 2012). Dispatching rules are quick but lack robustness and adaptability(Atif Shahzad, 2016). (Edna Barbosa da Silva, 2014) In this work, a simulation model was proposed to evaluate sequencing solutions and present a simulation study of dispatching rules in stochastic job shop dynamic scheduling. (Atif Shahzad, 2016) Stated that dynamic scheduling uses priority dispatching rule (PDR) to prioritize jobs waiting for processing at a resource.

b) Heuristics techniques

Heuristics are problem specific schedule repair methods, which do not guarantee to find an optimal schedule, but have the ability to find reasonably good solutions in a short time. The most common schedule repair heuristics are: right-shift schedule repair, match-up schedule repair, and partial schedule repair (Ouelhadj D., 2009). Dispatching rules are also heuristics that have played a significant role in completely reactive scheduling. And used in real-time to select the next job waiting for processing at a resource (Djamila Ouelhadj, 2008). (JurgenBranke 2016) In this work constitutes the first comprehensive review of hyper-heuristics for the automated design of production scheduling heuristics, providing a simple taxonomy and focusing on key design choices such as the learning method, attributes, representation and fitness evaluation. (Andrea Rossi, 2013).

c) Meta-heuristics Techniques

Meta-heuristics (tabu search, simulated annealing, the ant colony algorithm, bee colony and genetic algorithms) have been successfully used to solve production scheduling problems (Ouelhadj D., 2009). Meta-heuristics have been widely used to solve static deterministic production scheduling. However, little research work has addressed the use of meta-heuristics in dynamic scheduling (Djamila Ouelhadj, 2008). Tabu search algorithm is the alternative approaches to the modern meta-heuristic optimization techniques (Balicki, 2007) . In this work a framework for multi objective bee colony optimization is proposed to schedule batch jobs to available resources where the number of jobs is greater than the number of resources (Sana Alyaseri, 2013) . Ant Colony Optimization (ACO) is a meta-heuristic technique and is used to find shortest path between source and destination (Sahana et al., 2014) . The ant colony algorithm is a new method to deal with the rescheduling problem of observing spacecraft (Li Yuqing 2014) . In this work, an efficient an improved ant colony optimization IACO is proposed for flexible job shop scheduling problem FJSP in order to minimize make span(Lei Wang, 2017) .There was another method proposed that makes use of the greedy randomized adaptive search procedure (GRASP) also used to solve dynamic scheduling problems (Adil Baykasoğlu, 2017).Also, a hybrid genetic and simulated annealing algorithms is developed because of the high potential of outcomes to be trapped in the local optima (Aidin Delgoshaei, 2016). As solution approaches, two meta-heuristic solution approaches based on the simulated annealing (SA) algorithm and the discrete particle swarm optimization (DPSO) are proposed to obtain a near optimal solution in a reasonable amount of time (Byung Jun Joo, 2015). There was another work proposed a GA for solving the agile job shop scheduling to minimize the make span(Li and Chen, 2010). Also in this work, an implementation of a standard GA (SGA) to solve the task scheduling problem has been presented (Omara and Arafa, 2010). A genetic algorithm approach is applied to hypothetical numerical examples with the objective of minimizing the makespan in the work of (C. S.Wong, 2013).

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d) Hyper-heuristics techniques

Hyper-heuristics are defined as "an automated methodology for selecting or generating heuristics to solve hard computational search problems" (Jurgen Branke, 2016). There was another work developed a two-stage hyper-heuristic to automatically generate sets of dispatching rules for complex and dynamic scheduling problems. The approach combines a GP hyper-heuristic that evolves a composite rule from basic attributes (Christoph W. Pickardt, 2013). There was another study used a hybrid heuristic model combining both Genetic Algorithm (GA) and Fuzzy Neural Network (FNN) (Alper Seker, 2013). This work introduces a two-phase hybrid solution method. The first phase relies on solving a series of linear programming problems to generate an initial solution. In the second phase, a variable neighborhood descent procedure is applied to improve the solution (Amina Lamghari, 2014). This work presented a Greedy Randomized Adaptive Search Procedure (GRASP)-Mixed Integer Programming (MIP) hybrid algorithm for solving the precedence constrained production scheduling problem (PCPSP) of mine optimization (Angus Kenny, 2017). For solving a multi-objective optimization problem, a mathematical model formulated and a new hybrid multi-objective backtracking search optimization algorithm developed with an energy saving scenario (Chao Lu, 2017a). A dynamic and heterogeneous hybrid Architecture for Optimized and Reactive Control, ORCA, was introduced and applied to the manufacturing scheduling of an FMS (Cyrille Pach, 2014).

e) Artificial intelligence techniques

A number of dynamic scheduling problems have adopted artificial intelligence techniques such as knowledge-based-systems, neural networks, case-based reasoning, fuzzy logic, Petri nets, etc. (Banu Çaliş 2013). (LIXIN TANG 2005)(T. Eguchi, 1999) In this works a neural network approach was proposed to a dynamic job shop scheduling problems. There was another work present a survey of the use of an AI technique, in various manufacturing systems (Kumar, 2014). To derive better dynamic scheduling systems, some researchers developed hybrid systems which combine various artificial intelligence techniques (Binodini Tripathy, 2015).

f) Multi-agent-based dynamic scheduling

To optimize performance, scheduling decisions are made centrally at the level of the supervisor, and then distributed to the manufacturing resource level for execution(Kaminsky, 2006). In the present work, Multi-agents was proposed to find the near optimal solution for job shop scheduling problem using GA and VNS approach in parallel (Rakesh Kumar, 2016).

g) The model of network topology technique

A contribution made towards solving the problem of dynamic scheduling on parallel machines by introducing a model of network topology technique which captures some important aspects of the practical scheduling problem (Anja Feldmann 1994).

h) Constraint programming technique

Recently, Constraint Programming (CP) attracts a high interest among both planning and scheduling community. It was based on the idea of describing the problem declaratively by means of constraints, logical relations among several unknowns (or variables), and, consequently, finding a solution satisfying all the constraints (Barták, 1999).

i) Environment driven, function-based technique

In this technique, an environment driven, function-based was developed for solving the dynamic single-machine scheduling problem. This technique can capture uncertainty and dynamic characteristics associated with the dynamic environment. (Arezoo Atighehchian 2013). There is another work proposes an innovative approach to study the dynamic scheduling problem in FMS, taking the objectives of minimum or maximum energy consumption into account (Liping Zhang, 2013).

j) Comparison of dynamic scheduling techniques

In order to ascertain the value of the various solution techniques, there has been some published work comparing some of these techniques. Heuristics have been widely used to react to the presence of real-time events because of their simplicity, but they may become stuck in poor local optima. To overcome this, meta heuristics such as tabu search, simulated annealing, and genetic algorithms have been proposed. Several comparative studies have been provided in the literature to compare the performance of tabu search, genetic algorithms, and simulated annealing. Unlike simulated annealing and tabu search based on manipulating one feasible solution, genetic algorithms manipulate a population of feasible solutions. Genetic algorithms were found not efficient to find a near-optimal solution in a reasonable time compared to tabu search and simulated annealing which operate on a single configuration and not on an entire population. Knowledge-based systems possess the potential for automating human expert reasoning and heuristic knowledge to run production scheduling systems. In terms of effectiveness of the decision-making capability, knowledge-based systems are limited by the quality and integrity of the specific domain knowledge. Fuzzy logic has not yet been explored to its fullest potential. Neural networks cannot guarantee to provide optimal decisions, but their learning capability makes them

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ideally suited for rapidly changing systems. Integrating neural networks, simulation, and expert systems seems to have a lot of promise. In addition, in developing practical integrated dynamic scheduling systems, it is necessary to combine together different techniques such as operational research and artificial intelligence to endow the scheduling system with the required flexibility and robustness (Djamila Ouelhadj, 2008). In order to give recommendations on when it is beneficial to use a hyper-heuristic and how to design it, extensive and meaningful performance comparisons of evolved heuristics with more sophisticated (global) solution algorithms as well as between different hyper-heuristics are needed. So far, such comparisons have been rather limited hyper-heuristic approaches have strengths compared to global optimization approaches in particular in dynamic and stochastic environments where a quick reaction is important. They also become more competitive as the problem size (and thus the search space for the global optimizer) increases. One reason for the limited number of comparisons may be that hyper-heuristics possess several properties that make a fair comparison particularly difficult. For example, not only are the hyper-heuristics stochastic algorithms with many parameters to tune, but also is the evaluation function often a stochastic simulation, resulting in stochastic fitness values. Also, the running time for the simulations can be quite substantial, and, to make things worse, the running time to evaluate a particular dispatching rule strongly depends on the rule itself, as the time to calculate the priority value and the numbers of jobs in the system depend on the rule itself. This implies that a comparison of hyper heuristics based on the same number of function evaluations has limited validity (Jurgen Branke, 2016). For The network topology technique there was a question which remain open were, how can the model be extended to capture the practical scheduling even better? and if the competitive ratio is the right performance measurement? also of interest is whether randomization can help to improve the performance of the scheduling algorithm (Anja Feldmann 1994). About constraints programming despite of studying the proposed framework using the complex process environment background we believe that the results are applicable in general to other (non- production) problem areas where mixed planning and scheduling capabilities are desirable (Barták, 1999). The efficiency of the function-based approach is evaluated against the most commonly used dispatching rules. Moreover, the proposed approach is compared with an agent-based approach, which employs the Q-learning algorithm to develop a decision-making policy. Experimental results show that the proposed approach is an effective method for dynamic single-machine scheduling (Arezoo Atighehchian 2013).

V. Results and Discussion

A dynamic scheduling is not dissection making problem but it is optimization problem. And it concerns with resources available, the jobs that should be done and the perfect time to do jobs. In manufacturing operations there should be an optimum utilization between resources and jobs in minimum time to gain markets. I think that a dynamic scheduling is a good way to solve any problem of scheduling in the presence of real-time events for allocating jobs to resources in manufacturing. From the above we can define dynamic scheduling like this "A dynamic scheduling is the optimum Utilization between resources and jobs in real time events ". Predictive-reactive scheduling is the most common approach in doing dynamic scheduling. It searches in a larger solution space, generate high quality schedules, and can generate better system performance to increase productivity and minimize operating costs compared with on-line scheduling and predictive scheduling. In computational complexity sense optimization problems belongs to the class of NP-hard problems. Not all NP-hard problems are equally hard from a practical perspective. We have seen that some NP-hard problems can be solved pseudopolynomially using dynamic programming or “hill climbing”, known as local (or neighborhood) search Dynamic scheduling has been solved using many techniques. It is necessary to combine together different techniques such as operational research and artificial intelligence to endow the scheduling system with the required flexibility and robustness for example integrating neural networks, simulation, and expert systems or a hybrid approach. I think that dynamic scheduling has a main role in developing the fourth industrial revolution.

VI. Conclusion and the Research Opportunities

A Dynamic scheduling is the optimum Utilization between resources and jobs in real time events. The scheduling problems were classified based on the nature of the shop configuration into five classes. Dynamic scheduling divided into four categories. Predictive-reactive scheduling is the most common approach. In computational complexity sense optimization problems belongs to the class of a NP-hard problems, practical experience shows that some computational problems are easier to solve than others. To solve dynamic scheduling, it is necessary to combine together different techniques such as operational research and artificial intelligence. Further work in this topic is expected to investigate the role of dynamic scheduling in manufacturing systems in Industry 4.0"the fourth industrial revolution", and as a core element of systems engineering, also doing

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dynamic scheduling as a program in the embedded systems in manufacturing environment

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Determinación Del Nivel De Seguridad En Calderas Pirotubulares, Mediante La Aplicación Del Software Soscal

By Sepúlveda Mejía, Diego L., Ramírez García, Jairo, Roldán Aguilar, Óscar L. & Vásquez Echavarría, Gladis H.

Abstract- Este trabajo presenta los resultados de la aplicación del software de seguridad en calderas –SOSCAL- cuyo objetivo fue establecer el nivel de seguridad en calderas pirotubulares de empresas ubicadas en la ciudad de Medellín y en el oriente cercano del departamento de Antioquia, Colombia, seleccionadas a conveniencia por la disponibilidad de estas para la aplicación de este instrumento, con el fin de controlar los riesgos asociados a la operación de estos equipos. Dicho instrumento es pionero a nivel mundial, ya que no se tiene evidencia de un aplicativo informático similar que evalúe el nivel de seguridad y dé recomendaciones para el control de los posibles riesgos encontrados.

Keywords: *seguridad en calderas, aplicativo informático, nivel de seguridad.*

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Determinación Del Nivel De Seguridad En Calderas Pirotubulares, Mediante La Aplicación Del Software Soscal

Sepúlveda Mejía, Diego L. [α], Ramírez García, Jairo [σ], Roldán Aguilar, Óscar L. [ρ] & Vásquez Echavarría, Gladis H. [ω]

Abstract- Este trabajo presenta los resultados de la aplicación del software de seguridad en calderas – SOSCAL - cuyo objetivo fue establecer el nivel de seguridad en calderas pirotubulares de empresas ubicadas en la ciudad de Medellín y en el oriente cercano del departamento de Antioquia, Colombia, seleccionadas a conveniencia por la disponibilidad de estas para la aplicación de este instrumento, con el fin de controlar los riesgos asociados a la operación de estos equipos. Dicho instrumento es pionero a nivel mundial, ya que no se tiene evidencia de un aplicativo informático similar que evalúe el nivel de seguridad y dé recomendaciones para el control de los posibles riesgos encontrados.

El nivel de seguridad en las calderas pirotubulares se evalúa con base en 5 dominios: mantenimiento, operación, capacitación, combustible y ambiental, y condiciones locativas, ya que son los aspectos que tienen relación con la seguridad de las calderas, y de acuerdo a la validación de expertos que se hizo durante el diseño inicial del instrumento, cada dominio tiene un nivel de afectación diferente a la seguridad de dichos equipos, que si se llega a presentar una explosión, no solo puede afectar al personal e infraestructura de la empresa, sino también al vecindario y al medio ambiente.

Los resultados principales están relacionados a que el 24 % de las empresas participantes tienen sus calderas con un nivel de seguridad deficiente (nivel más bajo de seguridad), y el 41 % de las empresas tienen un nivel de seguridad aceptable; así mismo los dominios de menor calificación, fueron mantenimiento, y capacitación, que tienen gran incidencia en la operación segura de estos artefactos.

Como conclusiones se tiene que este software es un soporte para la gestión del riesgo tecnológico en las calderas pirotubulares, y aportar a la comunidad local, nacional, e internacional, un software de libre acceso, para que las empresas lo apliquen y puedan establecer un plan de acción con base en las recomendaciones dadas por este.

Keywords: seguridad en calderas, aplicativo informático, nivel de seguridad.

I. Introduction

El desarrollo de este aplicativo informático SOSCAL es un producto de investigación del trabajo de grado de un estudiante para optar el título de Ingeniería Informática, y parte del instrumento desarrollado por Sepúlveda y Ramírez (2011) el cual determina el nivel de seguridad de calderas con base en cinco dominios que tienen relación directa con la seguridad de estos equipos: mantenimiento, operación, capacitación, combustible y ambiental, y condiciones locativas. En el dominio de combustible el software tiene la posibilidad de evaluar los combustibles sólidos como el carbón y gaseosos como el gas natural; dentro de la muestra seleccionada se tienen dos empresas que utilizan el ACPM como combustible, las cuales pertenecen al Sector Educativo. Para la evaluación del nivel de seguridad mediante SOSCAL se asimila el combustible líquido como combustible gaseoso.

El aplicativo SOSCAL además de establecer el nivel de seguridad de las calderas pirotubulares, mostró posibles escenarios que se pueden presentar de acuerdo con la falencia encontrada, y presenta recomendaciones para el control de los riesgos encontrados al evaluar cada ítem en los diferentes dominios. Este aplicativo informático es un aporte del sector académico a los diferentes actores del sector productivo que utilizan calderas en sus procesos, a los entes gubernamentales responsables del cumplimiento de la normatividad relacionada con el control del riesgo tecnológico, y se enmarca dentro de la Ley de Gestión del Riesgo de Desastres (2012), y la Resolución Metropolitana 912 de 2017 (2017), la cual normatiza la operación de las calderas en la Ciudad de Medellín. A nivel mundial no se tiene evidencia de la existencia de instrumentos similares para determinar el nivel de seguridad en estos equipos, los cuales están relacionados directamente con el riesgo tecnológico, y el posible impacto catastrófico que pueden tener en el entorno, en caso de una explosión.

Se realizó una prueba piloto a conveniencia de 17 empresas ubicadas en la ciudad de Medellín y el oriente cercano, que utilizan calderas pirotubulares en sus procesos productivos, las cuales permitieron la aplicación del SOSCAL para establecer el nivel de seguridad de sus calderas. Los tipos de combustible que utilizan están distribuidos de la siguiente manera: 7 a carbón, 8 a gas natural y las 2 restantes ACPM.

II. Metodologia

Estudio descriptivo de corte transversal, a partir de la aplicación del software SOSCAL, que permitió

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determinar el nivel de seguridad de las calderas pirotubulares, de una muestra a conveniencia en 17 empresas, localizadas en la ciudad de Medellín y el oriente cercano, pertenecientes 10 de ellas al sector manufactura, 3 al sector alimentos, 2 al sector servicios y 2 al sector educativo, de las cuales 8 utilizan gas natural, 7 carbón y 2 ACPM. La selección de dichas empresas se dio por el conocimiento directo de los investigadores con los responsables del área de mantenimiento o Salud y Seguridad en el Trabajo de las empresas seleccionadas.

Vale aclarar que según la normatividad ambiental de la ciudad de Medellín (2005) no está permitido el uso de ACPM en calderas y fuentes fijas, pero por tratarse de 2 Instituciones de Educación Superior se permite este combustible por su poco tiempo de operación, ya que se usa únicamente para algunas prácticas de laboratorio.

El nivel de seguridad se determinó mediante el análisis de las categorías o dominios asociados a la seguridad de las calderas, con base en la ponderación dada por Sepúlveda y Ramírez (1), en una escala de 1 a 100: mantenimiento (30 puntos), operación (30 puntos), capacitación (20 puntos), combustible y ambiental (10 puntos), y condiciones locativas (10 puntos).

SOSCAL además de determinar el nivel de seguridad de las calderas, presenta algunas recomendaciones generales a desarrollar con base en las falencias encontradas en cada dominio, al describir los posibles escenarios relacionados con los riesgos de cada ítem evaluado.

Con la aplicación de esta prueba piloto y la publicación de este artículo se espera contribuir a la difusión del conocimiento en la operación segura de las calderas ubicadas en la ciudad de Medellín y oriente cercano, y podrá servir de guía para el control del riesgo tecnológico relacionado con estos equipos y ayudar a mejorar las competencias técnicas de los operadores de los mismos.

III. Resultados

Del análisis de resultados mediante la aplicación del software SOSCAL, se observa que el 6% de las calderas presenta un nivel de seguridad Excelente (100 puntos), el 29% presentan un nivel de seguridad buena, aceptable el 41% de las calderas analizadas, y el 24% restante presenta nivel de seguridad deficiente, como se muestra en la Figura 1.

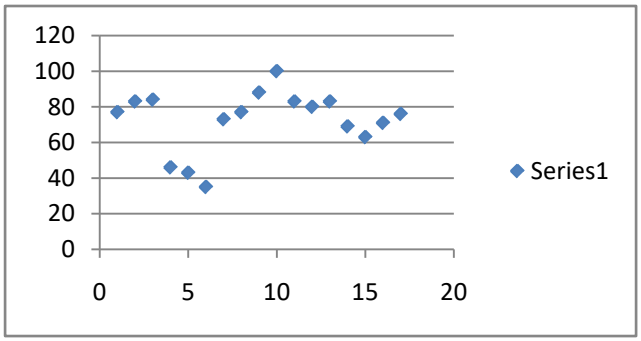

Figure 1: Distribución del nivel de seguridad de las calderas en estudio

Llama la atención que las calderas con la calificación más baja en sus niveles de seguridad son las de menor calificación en los dominios de mantenimiento y operación, que son los dominios que mayor incidencia tienen en la operación segura de las calderas. De estas calderas el 75% usan como combustible gas natural y ACPM, siendo una situación en la que se debe prestar mayor atención, porque los administradores piensan que las calderas al funcionar de manera automática no requieren de la presencia de un operador responsable de este equipo y capacitado en su operación segura (Sepúlveda y Ramírez, 2011). Con relación al dominio de mantenimiento es común en estas calderas la no realización de las actividades de mantenimiento preventivo y predictivo, y el no seguimiento de los procedimientos requeridos en la realización de las tareas de alto riesgo, como son el aseguramiento de energías, y el trabajo en espacios confinados. Coincide la condición de estas calderas con bajo nivel de seguridad a lo reportado por Soler, A. (5), quien reporta en su estudio que el 16% de las causas de accidentes con calderas obedecen a un mantenimiento e inspección inadecuados, a pesar de ser un aspecto que puede disminuir el riesgo de accidentes. El mantenimiento correcto, es decir aquel recomendado por el fabricante del equipo, es uno de los aspectos que garantiza la prevención en la operación de estos, y puede eliminar o limitar las acciones nocivas a que pueden verse sometidas las partes a presión de este tipo de aparatos (Soler,A.).

Con relación al dominio de operación, es común en las calderas de menor nivel de seguridad la no existencia del respectivo instructivo de operación; no existencia de alarma sonora y/o visual; el no registro y monitoreo de las condiciones de operación; y la ejecución de actividades diferentes a la operación de la caldera por parte del calderista. Condiciones que reflejan una posible situación crítica que debe ser intervenida, ya que no se tiene conocimiento de cómo operan las calderas, así como en caso de presentarse una emergencia, no se tiene la respectiva alarma para indicar dicha situación de peligro. Igualmente Soler encontró que el 15% de los accidentes en calderas se

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deben a la "operación y manipulación incorrectas realizadas por el operario que se halla al frente de una caldera", y que podría solucionarse mediante una correcta formación del operario. Así mismo Toro, D. (2013) encontró que la operación segura de las calderas se ve altamente afectada por la no existencia de protocolo o instructivo de operación, y por el no registro de las condiciones de operación de estos equipos.

Respecto al dominio de capacitación, se tiene que en el 50% de las calderas de más baja calificación sus operadores no han recibido capacitación en la operación segura de estos equipos. Se observa de manera general que las empresas no tienen programas de reinducción para sus calderistas. También (Toro, D.) reporta en su estudio que los operadores no han recibido capacitación periódica para el desempeño seguro de las calderas.

A partir del año 2017 en Medellín, Colombia, se expide la Resolución Metropolitana 912, la cual está orientada principalmente al control de contaminantes atmosféricos, al control y eficiencia de las calderas a través del registro y monitoreo de sus condiciones de operación y mantenimiento. Así mismo esta resolución exige que los operadores de calderas tengan las competencias técnicas necesarias para la operación segura de las calderas, y que sean reentrenados semestralmente.

En la muestra seleccionada se encontró que el 24% de las calderas tienen un nivel de seguridad deficiente, y mostró, al igual que los estudios realizados por Toro, D., y Sepúlveda y Ramírez, que aún se encuentran calderas operando con un nivel de seguridad deficiente, siendo una situación que debe llamar la atención de los entes gubernamentales para la definición de normas precisas para la operación segura de las calderas.

IV. Conclusiones

El software SOSCAL es un aplicativo informático que ayuda a identificar de manera fácil el nivel de seguridad en la operación de las calderas pirotubulares, siendo un soporte a las áreas de mantenimiento y de gestión de riesgos Para la operación segura de estos equipos, no solo por la valoración del nivel de seguridad, sino también por las recomendaciones propuestas al encontrar aspectos susceptibles de mejora en su calificación.

Se pudo evidenciar a nivel académico la no disponibilidad de una herramienta informática disponible a nivel mundial, ni literatura relacionada que ayude a identificar el nivel de seguridad de las calderas de manera automática.

En la muestra seleccionada se encontró que el 24% de las calderas tienen un nivel de seguridad deficiente, y un 41% aceptable, siendo el más alto porcentaje de calificación, y que debe llamar la atención de la academia y las autoridades respectivas, para que se normatice y vigile la operación y mantenimiento de las calderas en nuestro país.

Mediante la aplicación del SOSCAL se espera que se establezca un plan de acción en las empresas que lo apliquen, para controlar los posibles riesgos catastróficos, y contribuya al mejoramiento de las condiciones de seguridad de los trabajadores y población cercana a la ubicación de las calderas.

El software SOSCAL al ser de libre uso es una herramienta informática que ayuda a la generación de conocimiento sobre la seguridad en calderas, y se espera que sea una guía de consulta para todas las empresas con calderas pirotubulares, ya que se encuentra disponible en la página web del Politécnico Colombiano Jaime Isaza Cadavid (http://webnet.El poli.edu.co/soscal).

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Performance Evaluation of Refractory Bricks Produced from Nigerian Fireclays Blended with Zircon

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Abstract- In Nigeria, importation of several additives usually used in blending fireclays is on the increase. Similarly, other materials available in the country are currently underutilized. These materials could be used as additives to alter/improve the refractory properties of fireclay. The performance behavior of refractory bricks produced from a single and multi-component blending of Osiele and Ikorodu fireclays with Azara-Lafia zircon was studied. The chemical compositions of the raw materials were determined using the Atomic Absorption Spectrophotometer (AAS-PG990AFG). The Osiele and Ikorodu fireclays were blended with Azara-Lafia zircon at varying mass proportions of 10 – 35%. The blended samples were mixed with water (3 – 4%), molded into bricks using the Hydraulic Press (Paul-Weber D-7084) to 300KN. The bricks were air dried for 24 hours and later fired in the Carbolite RHF-16/15 furnace at 800oC to 1200oC. Cold crushing strength test were conducted using Testometric M-500-30KN D7940.

Keywords: zircon, osiele clay, ikorodu clay, refractory bricks, refractory properties.

GJRE-J Classification: FOR Code: 091299

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Performance Evaluation of Refractory Bricks Produced from Nigerian Fireclays Blended with Zircon

Ochieze, P. U.[α] & Esezobor, D. E.[σ]

Abstract- In Nigeria, importation of several additives usually used in blending fireclays is on the increase. Similarly, other materials available in the country are currently underutilized. These materials could be used as additives to alter/improve the refractory properties of fireclay. The performance behavior of refractory bricks produced from a single and multi-component blending of Osiele and Ikorodu fireclays with Azara-Lafia zircon was studied. The chemical compositions of the raw materials were determined using the Atomic Absorption Spectrophotometer (AAS-PG990AFG). The Osiele and Ikorodu fireclays were blended with Azara-Lafia zircon at varying mass proportions of 10 – 35%. The blended samples were mixed with water (3 – 4%), molded into bricks using the Hydraulic Press (Paul-Weber D-7084) to 300KN. The bricks were air dried for 24 hours and later fired in the Carbolite RHF-16/15 furnace at 800ºC to 1200ºC. Cold crushing strength test were conducted using Testometric M-500-30KN D7940. The results showed that Osiele clay and Ikorodu clay consist of 30 – 31% Al_2O_3 and 41 – 51% SiO_2 which belongs to the alumino-silicate groups while the zirconia content in Azara-lafia is 65.3%. The bricks produced from Osiele clay and Ikorodu clay with no zircon additive has refractoriness values of 1500ºC and 1400ºC, thermal shock resistance of 20 and 24 cycles, compression strength of 132KN/m^2 and 108.4KN/m^2 respectively. The refractoriness of the bricks produced from Osiele clay and Ikorodu clay with zircon additives of 10 – 35% has a constant value of 1300ºC. The fired linear shrinkage, loss on ignition, compressive strength and apparent porosity decreased linearly with increasing percentage of zircon. These bricks exhibited poor thermal shock resistance as they failed in the first cycle. The result shows that the Azara-Lafia zircon additives are found unsuitable for blending fireclays in the production of high-quality refractory bricks. However, these bricks can find application in lining of ovens, dryers, and furnaces used for various purposes in the industries operating below 1200ºC.

Keywords: zircon, osiele clay, ikorodu clay, refractory bricks, refractory properties.

I. Introduction

Refractory materials are said to be high resistant products to the generation of high temperatures of the process at the furnaces and reactors (Kingery et al., 1976). The reliability of refractory for specific applications is determined for its chemical attack resistance to molten slags and molten products, as soon as its mechanical and thermal propertiesarein use (Guzmán et al., 2006). It is also known that all refractory materials deteriorate during application and a common factor in the destruction is the temperature. For this reason, development of new refractory materials with high-temperature resistance and very high resistance in contact with aggressive environments is ongoing. Refractory materials are made in varying combinations and shapes depending on their applications.

Then need to achieve the best performance is a requirement in selecting refractory materials for different applications, such that sudden failure of lining materials is prevented, thus avoiding loss of capital, equipment, energy, and products (Esezobor et al., 2014; Apeh et al., 2011).

These applications include the use in furnace linings for high-temperature operations such as melting of metals for casting, heat treatment of materials to change or enhance the refractory properties, or in the heating of materials to change their shape during metal working operations such as forging or rolling.

Some refractory materials such as zirconia find operations in the lining furnaces for glass production (Guzmán et al., 2006). Zirconia (ZrO_2) which is an oxide form of Zirconium comes as a white powder which possesses both acid and base propertiesis a component in some abrasives, such as grinding wheels and Send Paper (Kerbs, 1998).Because of its mechanical strength and flexibility, sintering into Ceramic Knives and other blades is possible.

In combined form with silica is called Zirconas it exists with silica (SiO_2) in the form of Zircon sand ($ZrSiO_4$). Zircon is a mineral occurring in tetragonal crystal, usually of a brown or grey color. It is sometimes used as a false gemstone.

Zircon Send is used in laboratory crucibles, in metallurgical furnaces, and as a refractory material in developing AZS refractory materials (Lide, 2007–2008).

Zircon has properties such as high melting point of about 2700°C, high thermal insulation, and high strength up to a temperature of 1500°C, reduced porosity, cracking and warping arresting functions and the ability to bind with clay when formed (Guzmán et al.,

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2006). Hence, most zircon is used directly in high-temperature applications. Use of zircon in aggressive environment such as in molds is possible due to its chemical resistant ability.

However, this material is also refractory, hard, and resistant to chemical attack. Hence, the consideration of producing bricks by blending this readily available zircon sand with some selected fireclays to enhance their properties. This will solve the problem of shortage of refractory bricks in Nigeria thereby improving the economy of the nation and also provide a reasonable overview of the current status of this type of refractory brick.It will also provide a summary of recent information concerning the characteristics of this refractory and subsequent blending of Nigerian fireclays with zircon sand for the production of quality refractory bricks.

The research studies the performance behavior at a laboratory scale of refractory bricks produced from selected Nigerian fireclays blended with varied volume fractions zircon sand for high-temperature furnace linings by characterizing their physical, chemical, mechanical, and thermal properties in relation to industrial standards. In effect, it will help to investigate the effects of the volume fractions of zircon sand on the physio-thermal and mechanical properties of the refractory bricks produced from selected Nigerian fireclays.

II. Methodology

a) Materials

- Fired clay samples - from Ikorodu in Lagos State and osiele in Ogun State, South West of Nigeria.
- Zircon - from Azara-Lafia in Nassarawa State, North Central of Nigeria.

b) Equipment

The equipment used in the project includes: Furnace (Carbolite RHF-16/15, Insulating brick lining 501/20ED Model No. 8477 230 -400 volts, England), Oven, Electronic Weighing Apparatus, Hydraulic Press (Paul-Weber D-7084Remshaden-Grunbaoh, Max. pressure: 350KN), Compressive Strength Machine (Testometric M-500-30KN, D7940 Seidner+CO GMBH, Germany), Atomic Absorption Spectrophotometer (AAS-PG990AFG),Hammer crusher (Shanghai Shibang Model 1183), Ball mill, Sieves of mesh sizes of 1183 microns to 150 microns, Tongs, Beakers, Conical flask.

c) Experimental procedure

The chemical analysis of the clay was carried out using an Atomic Absorption Spectrophotometer. The samples were crushed using jaw crusher and hammer crusher and ground with a ball mill in Nigerian Building and Railway Research Institute (NBRRI) Otta, Ogun state. The ground samples were further soaked, dried, and sieved through mesh sizes 600 to 150 μm. The clay samples were blended with zircon at various proportions of 10%, 20%, 30% and 35% by mass (Table 3.2). The blended mix samples were done in conformity with ASTM standards 1989 for tests by mixing with water (3 – 4%), molding and pressing with a hydraulic press to 300KN. The molded bricks were air dried for 24 hours and later fired in the Carbolite RHF-16/15 furnace up to 1200°C. The refractories bricks were tested for refractoriness, thermal shock resistance, cold crushing str

i. *Apparent Porosity Test*

Representative pieces of test bricks were prepared and air-dried for 24 hours. Apparent porosity test procedure was carried out and the apparent porosity was calculated using equation 1;

$$\text{Apparent Porosity} = \frac{W-D}{W-S} \times 100 \quad (1)$$

ii. *Bulk Density Test*

Three test pieces of each clay bricks measuring 60mm x 60mm x 15mm were molded and the bulk density was calculated using equation 2 from the bulk density experimental procedure.

$$\text{Bulk Density} = \frac{D \times \rho_w}{W-S} \text{ (g/cm}^3 \quad (2)$$

iii. *Fired Linear Shrinkage Test*

Fired linear shrinkage was calculated from equation 3 and test pieces were made into standard slabs for this experiment.

$$\text{Fired Linear Shrinkage} = \frac{D_1-F_1}{D_1} \times 100 \quad (3)$$

Table 1: Chemical composition of materials

Materials	Chemical Composition Analysis (%)									
	Al_2O_3	SiO_2	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	ZrO_2	LOI
Osiele Clay	30.31	51.73	1.46	0.28	0.16	0.62	2.31	0.07	-	13.08
Ikorodu Clay	37.10	41.46	0.10	1.32	0.92	0.20	0.12	-	-	18.78
Zircon Sand	0.47	29.56	0.39	-	-	-	-	0.14	65.30	4.14
Standard *(Devon)	26 – 70	35 - 57	0.5 - 1.6	<0.7	<0.2	<0.10	<2.0	<1.1		12 – 15

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iv. *Moisture Content Test*

Dried sample was weighed and then placed in a furnace and heated to a constant temperature of 110°C for 24hours. To calculate the moisture contents the following expression in equation 4 played a role;

$$\text{Moisture Content} = \frac{W - W_1}{W} \times 100 \quad (4)$$

v. *Cold crushing strength (CSS) Test*

Fired test pieces of clay samples prepared to a standard size of 76.2mm^3 on a flat surface used to conduct a compression strength analyses was made and the Compression Strength (C.S) was calculated from equation 5;

$$\text{Comp. Strength} = \frac{\text{Maximum load (KN)}}{\text{Cross Sectional Area (m}^2\text{)}} \quad (5)$$

vi. *Refractoriness Test*

Refractoriness was determined via pyrometric cone equivalent on test pieces carried out in the Carbolite RHF-16/15 furnace in reference to ASTM standard C-24 (ASTM, 2008).

vii. *Thermal Shock Resistance Test*

Samples measuring 50mm by 75mm fired in a furnace maintained for 10 minutes at 900°C and cooled repeatedly. The numbers of heating and cooling cycles for each specimen was recorded.

viii. *Loss on Ignition Test (LOI)*

Dried mass of the test sample at 110°C was heated in a muffle furnace to a temperature of 900°C for 3hours in a clean and dried porcelain crucible. The loss on ignition (LOI) was calculated using equation 6

$$\text{LOI} = \frac{m_2 - m_3}{m_2 - m_1} \times 100\% \quad (6)$$

Where, m_1 = weight of the crucible (g); m_2= weight of clay and crucible (g); m_3 = weight of the dried clay and crucible (g).

III. Results

a) Chemical Analysis

The chemical analyses of the refractory raw materials are shown in Table 1.

The major constituents of clay samples are silica and alumina while that of zircon is zirconia. The silica content in Osiele clay is greater than 50%, while the alumina content is about 30% and iron oxide is 1.5% with other substances such as oxides of sodium, titanium, and calcium are in small proportions. Ikorodu clay has silica content less than 50%, alumina content greater than 30% with iron oxide of about 0.1% and other oxides still exist in traces. The result shows that the clay samples belong to the family of alumino-silicate and semi-acid refractory since the alumina value falls within the classification of the standard value range of 25-45% (Gupta, 2008). The presence of impurities in alumino-silicate refractory, such as, Fe_2O_3, K_2O, MgO, lowers the refractoriness and service limit of the bricks. The values of the clay sample's loss of ignition are also within the recommended range of 6 - 15% for kaolinitic clay. The Zircon sand contains 65.30% of zirconia, 29.56% of silica and traces of iron oxide and titanium oxide. Zircon would increase the corrosion resistance of the refractory materials but alternatively reduces the binding properties of the zircon with the clay samples. The presence of high silica content (29.56%) in the zircon when bound with the clay materials can lead to the susceptibility of the bricks to spalling at temperatures below 600°C, hence decrease in strength of the refractory bricks. The presence of traces of Iron in the form of haematite (Fe_2O_3) compounds in clay acts as a flux and causes fusion which subsequently affects the refractoriness of the product.

b) Physical Properties

The essential brick properties like moisture content, apparent porosity, and bulk density are in the result. Observation during the processing and firing of the materials showed that zircon absorbed less water from clay which enhanced its mouldiness. The refractory products were soft, and the water absorption rate differs in the two clay samples. The moisture content of the bricks produced from the samples is high because the addition of zircon needed more water before it could bind with the fireclay samples.

The apparent porosity of the refractory bricks produced from clay samples with no zircon additive which are 15.27% and 16.11% respectively falls below the standard value of 20 – 30 according to Chesti (1986) while their bulk densities on the other hand of 2.20 and 2.36 g/cm^3 respectively falls within the standard range of 2.2 – 2.8 g/cm^3 showing the presence of few pores in the refractory bricks.

The apparent porosity of the refractory bricks decreased linearly with the introduction of zircon in increasing percentages for the two clay samples while their bulk density had a linear increase as shown in Figures 1 and 2 respectively. The low apparent porosity and high bulk density hinders the entrapping of gases in the material during operation, and will enhance the life-span of the refractory brick (Gupta, 2008). The values increased with the addition of fine grains of zircon which decreased the number of pores in the refractory bricks thereby increasing the bulk density of the material. The addition of zircon makes the refractory bricks material dense.

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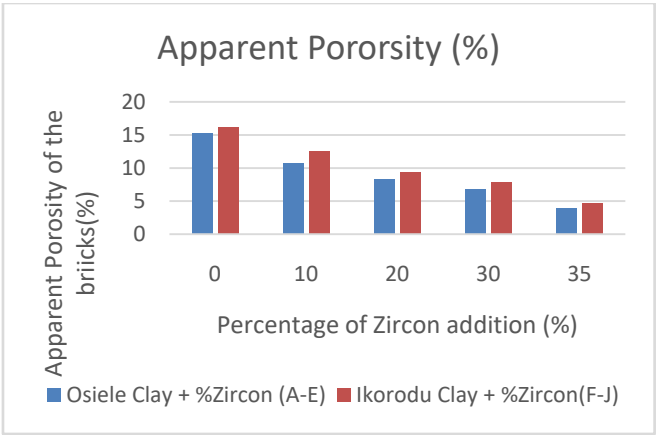

Figure 1: The variation of apparent porosity of the refractory bricks with percentage zircon addition

c) *Mechanical Properties*

The mechanical property of the tested refractory material was the compression strength (cold crushing strength). The behavior without and with the addition of zircon are shown in Figure 3.

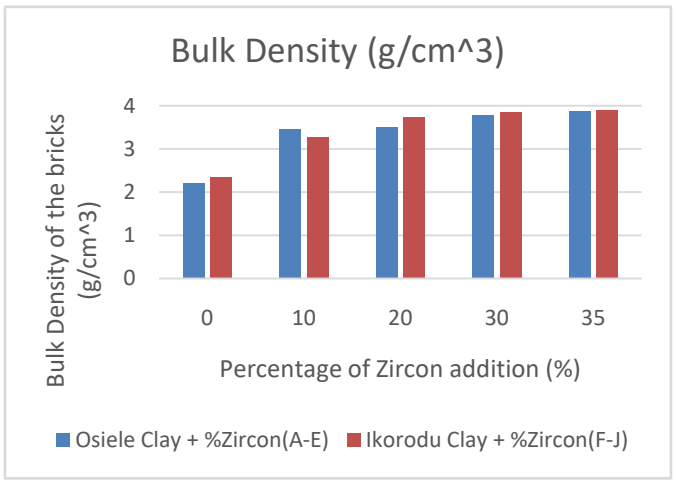

Figure 2: The relationship between bulk densities of the refractory bricks with percentage zircon addition

The refractory bricks produced from the Osiele clay and Ikorodu clay with no zircon additive has high compressive strengths of 131.95 KN/m^2 and 108.39 KN/m^2 respectively. These values fall within the recommended range of 15.0 KN/m^2 minimum values. The presence of high silica content in the clay samples may have caused this high strength. Silica content above 46.5% indicates free silica which enhances the strength of refractory materials (Gunter, 2005; Esezobor et al., 2014). The strength of the refractory bricks produced from the samples, however, decreased appreciably as a result of the addition of zircon as shown in Figure 3. The addition of 10% zircon to Osiele clay slightly reduced the compressive strength of the refractory brick but further additions of zircon (20%, 30%, and 35%) drastically lowered the compressive strength of the refractory bricks produced. From 10% addition of zircon to Ikorodu clay lowered the compressive strength of the refractory material so much that it failed below 15 KN/m^2 (recommended for refractory materials). Hence, the cold crushing strength of the refractory bricks produced with zircon above 30% for Osiele clay and the addition of zircon to Ikorodu clay falls below the standard value of 15 KN/m^2 minimum recommended. These additives also enhanced clay cracking and rupture during firing as it occurred in the case of increasing percentages of the zircon.

However, the addition of zircon significantly reduced the cold crushing strength of the refractory material as the samples have values that are below the recommended standard value. Thus, the refractory bricks produced have less resistance to load in compression, and the presence of zircon worsens this load-bearing capacity.

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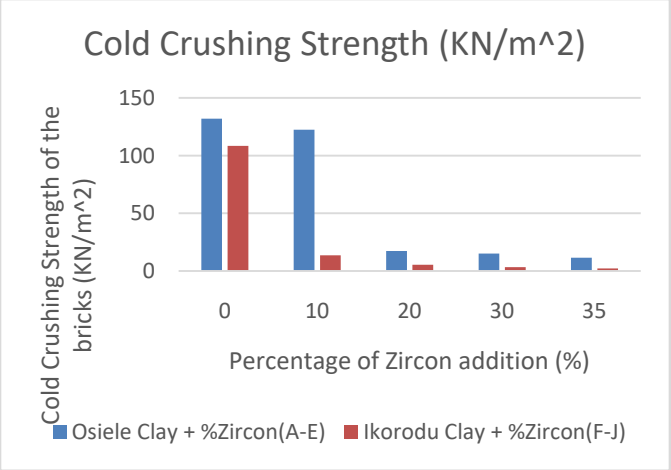

Figure 3: The relationship between crushing strength of the refractory bricks with percentage zircon addition

d) Thermal Properties

Table 2 shows the results of the thermal properties such as refractoriness and thermal shock resistance.

As seen in the result in Table 2, the average fired linear shrinkage for refractory bricks produced from the Osiele clay sample with no zircon additive is 11.4%, which falls above the range for conventional fireclay materials when compared to a standard value, while that of Ikorodu with no zircon additive of 9.4% is within the recommended values of 2 – 10% (Chesti, 1986). The materials, however, will have a superior interlock of grains, which will consequently enrich the strength o refractory when in operation.

Table 2: Thermal properties of the refractory bricks produced from the samples

Sample (%)	Refractoriness (°C)	TSR (cycles)
100Os	1500	20 + (Good)
90Os+10Zr	1300	Cracks at initial firing (Poor)
80Os+20Zr	1300	Cracks at initial firing (Poor)
100Ik	1400	24 (Good)
90Ik+10Zr	1300	Cracks at initial firing (Poor)
80Ik+20Zr	1300	Cracks at initial firing (Poor)
Standard*	1500 – 1750	20

However, Figure 4shows that there was a linear decrease with the increase in zircon addition for refractory bricks produced from Osiele clay samples whereas the behavior of the refractory brick produced from Ikorodu clay was not uniform with the addition of 10% zircon. However, there was a linear decrease in the fired linear shrinkage on the refractory bricks produced from Ikorodu clay sample with further zircon additive (20%, 30%, and 35%). The zircon does not burn off during firing but has a shrinkage arrest function which is adequate for refractory production.

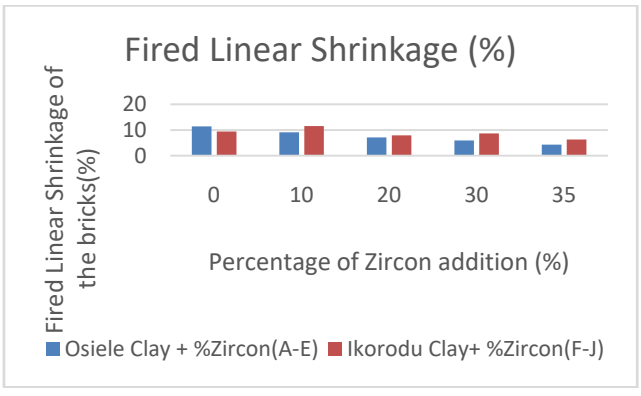

Figure 4: The relationship between fired linear shrinkage of the refractory bricks with percentage zircon addition

The loss on ignition on refractory bricks produced from the samples that contain no zircon addition with values of 7.65% and 9.67% respectively, fall within the recommended range of 2-13% for fireclays (Gupta, 2008). It means that the amount of organic matter content in the clay samples used to produce the bricks is low. But with the introduction of percentages of zircon to the clay samples, the loss on ignition of the

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refractory bricks increased linearly with increasing percentage zircon addition. Figure 5 shows this variations.

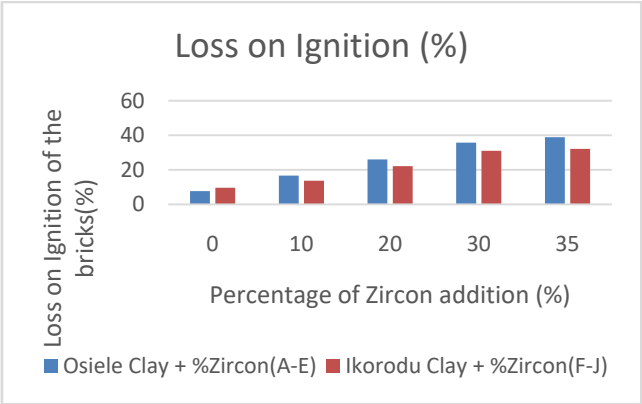

Figure 5: The variation of loss on ignition of the refractory bricks with percentage zircon addition

The thermal shock resistance of the refractory bricks produced from the two clay samples without the addition of zircon are 20 cycles and 24 cycles respectively. These values are within the acceptable values of 20-30 cycles. The refractory bricks produced by the addition of zircon to the clay samples failed at the initial firing stage of the test. It shows that the addition of zircon to the clay samples imbibes poor thermal shock resistance behavior in the fireclay refractory materials.

The refractoriness value obtained for the refractory bricks produced from the clay samples falls below the range of 1,500 – 1,750°C for the fireclay according to Table 2. This low refractoriness can be as a result of the amount of alumina present in the samples. The addition of zircon in percentages of 10, 20, 30 and 35 reduced the refractoriness to a constant value 1300°C for the refractory bricks produced from these samples as seen in Table 2. This behavior can be said to be that the binding property of the clay during the rick formation at 1300°C slowed down due to introduction of zircon. Hence, the drop in refractoriness of the refractory bricks from samples with the addition of any percentage of zircon used for the analysis to a temperature of 1300°C.

IV. Conclusions

The investigation carried out on the addition of zircon to Osiele and Ikorodu fireclays revealed that the service properties of Osiele clay as compared with Ikorodu clays have favourable results. Addition of Azara–Lafia zircon to these fireclays will reduce these properties. The chemical analysis of the clay materials revealed the percentage composition of the raw materials. The Azara-Lafia zircon contains 65.30% zirconia. The silica content for Osiele and Ikorodu clays are 51.73% and 41.46% respectively. The alumina content is 30.31% for Osiele clay and 37.10% for Ikorodu clay. The composition of the clay materials indicated that they are richer in silica than alumina and belong to the alumino-silicate group. The high impurities, such as, Fe_2O_3, CaO, TiO_2 and Na_2O which are very much present in the clays have drastically affected the service properties of the clays by reducing its refractoriness (observed from the increasing loss on ignition with increasing percentages of zircon additive), reducing the binding property and also the strength of the refractory material produced.

With the addition of 10% zircon to Ikorodu clay, the refractory materials becomes dense and with good compressive strength but low refractoriness and thermal shock resistance. The refractories produced from further addition of zircon to Ikorodu clay and the addition of any percentage of zircon to Osiele clay have poor thermal shock resistance, low compressive strength with refractoriness of 1300°C. These refractory bricks cannot find application in lining furnaces used for high-temperature applications above 1200°C. However, they can work furnaces with temperature below 1200°C.

From the results of the research carried out, zircon is an industrial material in the mineral processing industry which can serve as reinforcement for refractory bricks production. Based on the outcomes of the research, we can conclude that:

1. The decrease in cold crushing strength with increasing weight percentage of zircon show that low strength refractory brick can be made from this blend.
2. The refractory brick made with 0-10wt% zircon has the lowest value of firing shrinkage, porosity and with acceptable range of thermal shock resistance. This implies that there could be a possibility to produce good refractory brick from the blend.
3. These refractory bricks have properties which can be compared favourably with Indian fireclay refractory hence can reduce refractory importation.
4. Use of these refractory bricks for furnace lining and casting ladles is possible.

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5. The Azara-Lafia zircon additives are found suitable as blending materials for production of dense refractory bricks in clay for better performance to be used only in ovens operating at temperatures below 1200°C, ladles and transfer pots.

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CFD Analysis of A Typical Hydraulic Pressure Pipe Line in an Aircraft and Suggest Methods to Optimize its Stress and Vibration

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Abstract- The Hydraulic system of an aircraft is one of the most critical systems which operates essential services like the Control surfaces and Undercarriage system. Operators of Airlines and MROs have frequently complained about premature hydraulic line failures. This paper is aimed at studying the Fluid-Structure Interaction (FSI) of a typical hydraulic pipeline running in tandem with other pipe lines (which is a common feature in Aircraft) and suggest solutions to optimize the stress and vibration in them which is considered as the main factor for such catastrophic failures. Both CFX and FLUENT Solvers are used in our case. The analysis is carried out concerning suitability of material properties and support structure (for a high-speed aircraft) which are under the control of designers and MROs. The Von Misses stress has been simulated and analysed to substantiate various solutions being proposed.

Keywords: high speed aircraft hydraulic system, FSI, CFD of hydraulic pipe, CFX solver, FLUENT, active vibration dampers, MRO, von misses stress.

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CFD Analysis of A Typical Hydraulic Pressure Pipe Line in an Aircraft and Suggest Methods to Optimize its Stress and Vibration

Sravan Kumar Khuntia [α], Tariq Anwar [σ] & Gopal Gupta [ρ]

Abstract- The Hydraulic system of an aircraft is one of the most critical systems which operates essential services like the Control surfaces and Undercarriage system. Operators of Airlines and MROs have frequently complained about premature hydraulic line failures. This paper is aimed at studying the Fluid-Structure Interaction (FSI) of a typical hydraulic pipeline running in tandem with other pipe lines (which is a common feature in Aircraft) and suggest solutions to optimize the stress and vibration in them which is considered as the main factor for such catastrophic failures. Both CFX and FLUENT Solvers are used in our case. The analysis is carried out concerning suitability of material properties and support structure (for a high-speed aircraft) which are under the control of designers and MROs. The Von Misses stress has been simulated and analysed to substantiate various solutions being proposed. The ability of CFD to resolve such practical and field level problems and common snags in aircraft and associated components have made it quite popular among the aviation experts.

Keywords: high speed aircraft hydraulic system, FSI, CFD of hydraulic pipe, CFX solver, FLUENT, active vibration dampers, MRO, von misses stress.

I. Introduction

Hydraulic pipeline systems range from the very simple ones to very large and quite complex ones. A system may consist of a number of sub-networks separated by differing energy lines or pressure values. In order to study the Head loss and Energy loss across a pipe flow and to design Hydraulic pipelines individually or in manifold configuration, the following notations were used. The notations are shown in figure 1 for a computational sequence flow design.

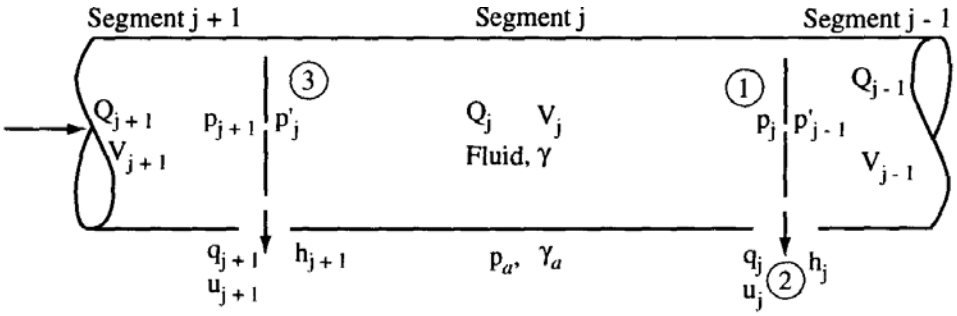

Figure 1: A two port hydraulic pipe segment

The manifold ports and barrel segments are numbered from the downstream end toward the upstream supply head or reservoir, with each port and segment number that is up stream of it denoted by j, which will also be used as a subscript on the other variables to indicate their location. Other variables are Q= discharge in the barrel segment, V= mean velocity in the barrel segment, A= cross-sectional area of the barrel segment, D= diameter of the barrel segment, q= discharge from a port, u= mean velocity through a port, a= cross-sectional area of a port, and d= diameter of a port. The fluid being conveyed has a unit weight of γ. The hydraulic model of flow in a pipe Has a discrete jump in pressure across a port; just upstream of port j the internal pressure is P_j, and the pressure immediate downstream of the next port is p_j.

We write an energy equation from a point inside the main control volume, point 1 to another rinstance in the port efflux stream, point 2:

$$-h_j + \frac{V_j^2}{2g} + \frac{p_j}{\gamma} = -h_j + \frac{u_j^2}{2g} + \frac{p_{aj}}{\gamma} + k_L \frac{u_j^2}{2g}$$

In the above equation, K_L is the port head loss coefficient. If we define an energy parameter E at port J as

$$E_j = \frac{p_j - p_{aj}}{\gamma} + \frac{V_j^2}{2g}$$

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Then the fluid exit velocity through the port is given by

$$u_j = \left(\frac{1}{1+k_L}\right)^{1/2} \left(2gE_j\right)^{1/2}$$

What makes the hydraulic system of aircraft more complicated is the fact that there is continuous transfer of forces and momentum between the pipe structure and hydraulic fluid (at high pressure of about 3000 Psi). Excitation caused by high frequency pulsation of flow coupled with vibration from equipment around viz Gas Turbine, gear mechanisms, etc. can lead to fatigue failure of these pipes.

II. CFD Analysis of Pipelines

The CFD analysis of commonly occurring defects in hydraulic pipelines carrying high pressure hydraulic fluid follows a sequence of technical processes along with scientific data analysis. The processes are explained in brief.

a) Preliminary study phase

It is necessary to study the physical problem analytically prior approaching the modeling and simulation phase. A proper preliminary study of the physical problem will help us individuate the assumptions and simplifications that are acceptable. In our case simplification lead to reduction in geometric complexity while allowing the thermal transfer equations. Hence this phase is fundamental to an accurate simulation result.

b) Geometric modelling

Geometrical models can be either 3D or 2D. It has to be an optimal choice so that it is easy to pass the data to the mesher software.

c) Meshing

Mesher plays an essential role in providing simulation related information to our model. During this process the model was divided into regions and surfaces. For the mesh to be usable all the boundaries relevant to the physical problem must be identified. These features will be used during the simulation setup phase to define fluids, solids and boundary conditions properties. The accuracy of the simulation result is dependent on the mesh geometry to a great extent. *This was evident during our various iterations and subsequently an Optimal.*

d) Solver for Simulation

During this phase we define the properties of all the fluids, solids and boundaries in fine detail. The choice of solver that is most suitable for the particular case is also decided in this phase viz. incompressible flow, compressible flow, steady solution, dynamic solution heat transfer and so on. *We chose SOLID 185 and FLUID 142 for representing our Material of pipeline and Hydraulic Fluid respectively.* We have defined the initial conditions as encountered by a hydraulic pipeline in an aircraft system (these are the values that the variables take at the beginning of simulation). The solution is accepted through verification and validation.

e) Data visualization and post processing

Post processing data visualization is the most important human interface to understand the analysis. The incremental behaviour of various parameters associated to our analysis like speed, pressure and density need to be visualized. The data compilation and visualization should be such that the value of particular physical parameter can be extracted or derived as per requirement for further detail analysis.

III. Experiment

In order to carry out the study, a particular hydraulic pipe line, of one of the high-speed aircrafts, which had shown signs of frequently failure was considered. To carry out CFD analysis and stress analysis, we collected various parameters required for initialization as per Aircraft Manual. These parameters are required to be fed exactly as per dimension during mathematical modeling of the pipeline to obtain an accurate and stable solution. The parameters are:

a) The Internal and external diameter of the pipeline.
b) Viscosity of the fluid flowing through the pipeline.
c) The Material of the pipeline.
d) Flow rate.
e) Pressure and temperature at the inlet of the pipeline.
f) Length of the pipeline.
g) Pipe profile and its shape.
h) Maximum vibration in the equipment bay/zone.
i) Distance between support clamps.

The figure given below is the photograph of a frequently failing hydraulic pipeline on the pressure side. This hydraulic pipe supplys required hydraulic pressure to the actuator of flying controls of an aircraft.

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Figure 2: Actual photo of Hydraulic pr line of a fighter aircraft

Figure 3: Damage to hydraulic pipelines followed by leakages and Pressure drop

Figure 4: Routing (Zone 1) of a Hydraulic Pipeline and support clamping

IV. Parameters Required For Modelling

a) We collected various parameters of the specific hydraulic pipeline those were required for pre-processing phase and are tabulated below.

Table 1: Parameters of pipeline for Pre-Processing

S. no.	Parameters	Part no. y.yy.yyyy.yy
1	Internal diameter	8.22mm
2	External diameter	10.22mm
3	Flow rate	185 l/min
4	Length of pipeline	52”
5	Pressure through pipeline	210 kg/cm^2
6	Temp. of hydraulic fluid	-60c to +175 c
7	Distance between clamp	16”,26”,40.5”
8	Name of fluid	7-50c-3(synthetic oil)

b) *Vibrations readings at Zone1*
   i. Engine vibration - 3.4mm/s
   ii. Gear box vibration - 3.8mm/s

c) *Fluid properties*
   i. Density at 20c - - 930 kg/m^3
   ii. Solidification point - <-70c
   iii. Kinematic viscosity - - 25mm^2/s
   iv. Type - - mixture of polysiloxane fluid and organic ether with addition of anti wear additive + antioxidant

It is a known fact that the hydraulic pipelines are to be routed complexly inside an aircraft equipment bay due to space constraint. Also, the various components of the Hydraulic system including actuators are located at distant positions, depending on their utility and design criteria, which causes sufficient length of pipelines to be laid out that further requires support and clamping to hard points on the fuselage. In our case the specific pipeline was clamped to 03 hard points at the bulkhead at mid fuselage. The defects reported by an MRO were of chaffing, *crack and dent*. On scrutiny it was discovered that the root cause would be excessive stress and vibration and dent being attributed to the process of bending or routing. In order to analyse the vibration related stress and provide a solution, three cases were considered:

a) Effect of choice of material on the stress induced in the hydraulic pipe (in terms of Fluid Structure Interaction - FSI). To ascertain the same, Von Misses stress or Equivalent stress was analyzed with Ti and Steel by customizing SOLID185.

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b) Since the vibration in the hydraulic pipeline can only get transferred to fuselage through the clamp points, two cases were considered for Von Misses stress analysis, one with 3-point support and the other with 4-point support. The working fluid was chosen to match the technical specification of the Hydraulic fluid of the aircraft that is FLUID 142 with customized properties.

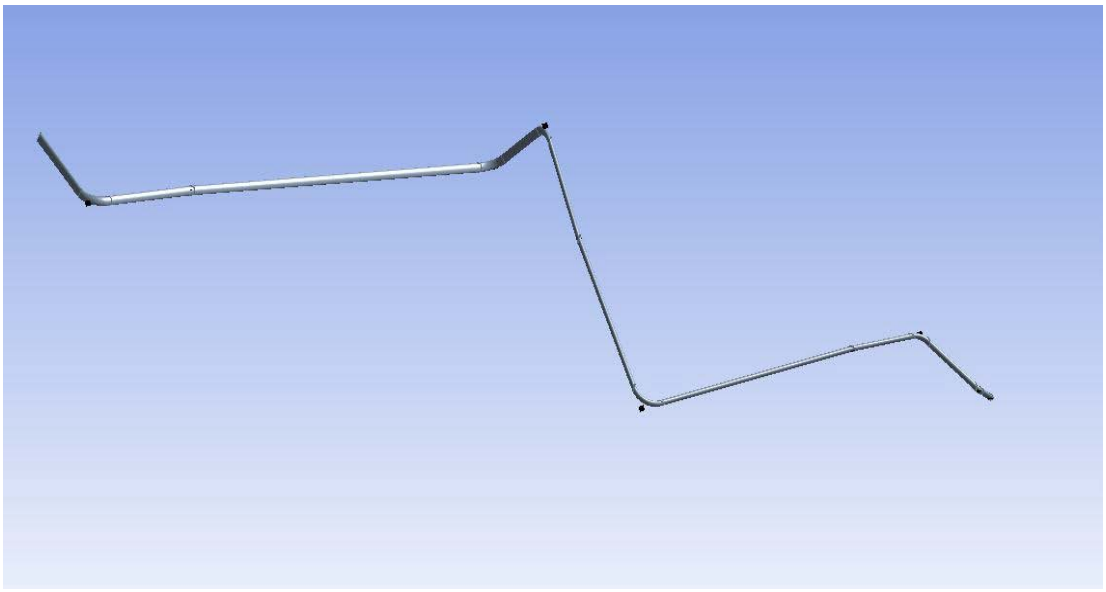

Figure 5: 3D Solid Model of the Hydraulic pipeline with 4-point clamp constraints

V. Fluent Analysis

As we deal with high pressure hydraulic fluids, which in our case are about 20 Mpa, the interactions between fluids and the walls of pipe lines that surround them cannot be neglected. When FSI occurs, fluid flow interacts with a physical structure, which in turn changes the fluid flow. This two-way interaction loop continues through multiple cycles, possibly resulting in structural damage and less-than-optimal flow. Traditional fluid flow simulation doesn't account for this interaction, so simulation results may be incomplete and even misleading. Thus accurate analysis of structural vibrations and fluid transients in pipes should be based on FSImechanism. In our paper, ANSYS FLUENT SOLVER and ANSYS Mechanical have been combined to solve the FSI problem.

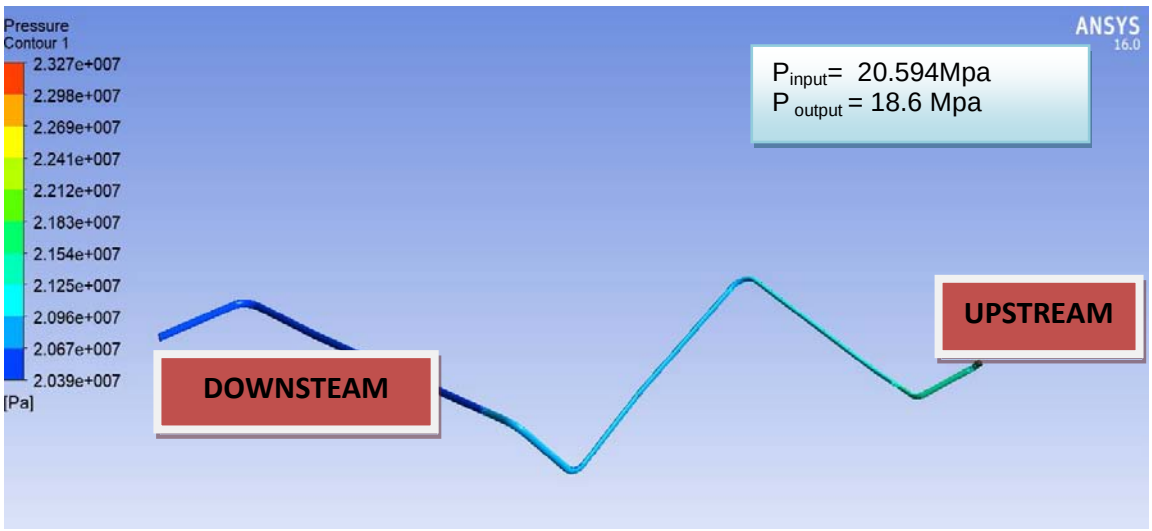

Figure 6: Wall Pressure

a) Three Support Hydraulic Pipe system

During this phase of the experiment the Hydraulic flow in the specific pipeline was simulated with the present configuration of 3 support clamps.

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i. *Steel pipe with 3 Support Clamps*

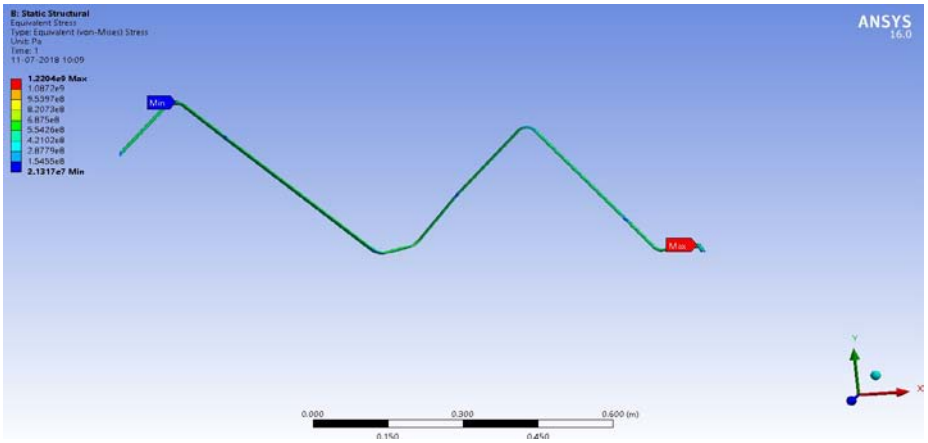

Figure 7: Equivalent Stress (Steel)

ii. *Steel pipe with 3 Support Clamps considering Vibration*

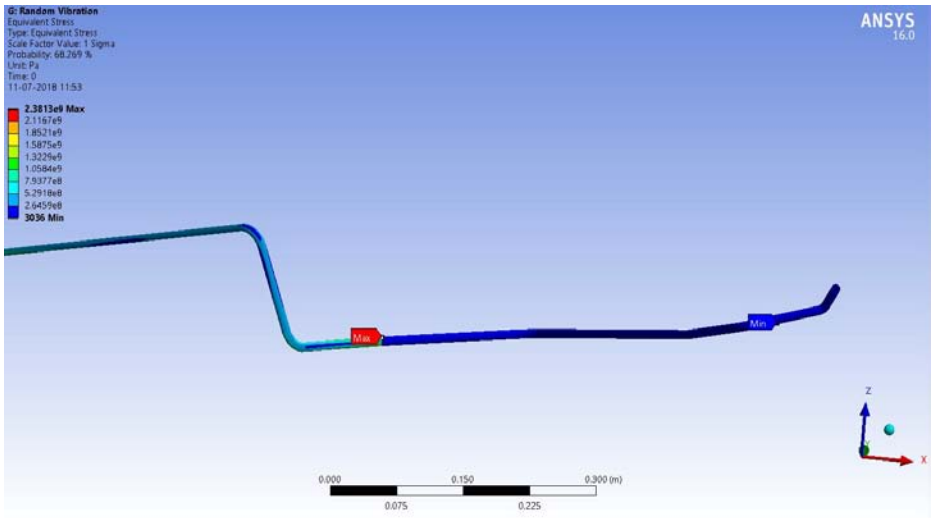

Figure 8: Equivalent Stress (Vibration= 3.8 mm/s)

iii. *Titanium pipe with 3 Support Clamps without Vibration*

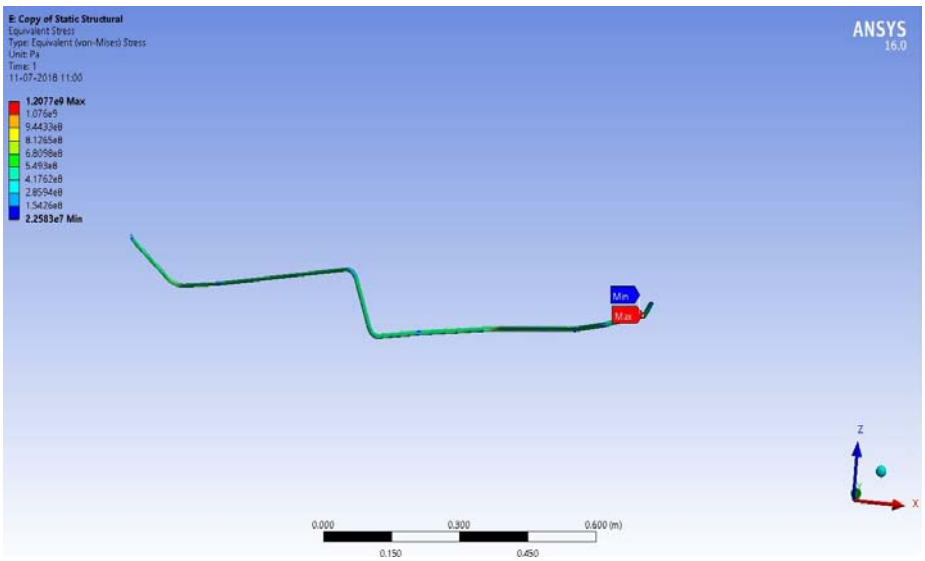

Figure 9: Static Structural Stress

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iv. *Titanium Pipe with 3 Support Clamps with Vibration*

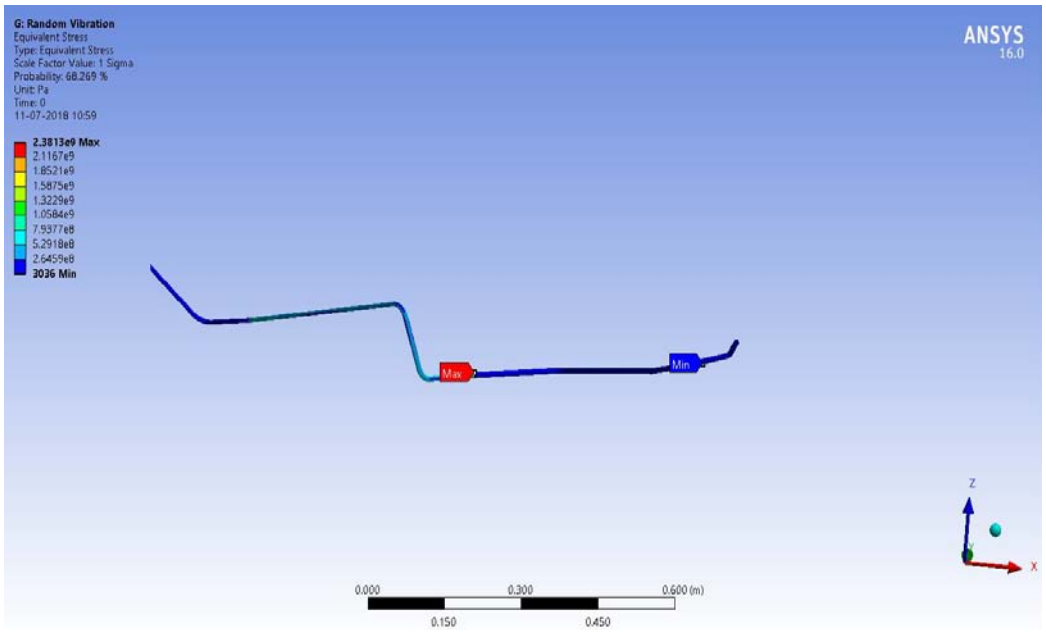

Figure 10: Equivalent Stress (Vibration = 3.8 mm/s)

b) Four Support Hydraulic Pipe system

Subsequently the specific pipeline was considered with 4 supports with hard point attachment on the aircraft bulkhead frame to ensure transfer of dynamic forces to fuselage from the pipelines. The equivalent stresses on the pipeline in static condition and with surrounding vibrations were simulated for comparison. The simulation figures are appended below.

i. *Steel pipe with 4 Support Clamps without Vibration*

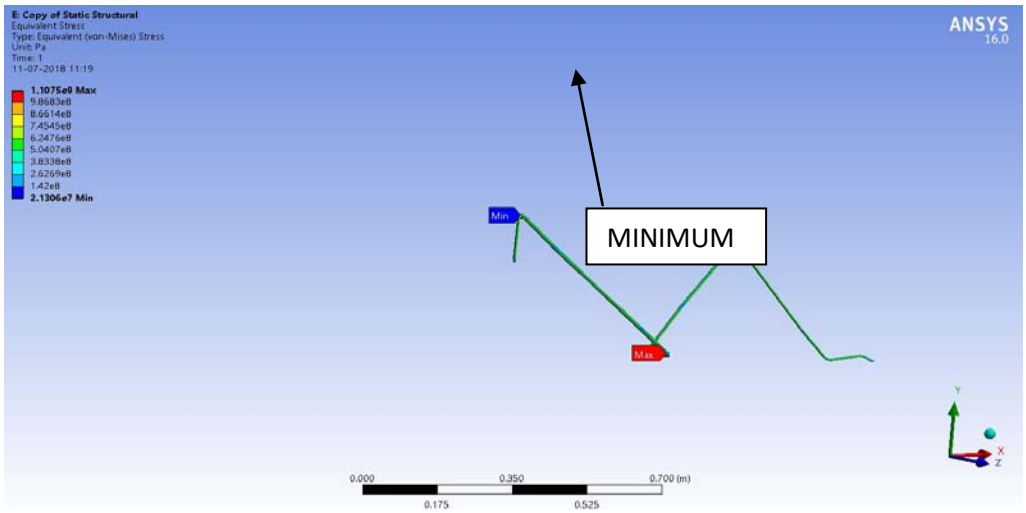

Figure 11: Equivalent Stress

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ii. *Steel pipe with 4 Support Clamps considering Vibration*

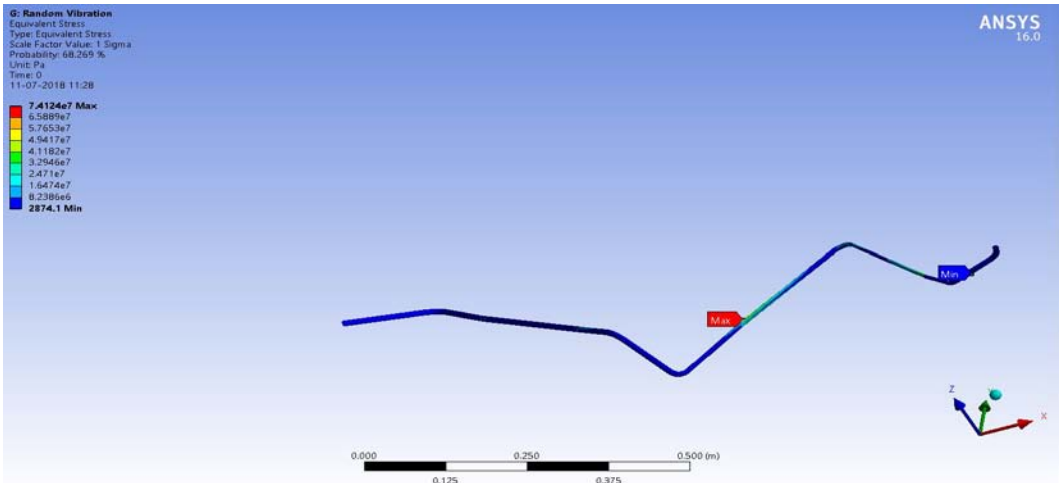

Figure 12: Equivalent Stress (Vibration = 3.8 mm/s)

iii. *Titanium Pipe with Four Support Clamps*

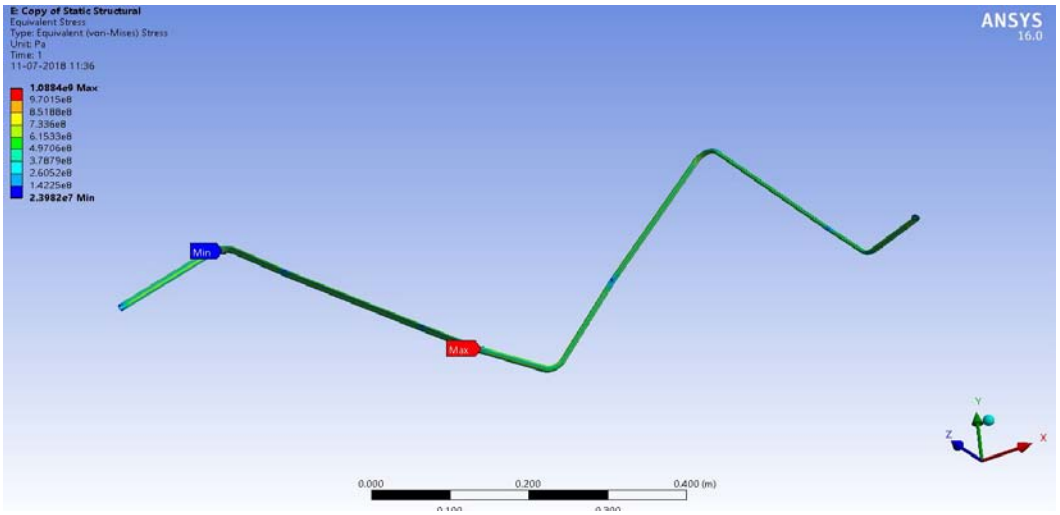

Figure 13: Equivalent Stress

iv. *Titanium Pipe with Four Support Clamps with Vibration*

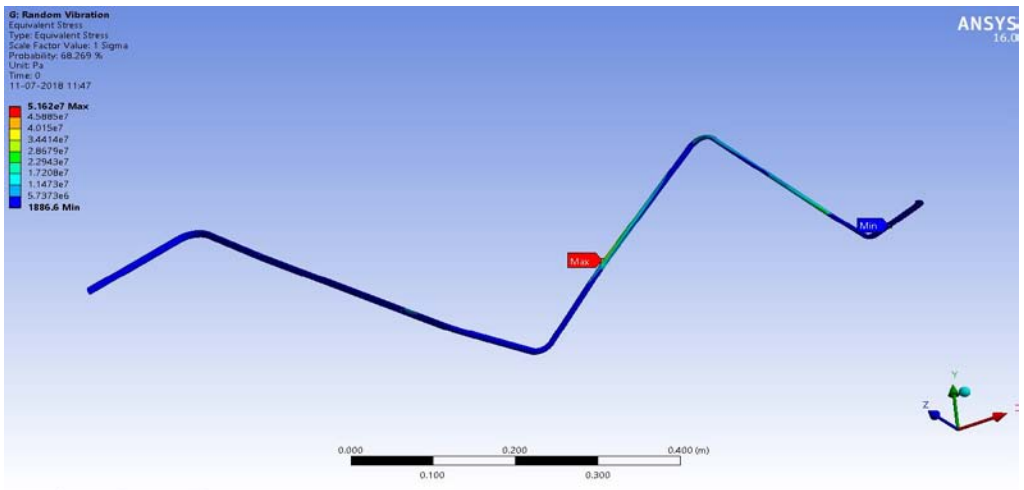

Figure 14: Equivalent Stress (Vibration= 3.8 mm/s)

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VI. Results

After the simulation with help of ANSYS and both CFX, FLUENT Solver, the equivalent stress distribution through the length of the pipeline was scrutinized for abnormality and the location of maximum stresses were identified. The simulation data are tabulated below in Table 2.

Table 2: Results Table

Test	Steel with 3 support	Titanium with 3 support	Steel with 4 support	Titanium with 4 support
Static structural analysis (stress)	1220.4Mpa	1207 Mpa	1107.5 Mpa	1088 Mpa
Random vibration analysis(stress)	2381.3 Mpa	2381 Mpa	74.12 Mpa	51.62 Mpa

VII. Analysis Report

Below mentioned are few of the common factors that can affect the health of Hydraulic pipelines which carry high pressure hydraulic fluid. The Hydraulic system plays an extremely vital role in aircraft operation. These common mistakes may be avoided for deterioration of hydraulic pipelines and any further catastrophic failure.

a) Manufacturing Process and Handling

Pipes are required to be casted as per routing. No further bending should be carried out by using primitive methods like hammering. It has been proved through various experiments that bending of pipeline causes severe stress concentration at the point of bend that may cause crack initiation (Griffith energy criteria)

It has been observed that external force is applied in order to fix pipeline into the system/ routing in the equipment bay. This external force is applied either by bending the pipeline or by hammering. This leads to increase in residual stress inside the body which reduces strength of material. Finally, it leads to crack initiation and propagation.

When external forces or hand pressure is applied on the pipeline to fix the pipeline then it reduces the distance between the pipelines. Sometimes pipelines come in contact with each other. It leads to the chaffing of material. Pipelines rub against each other, causing erosion of the surface and eventual failure. The transfer of vibration and other dynamic loads can cause deterioration of pipelines.

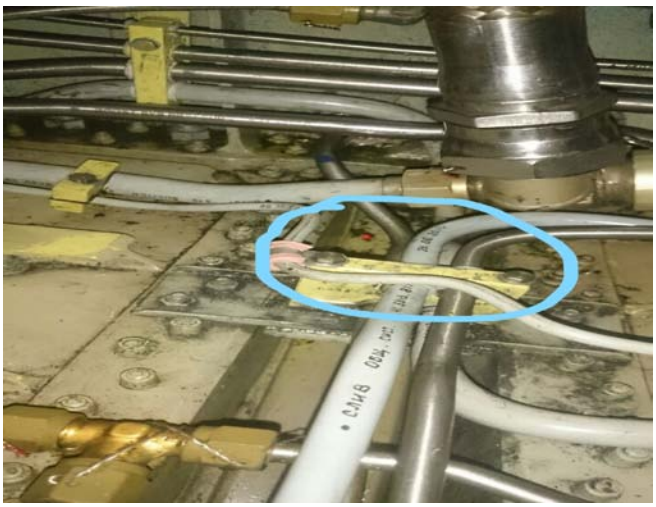

Figure 15: Pipelines Rubbing Against Each Other due to Zonal Vibration

i. *Clamping or Support System*

Due to Fluid Structure Interaction coupled with Vibration, these hydraulic piping systems become highly responsive, leading to amplified vibrations and fatigue failures. With low-damped systems, the vibration Ring-down time after the initial event can be severely long. Damping is a proven solution to control vibration and is used extensively in the automotive and aerospace industries.

In most of the aircraft systems NT (Nylon Titanium Composite Clamps) material are used as support system. Studies have shown that flour plastic gasket can reduce the vibration to some extent. The complexity of source of vibration that exists in an aircraft certainly requires an active Vibration Dampers with damping material liner and wear pad. One such active Damper available in the market (DamperX) is shown in Fig 16.

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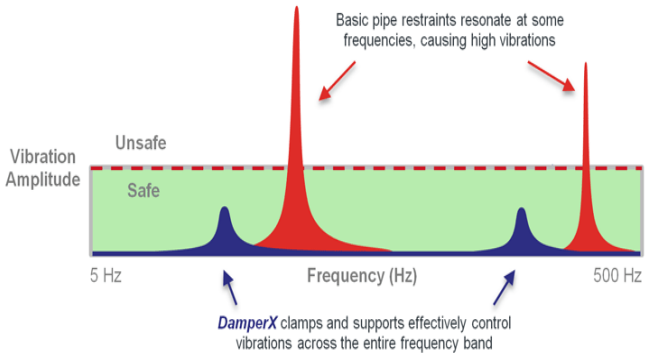

Figure 16: Anti Vibration Damper

ii. *Pipe Hanger or Pipe Support*

A pipe support or pipe hanger is a designed element that transfers the load from a pipe to the supporting structures. The four main functions of a pipe support are to *anchor, guide, absorb shock, and support a specified load*. Pipe supports used in high or low temperature applications may contain insulation materials. The overall design configuration of a pipe support assembly is dependent on the dynamic loading factor and operating conditions.

There is no thumb rule for number of supports to be used on particular pipeline. Generally, support is placed on the longer and straight pipelines. So, an attempt was made to observe stresses by increasing no. of supports. It was found out that stress could be reduced by *32 times*, by increasing the support points by 30% while keeping the material of pipeline same.

iii. *Changing Material of Pipeline*

Pipeline is subjected to high pressure (210 kg/cm^2) and vibration. So, Material strength was also considered as a reason of failure. Titanium was considered as a replacement of steel. It was found that with 4 no. of clamps, stresses in steel pipeline are 1.4 times titanium (as compared to 32 times decrease in equivalent stress due to an additional support clamp). It proves that material performance is satisfactory. So, there is no need to change material from steel to titanium.

VIII. Conclusion

The use of Hydraulics for operation of various components of an aircraft viz Control surfaces, Undercarriage etc is inevitable. With increase in AUW, the hydraulic system gets more and more bulky and complexity of pipeline system also increases. The flying envelope and max speed of the aircraft also decides the aerodynamic forces on various Control surfaces which in turn decide the robustness of the Hydraulic system. As these dynamic forces increase, the system requirement also becomes more stringent. We used CFX and FLUENT Solver to simulate the flow through a specific hydraulic pipeline which has a history of failing frequently. The conclusion of our experiment along with recommendation is appended below:

i. Locations of occurrence of maximum stress were obtained from Von Misses stress analysis to optimize the support clamp positions.
ii. With increase in no. of support clamps (in our case 3 to 4), stresses on the hydraulic pipeline reduced drastically. With proper and iterative simulation, the exact positions of support clamps were ascertained.
iii. In case of steel, when supports are increased from 3 to 4 then stress is reduced by 32 times from 2381.3 Mpa to 74.12 Mpa.
iv. Changing the material from steel to titanium didn't have any profound effect on reduction of Equivalent stress in pipeline. However, stress reduced from 74.12 Mpa to 51.62 Mpa (with 4 Supports).
v. In order to reduce the vibration stress and reduce the chance of failure, an additional4thsupport clamp is proposed for the specific hydraulic pipeline as shown below.

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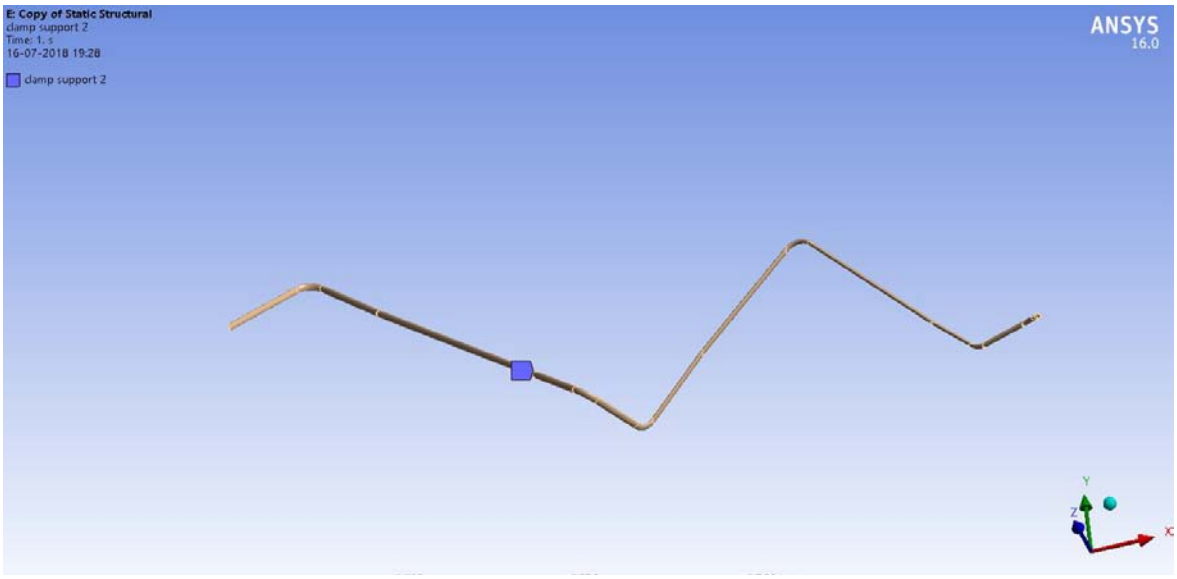

Figure 17: Location of the 4th Support

vi. Implementation of standardization

i. The hydraulic pipelines need to be of standard size and shape (pre-fabricated). No external force should be applied on the pipelines after fitment i.e. cold work is not permitted.

ii. Spacing between the pipelines should be standardised.

The hydraulic pipelines are subjected to higher dynamic stresses due to combinatory force of high pressure, temperature and vibration. Hence, clamping of these pipelines using active vibration dampers on main frame or bulkhead of aircraft should be explored. In order to avoid chaffing between pipelines, better pipeline routing may also be explored during design phase.

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- Fellow can also join as paid peer reviewer and earn 15% remuneration of author charges and can also get an opportunity to join as member of the Editorial Board of Global Journals Incorporation (USA)
- • This individual has learned the basic methods of applying those concepts and techniques to common challenging situations. This individual has further demonstrated an in–depth understanding of the application of suitable techniques to a particular area of research practice.

Note :

"

- In future, if the board feels the necessity to change any board member, the same can be done with the consent of the chairperson along with anyone board member without our approval.
- In case, the chairperson needs to be replaced then consent of 2/3rd board members are required and they are also required to jointly pass the resolution copy of which should be sent to us. In such case, it will be compulsory to obtain our approval before replacement.
- In case of "Difference of Opinion [if any]" among the Board members, our decision will be final and binding to everyone.

"

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3. Ensure corresponding author's email address and postal address are accurate and reachable.
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Acknowledgments

Contributors to the research other than authors credited should be mentioned in Acknowledgments. The source of funding for the research can be included. Suppliers of resources may be mentioned along with their addresses.

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The following is the official style and template developed for publication of a research paper. Authors are not required to follow this style during the submission of the paper. It is just for reference purposes.

Manuscript Style Instruction (Optional)

- Microsoft Word Document Setting Instructions.
- Font type of all text should be Swis721 Lt BT.
- Page size: 8.27" x 11'", left margin: 0.65, right margin: 0.65, bottom margin: 0.75.
- Paper title should be in one column of font size 24.
- Author name in font size of 11 in one column.
- Abstract: font size 9 with the word "Abstract" in bold italics.
- Main text: font size 10 with two justified columns.
- Two columns with equal column width of 3.38 and spacing of 0.2.
- First character must be three lines drop-capped.
- The paragraph before spacing of 1 pt and after of 0 pt.
- Line spacing of 1 pt.
- Large images must be in one column.
- The names of first main headings (Heading 1) must be in Roman font, capital letters, and font size of 10.
- The names of second main headings (Heading 2) must not include numbers and must be in italics with a font size of 10.

Structure and Format of Manuscript

The recommended size of an original research paper is under 15,000 words and review papers under 7,000 words. Research articles should be less than 10,000 words. Research papers are usually longer than review papers. Review papers are reports of significant research (typically less than 7,000 words, including tables, figures, and references)

A research paper must include:

a) A title which should be relevant to the theme of the paper.
b) A summary, known as an abstract (less than 150 words), containing the major results and conclusions.
c) Up to 10 keywords that precisely identify the paper's subject, purpose, and focus.
d) An introduction, giving fundamental background objectives.
e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition, sources of information must be given, and numerical methods must be specified by reference.
f) Results which should be presented concisely by well-designed tables and figures.
g) Suitable statistical data should also be given.
h) All data must have been gathered with attention to numerical detail in the planning stage.

Design has been recognized to be essential to experiments for a considerable time, and the editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned unrefereed.

i) Discussion should cover implications and consequences and not just recapitulate the results; conclusions should also be summarized.
j) There should be brief acknowledgments.
k) There ought to be references in the conventional format. Global Journals recommends APA format.

Authors should carefully consider the preparation of papers to ensure that they communicate effectively. Papers are much more likely to be accepted if they are carefully designed and laid out, contain few or no errors, are summarizing, and follow instructions. They will also be published with much fewer delays than those that require much technical and editorial correction.

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It is necessary that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

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The title page must carry an informative title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) where the work was carried out.

Author details

The full postal address of any related author(s) must be specified.

Abstract

The abstract is the foundation of the research paper. It should be clear and concise and must contain the objective of the paper and inferences drawn. It is advised to not include big mathematical equations or complicated jargon.

Many researchers searching for information online will use search engines such as Google, Yahoo or others. By optimizing your paper for search engines, you will amplify the chance of someone finding it. In turn, this will make it more likely to be viewed and cited in further works. Global Journals has compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

Keywords

A major lynchpin of research work for the writing of research papers is the keyword search, which one will employ to find both library and internet resources. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining, and indexing.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy: planning of a list of possible keywords and phrases to try.

Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, “What words would a source have to include to be truly valuable in a research paper?” Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

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Numerical methods used should be transparent and, where appropriate, supported by references.

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Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

Formulas and equations

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

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Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

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Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

Preparation of Eletronic Figures for Publication

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

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Tips for Writing a Good Quality Engineering Research Paper

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1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

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7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

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10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.

22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.

23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

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- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.

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- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- Single section and succinct.
- An outline of the job done is always written in past tense.
- Concentrate on shortening results—limit background information to a verdict or two.
- Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- Explain the value (significance) of the study.
- Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

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Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

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Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

INDEX

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