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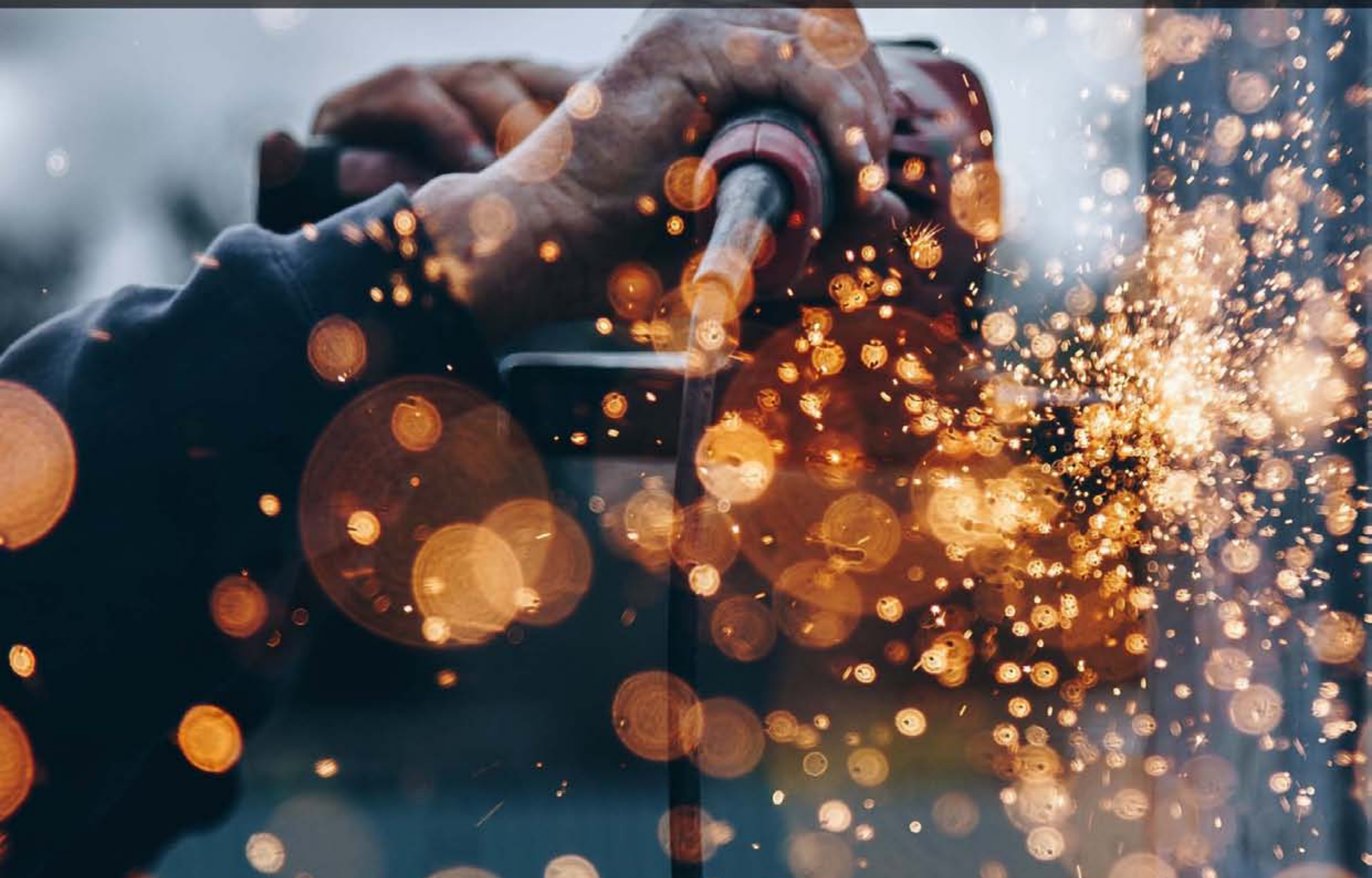

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Productivity in Apparel Industries

Highlights

Experimental Investigation on CI

Analysis of a Lightweight Aluminum

Discovering Thoughts, Inventing Future

VOLUME 20 ISSUE 1 VERSION 1.0

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Analysis of a Lightweight Aluminum Vehicle Chassis in a Simulation-based Design Approach

By Mohsen Alardhi, Fahad Almaskari, Melad Fahed & Jasem Alrajhi
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Abstract- This study investigates different chassis designs through a simulation-based design approach. The inherent aluminum ductility and softness could make chassis a daunting modification if not analyzed properly. Structural finite element analysis is comprehensively performed on a vehicle chassis for static loading cases up to 1G in equivalent acceleration. The analysis of the vehicle chassis of both A36 steel and 6061 aluminum for the scenarios of bump, front impact, side impact and a rollover. The von Mises stresses and displacement results showed that the steel chassis possessed higher safety factor in all load cases. The safety factors for an aluminum clone of the steel chassis in some load cases are below 1.0, hence indicating that the failure criterion has been triggered and failure would occur under the 1G load. The original aluminum chassis deformation is far more severe than steel reaching as high as 9.88 mm for the bump loading. A modified aluminum chassis is proposed, by optimizing the wall thickness of the rectangular bars. The slight increase in weight resulted in overcoming the deficiency of aluminum in load-carrying capacity. An evaluation matrix procedure is implemented to analyze the tradeoffs between cost, weight and safety factor for the three chassis materials.

Keywords: *chassis design; finite element analysis; simulation.*

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Strictly as per the compliance and regulations of:

Analysis of a Lightweight Aluminum Vehicle Chassis in a Simulation-based Design Approach

Mohsen Alardhi [α], Fahad Almaskari [σ], Melad Fahed [ρ] & Jasem Alrajhi [ω]

Abstract- This study investigates different chassis designs through a simulation-based design approach. The inherent aluminum ductility and softness could make chassis a daunting modification if not analyzed properly. Structural finite element analysis is comprehensively performed on a vehicle chassis for static loading cases up to 1G in equivalent acceleration. The analysis of the vehicle chassis of both A36 steel and 6061 aluminum for the scenarios of bump, front impact, side impact and a rollover. The von Mises stresses and displacement results showed that the steel chassis possessed higher safety factor in all load cases. The safety factors for an aluminum clone of the steel chassis in some load cases are below 1.0, hence indicating that the failure criterion has been triggered and failure would occur under the 1G load. The original aluminum chassis deformation is far more severe than steel reaching as high as 9.88 mm for the bump loading. A modified aluminum chassis is proposed, by optimizing the wall thickness of the rectangular bars. The slight increase in weight resulted in overcoming the deficiency of aluminum in load-carrying capacity. An evaluation matrix procedure is implemented to analyze the tradeoffs between cost, weight and safety factor for the three chassis materials.

Keywords: chassis design; finite element analysis; simulation.

I. Introduction

Most of the automotive manufacturers worldwide currently require that all new and modified manufacturing system designs be verified by simulation analysis before they are approved for final equipment purchases [1]. Studies performed in the past are indicators of how useful simulation could be in the design and operation of production systems of all kinds, including chassis manufacturing. Simulation is an essential stage of any chassis development to ensure proper functionality and safety under the anticipated loads. The objective of this paper is to develop a reliable chassis design according to standards and regulations in a simulation-based design approach [2, 3].

A chassis is the structural backbone of any vehicle. The chassis of a vehicle performs vital functions of protecting the driver and components within, as well as being a foundation to mount and assemble various drive systems on the vehicle. When a vehicle is in motion, it is subjected to stresses and vibrations induced by the roughness of the road, harsh weather conditions and the components within it. The design process of a vehicle chassis undergoes continuous modifications to full meet the requirements.

The chassis analyzed in this study is a small-sized chassis for a participating team within the Global Hybrid Electric Challenge (GHEC). The GHEC is the latest international collegiate competition promoting education, energy efficiency, and environmental consciousness [4]. The race is generally an efficiency race attempting to answer the question of "which team can drive the maximum distance given the same amount of energy?". There are many factors that go into the equation of "maximum distance", such as aerodynamics, acceleration, speed, tire conditions, driving style, and most importantly the overall vehicle weight. The weight of the A36 steel chassis currently in operation is around 12 kg. Considering the lightweight nature of the vehicle being around 70 kg in total excluding the driver, cutting a few kilograms from the chassis while maintaining stiffness will reap a lot of dividends.

This study investigates a lighter-weight alternative to the current chassis A36 steel which can withstand the high stress bump and collision scenarios. By using 6061 aluminum, the weight of the chassis is expected to reduce significantly to approximately one third of the current weight. The weight reduction saves energy, minimizes brake wear, improves steering, and cuts down emissions. However, the inherent aluminum ductility and softness could make it a daunting modification if not analyzed properly. Finite Element Analysis (FEA) is used to provide a reliable method for analyzing the effect of various load cases on the deformation and stress limits of the chassis structure by replacing the steel material with aluminum [5, 6].The scope of the study is to perform a structural FEA on the chassis body for static loading with up to 1G in equivalent acceleration. The analysis is based on linear elastic behavior of the vehicle chassis of both A36 steel and 6061 aluminum for the scenarios of bump, front impact, side impact and a rollover.

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II. Finite Element Analysis

a) Chassis 3D Model

A detailed 3D model of the chassis is developed in the ABAQUS software. A wire feature is used to represent the bars of the chassis, while assigning the corresponding profiles to each bar. Figure 1 below shows the model of the vehicle chassis with the assigned section profiles.

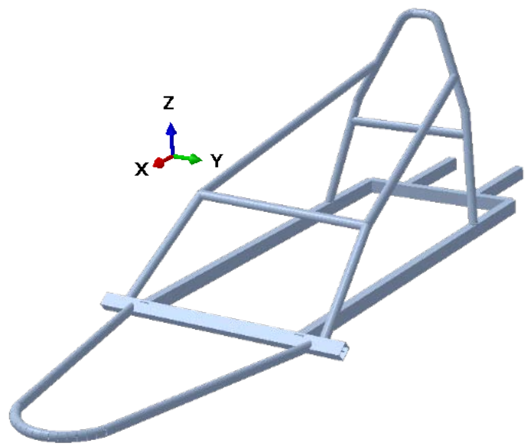

Figure 1: The 3D model of the vehicle chassis.

The rectangular and circular section profiles are shown in Figure 2 (a) and (b), respectively.

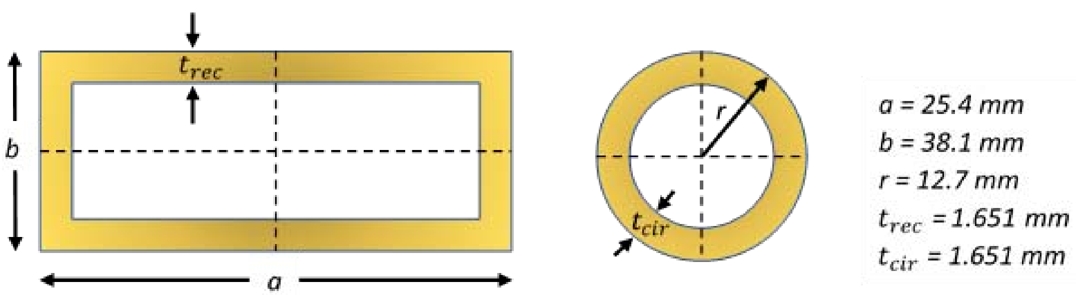

Figure 2: Original steel and aluminum chassis design section profiles (a) rectangular and (b) circular.

b) Material Definition

The mechanical response of the A36 steel and 6061 aluminum are listed in Table 1.

Table 1: Mechanical properties of A36 steel and 6061 aluminum [7, 8].

Property	A36 steel	6061 aluminum
Young's Modulus	200.0 GPa	68.9 GPa
Density	7,850 kg/m^3	2,700 kg/m^3
Poisson's Ratio	0.26	0.33
Yield Strength	250.0 MPa	55.0 MPa
Ultimate Tensile Strength	400.0 MPa	124.0 MPa

c) Original Design - Analysis

The structural FEA is performed on the two chasses with static loading. Each analysis is carried out for both A36 steel and 6061 aluminum. Several impact scenarios are simulated, which are: bump, front impact, side impact and rollover. The load cases for each scenario is defined as per the following:

i. *Bump (torsional test):* Fix rear and one front wheel, apply vertical load at third wheel (1G) [9].The vehicle speeds are fairly low, on the order of 45 kph, and the races are generally held on a smooth racetrack with flat run-off areas, so the 1G bump is a reasonable load. Figure 3 (a) below shows the bump loading conditions. The torsional stiffness/rigidity of the chassis is often an important measure of how much the chassis will twist under the loads transferred to it from the suspension.

ii. *Front impact:* Fix the wheels and apply 1G longitudinal load at bumper apex. The vehicles are of a comparable mass, and if they collide, the vehicles will slide with a tire/ground friction force that is less than 0.8G equivalent acceleration. Therefore, a 1G front impact force is adequate. Figure 3 (b) below shows the front impact loading conditions.

iii. *Side impact:* Fix the wheels and apply 1G lateral load distributed across 10 – 15 cm. This value is selected based on the same reasoning of the front impact load case. Figure 3 (c) below shows the side impact loading conditions.

iv. *Rollover (roll hoop) impact:* Fix the frame and apply a 1G vertical load on the roll hoop apex. This is based on the regulations that dictate a 1G load to be applied at the apex of the roll hoop. Figure 3 (d) below shows the rollover loading conditions.

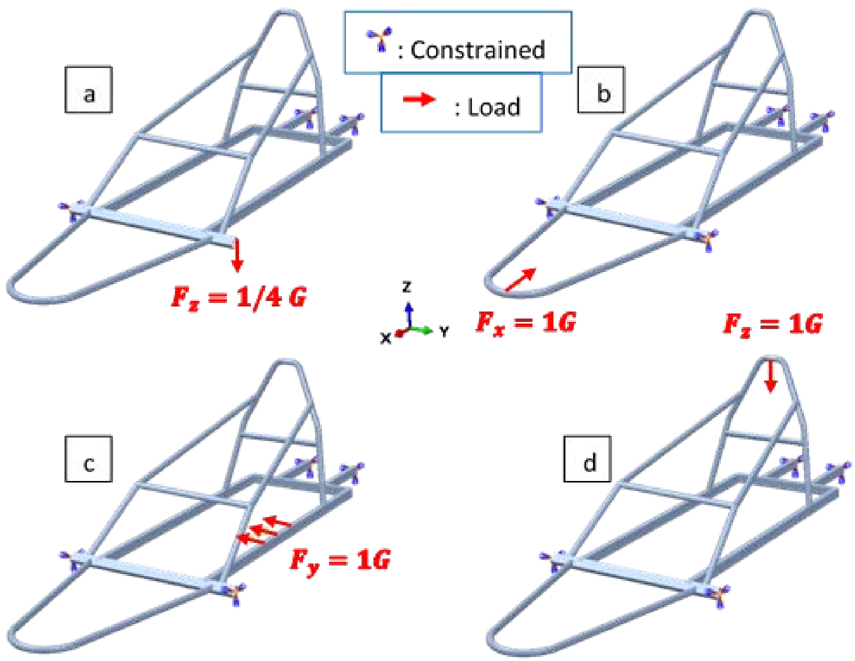

Figure 3: FEA loading conditions of the a) bump b) front impact c) side impact d) rollover.

d) Original Design - Results

The chassis models made of steel and aluminum weigh 11.9 kg and 4.1kg, respectively. The weight reduction advantage of using aluminum over steel is significant, resulting in a final mass that is 35% of the initial steel chassis mass.

The von Mises stress distributions as a result of the bump/torsional load for A36 steel and 6061 aluminum are shown in Figure 4.

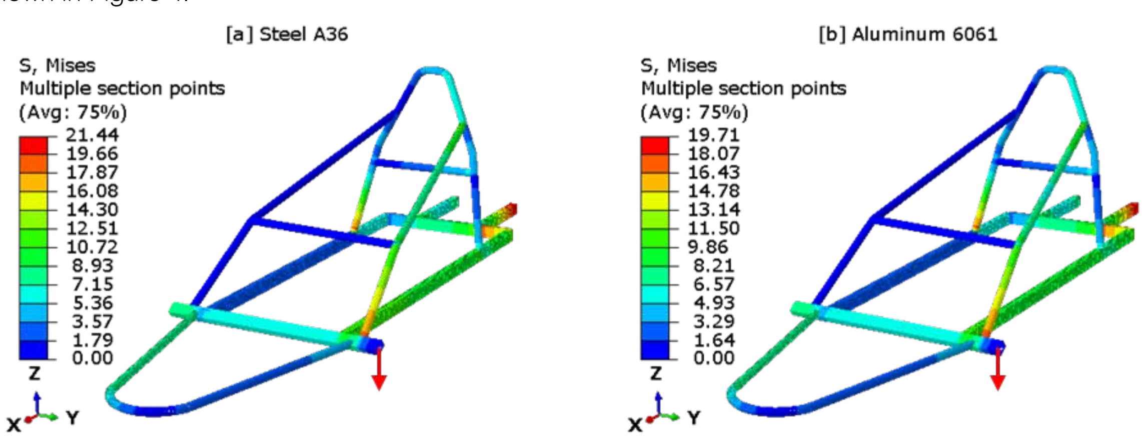

Figure 4: The von Mises stresses of the torsional test for a) A36 steel b) 6061 aluminum.

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The von Mises stress distributions of the front impact for A36 steel and 6061 aluminum are shown in Figure 5.

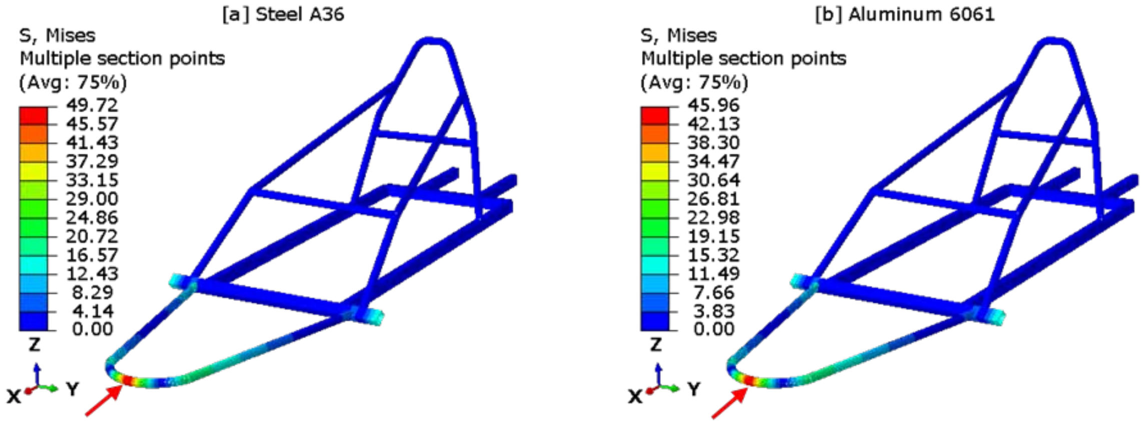

Figure 5: The von Mises stresses of the front impact test for a) A36 steel b) 6061 aluminum.

The von Mises stress distributions of the side impact for A36 steel and 6061 aluminum are shown in Figure 6. The stress in this case exceed the yield strength of 6061 aluminum (σ_y = 55 MPa) and hence will cause chassis plastic deformation/failure.

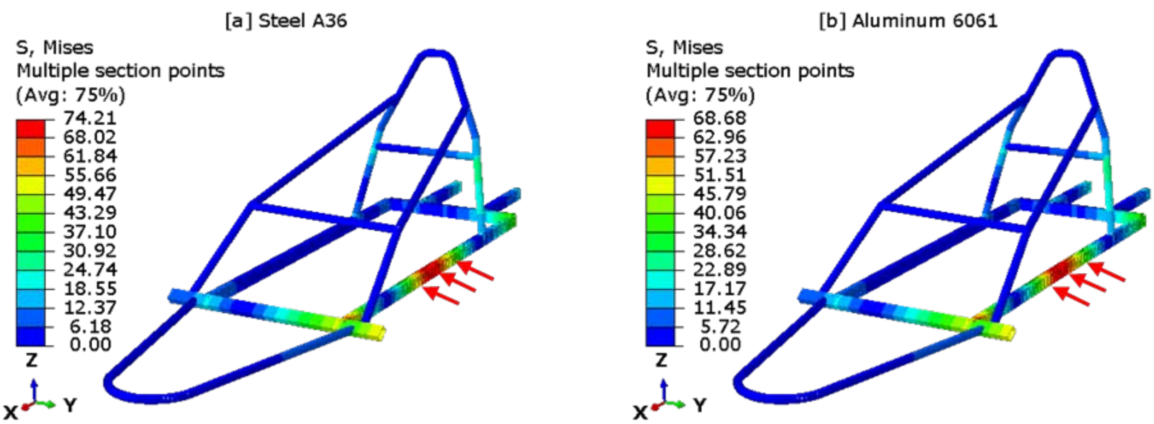

Figure 6: The von Mises stresses of the side impact test for a) A36 steel b) 6061 aluminum.

The von Mises stress distributions of the rollover impact for A36 steel and 6061 aluminum are shown in Figure 7. The stress in this case exceed the yield strength of 6061 aluminum (σ_y = 55 MPa) and hence will cause chassis plastic deformation/failure.

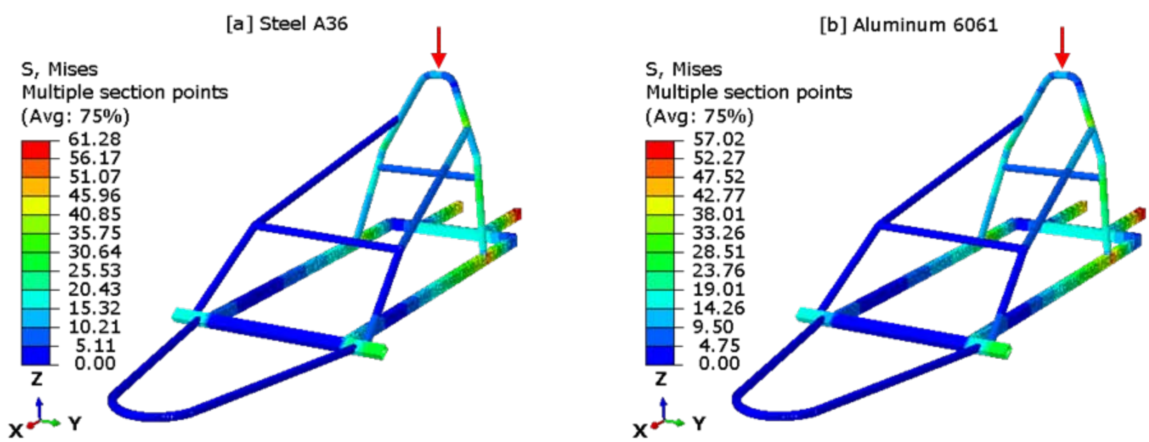

Figure 7: The von Mises stresses of the rollover impact test for a) A36 steel b) 6061 aluminum.

The 1G equivalent acceleration force applied to the steel chassis is calculated as follows:

$$F = m_{total\ ,steel} * g = 100\ kg * 9.81 m/s^2 = 981.0\ N \tag{1}$$

The 1G equivalent acceleration force applied to the aluminum chassis is calculated as follows:

$$F = m_{total\ ,Aluminum} * g = 92.2\ kg * 9.81\ m/s^2 = 904.5\ N \tag{2}$$

The displacements due to the bump/ torsional load for A36 steel and 6061 aluminum are shown in Figure 8. The deformation is visually scaled by 10. Both deformations of steel and aluminum are high. The aluminum deformation is far more severe than steel reaching up to 9.88 mm.

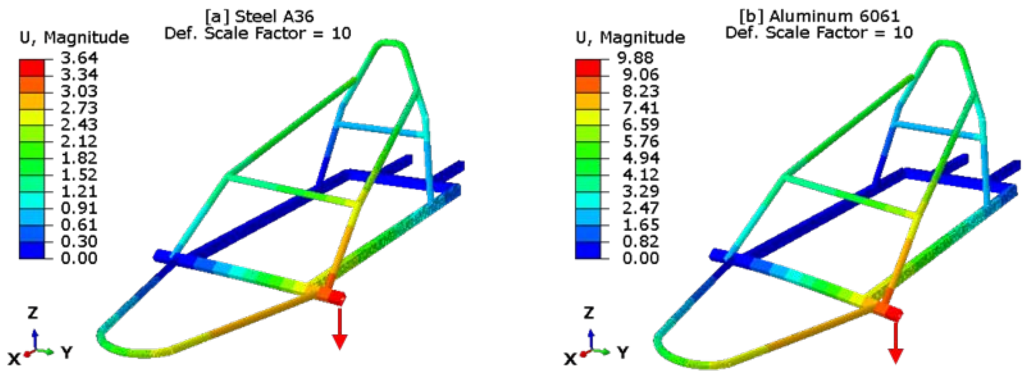

Figure 8: The displacements of the torsional test for a) A36 steel b) 6061 aluminum.

The displacements due to the front impact for A36 steel and 6061 aluminum are shown in Figure 9. The deformation is visually scaled by 10. Minimal deformations are shown in the front impact test (less than 1 mm).

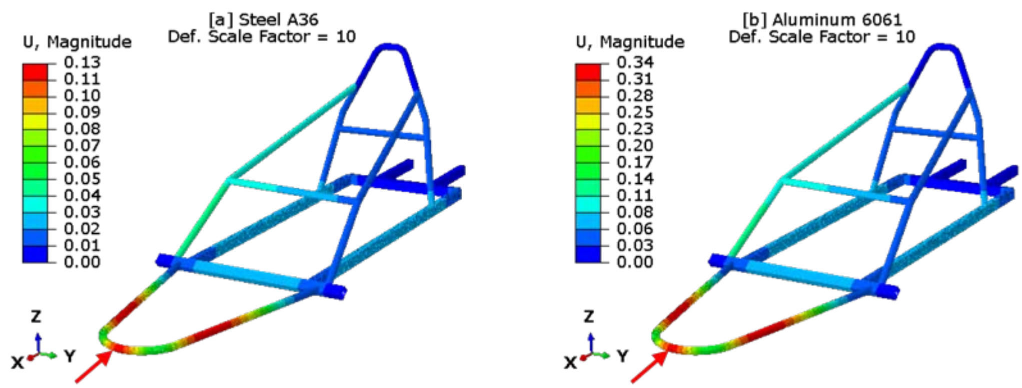

Figure 9: The displacements of the front impact test for a) A36 steel b) 6061 aluminum.

The displacements due to the side impact for A36 steel and 6061 aluminum are shown in Figure 10. The deformation is visually scaled by 10. Intermediate deformations are shown in the side impact test, reaching up to 5.36 mm in the aluminum frame.

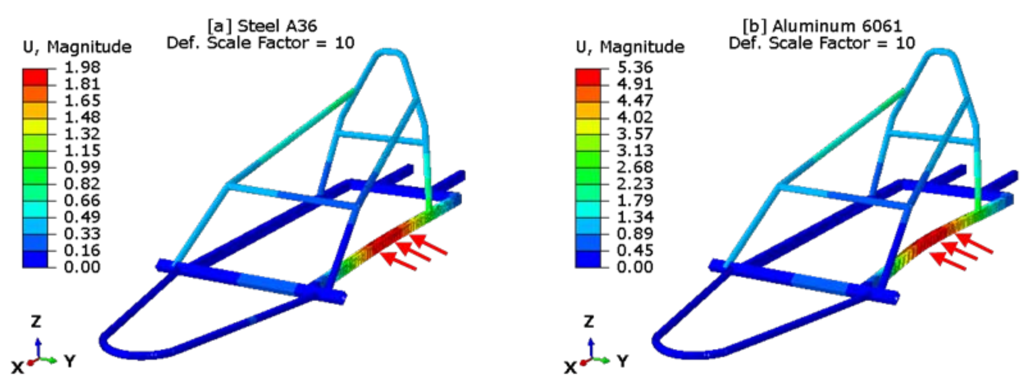

Figure 10: The displacements of the side impact test for a) A36 steel b) 6061 aluminum.

The displacements due to the rollover for A36 steel and 6061 aluminum are shown in Figure 11. The deformation is visually scaled by 10. Intermediate deformations are shown in the rollover test, reaching up to 6.53 mm in the aluminum frame.

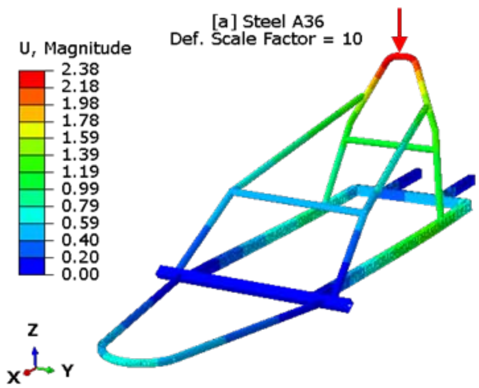

Figure 11: The displacements of the rollover test for a) A36 steel b) 6061 aluminum.

e) Modified Design – Analysis

Since the von Mises stress in the cases of side impact and rollover exceeded the yield strength of 6061 aluminum, additional material is added to the thickness of the rectangular tubes of the same aluminum model. The modified aluminum design section profiles are shown in Figure 12, at which the thickness of the rectangular tube is increased to 3.175 mm. This addition shall add to the chassis load-carrying capacity under the specified load cases, accompanied with a slight increase in weight. Similar load cases to those presented in Section 2.3 are applied to the modified aluminum chassis design.

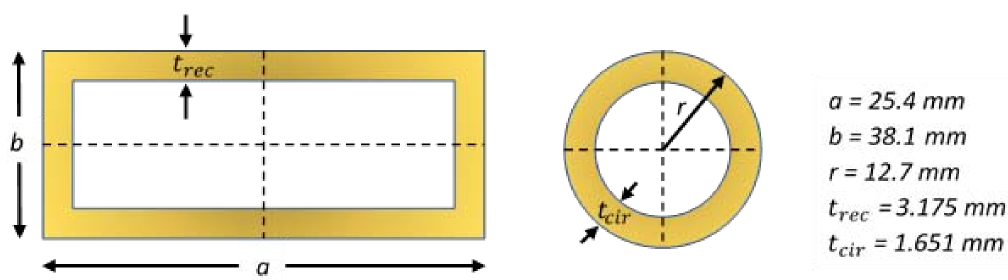

Figure 12: Modified aluminum chassis design section profiles (a) rectangular and (b) circular.

f) Modified Design –Results

The modified aluminum chassis model weighs 5.85 kg. This little compromise in weight (increasing from 4.1 kg) is expected to add the necessary stiffness to maintain a stress value below the yield strength of aluminum in all load cases. The mass of this modified aluminum chassis is around 50% of the original steel chassis mass. The von Mises stress distributions as result of the bump, front impact, side impact and rollover for the modified 6061 aluminum are shown in Figure 13 (a), (b), (c) and (d), respectively.

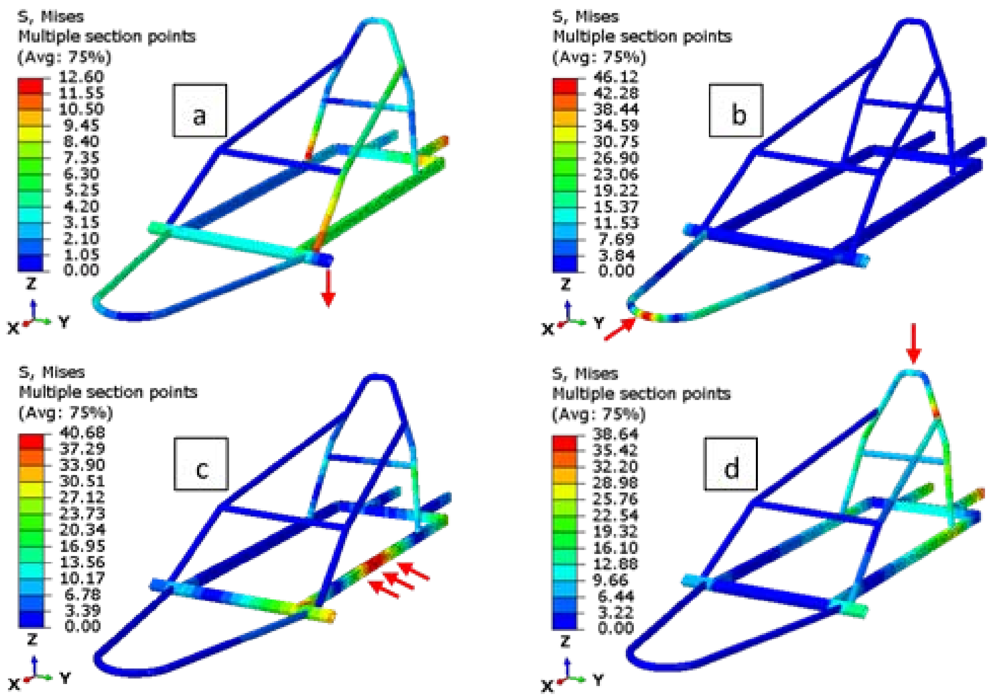

Figure 13: The von Mises stresses of the modified chassis during a) bump b) front impact c) side impact d) rollover.

The displacements as result of the bump, front impact, side impact and rollover for the modified 6061 aluminum are shown in Figure 14 (a), (b), (c) and (d), respectively. The deformations are visually scaled by 10. The modified aluminum chassis deformation is less severe than that of the original steel and aluminum.

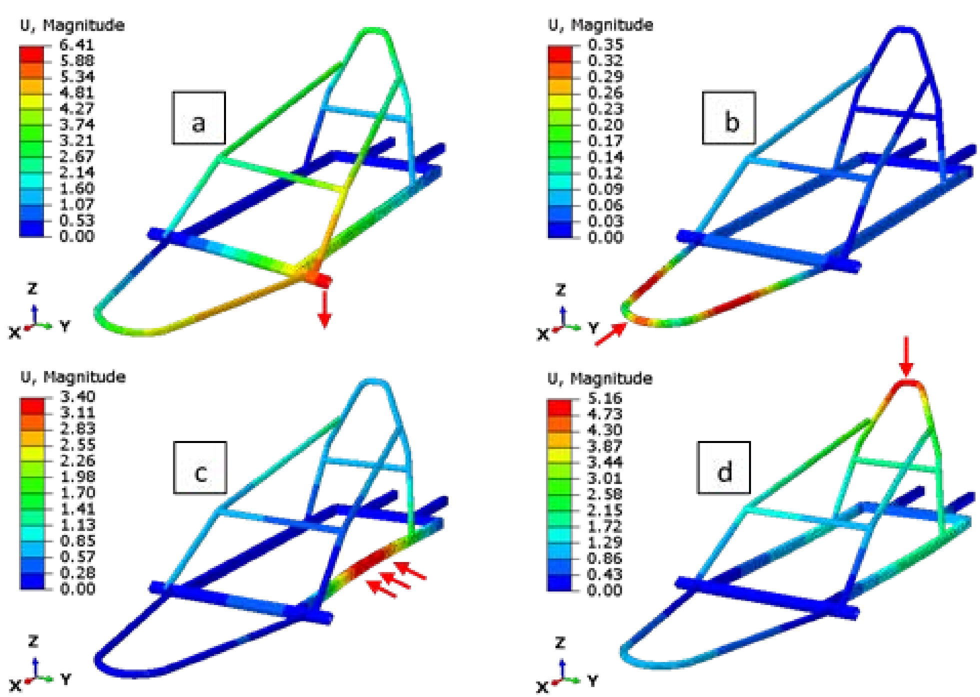

Figure 14: The displacements of the modified chassis during a) bump b) front impact c) side impact d) rollover.

III. Discussion

To identify failure occurrence, a conservative failure criterion is used, the material will fail (yield) when the maximum von Mises stress exceeds the yield strength σ_y of each material. The safety factor for each of the impact scenarios for each material is calculated using the formula $SF = \sigma_y / \sigma_{VM,max}$ and the results are summarized in Table 2. Within the table, the green-colored numbers indicate no failure ($SF > 1.0$), while red-colored numbers indicate failure (SF≤ 1.0). It is evident that steel possesses the higher safety factor in all load cases, and hence has a lesser likelihood of failure. However, both A36 steel and the modified 6061 aluminum' safety factors are within a safe window, indicating a minimum SF of 1.19 for the aluminum front impact scenario. Since these safety factors are above 1.0, the failure criterion has not been triggered and hence no failure occurrence on a 1G load. In contrast, the safety factors of the original 6061 aluminum chassis during side impact and rollover cases are below 1.0, which indicate failure occurrence. Figure 15 shows a bar plot of the SF for steel, original aluminum and modified aluminum under all loading scenarios.

Table 2: The safety factor (SF) for each impact load scenario for A36 steel and 6061 aluminum.

	A36 steel	6061 aluminum t_{rec}= 1.651mm	6061 aluminum t_{rec}= 3.175mm
SF for Bump	11.66	2.79	4.37
SF for Front impact	5.03	1.20	1.19
SF for Side impact	3.37	0.80	1.35
SF for Rollover	4.08	0.96	1.42

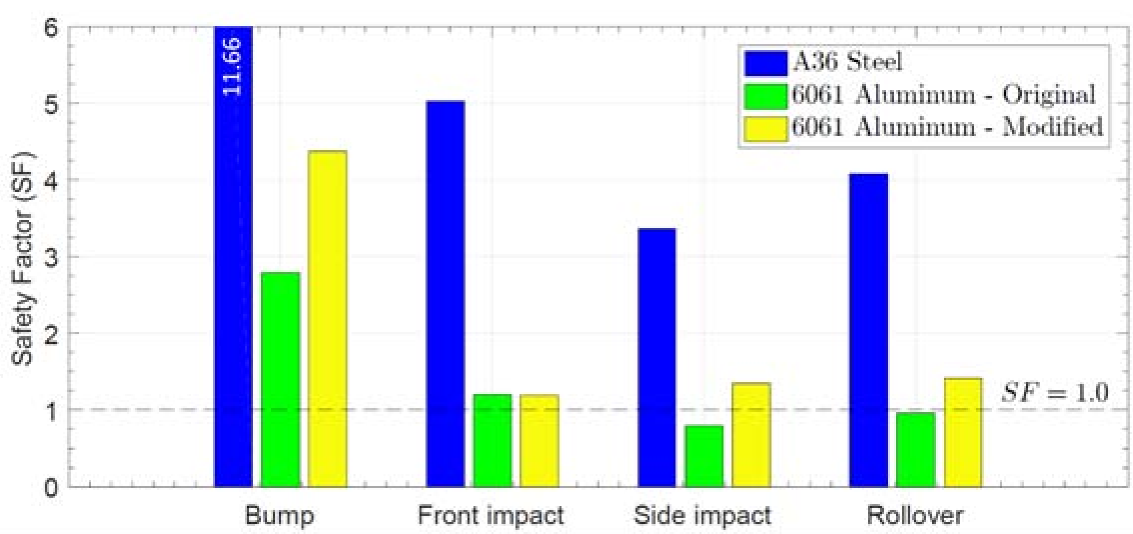

Figure 15: Bars plot of SF for steel and two aluminum chassis under the different loading scenarios.

A summary of the maximum displacements for each material and load case is presented in Table 3. It is expected that aluminum undergoes the higher strain since it is more ductile than steel.

Table 3: Maximum displacements for each material and load case.

	A36 steel [mm]	6061 aluminum t_{rec}= 1.651mm	6061 aluminum t_{rec}= 3.175mm
Max. disp. - bump	3.64 mm	9.88 mm	6.41 mm
Max. disp. - front impact	0.13 mm	0.34 mm	0.35 mm
Max. disp. - side impact	1.98 mm	5.36 mm	3.40 mm
Max. disp. - rollover	2.38 mm	6.53 mm	5.16 mm

IV. Evaluation Metrics

Since the material selection of the chassis is a tradeoff between cost, weight, and failure safety factor, the following evaluation matrix shown in Table 4 is used. The Cost scores are based on the current local market and fabrication prices of the A36 steel and 6061 aluminum. The Weight and SF scores are extracted from the FEA results. The overall scores are generic and must always be accompanied with the explanation of the compromise of benefits.

Table 4: Evaluation Matrix for chassis material selection.

	A36 steel	6061 aluminum t_{rec}= 1.651mm	6061 aluminum t_{rec}= 3.175mm
Cost	4	5	4
Weight	2	5	4
Safety Factor (*SF*)	5	0	4
Score (out of 15)	11	10	12

For the cost criterion, the following scoring system is used:

$$Cost\ [USD] \left\{ \begin{matrix} Cost < 200 \rightarrow 5 \\ 200 \leq Cost < 500 \rightarrow 4 \\ 500 \leq Cost < 700 \rightarrow 3 \\ 700 \leq Cost < 1000 \rightarrow 2 \\ Cost \geq 1000 \rightarrow 1 \end{matrix} \right\} \tag{3}$$

The raw material and fabrication costs for the steel, original aluminum and modified aluminum chassis are 371.00USD, 189.25USD and 210 USD, respectively. Hence, the score for steel cost is 4 points, 5 points for the original aluminum and 4 points for the modified aluminum.

As for the weight criterion, the following scoring system is used:

$$Weight[kg] \left\{ \begin{matrix} Weight < 5 \rightarrow 5 \\ 5 \leq Weight < 6 \rightarrow 4 \\ 6 \leq Weight < 9 \rightarrow 3 \\ 9 \leq Weight < 12 \rightarrow 2 \\ Weight \geq 12 \rightarrow 1 \end{matrix} \right\} \tag{4}$$

The weights given from FEA for the steel, original aluminum and modified aluminum chasses are 11.9 kg, 4.1 kg and 5.85 kg, respectively. Hence, the score for steel weight is 2 points, 5 points for the original aluminum and 4 points for the modified aluminum.

As for the SF criterion, the following scoring system is used:

$$SF \left\{ \begin{matrix} SF > 5 \rightarrow 5 \\ 4 < SF \leq 5 \rightarrow 4 \\ 3 < SF \leq 4 \rightarrow 4 \\ 1 < SF \leq 3 \rightarrow 2 \\ SF \leq 1 \rightarrow 0 \end{matrix} \right\} \tag{5}$$

The minimum safety factors (most severe case) are taken into consideration in the evaluation matrix. The minimum SF scores are taken from Table 2. The SF score for steel is 5 points, 0 points for the original aluminum and 4 points for the modified aluminum.

While chassis safety is one the most important aspects for the survival of the driver and the vehicle, weight reduction is a critical race-winning factor. Therefore, the decision of fabricating the chassis out of steel or aluminum cannot be simply made by accounting for the evaluation matrix numbers, especially when the score numbers are quite close (10, 11 and 12 points). Rather, factors like the difficulty and aggressiveness of the racetrack in terms of turns radii, surface roughness and berms steepness must be considered. These factors will either decrease or increase the likelihood of failure, and hence will necessitate conservative or non conservative design decisions.

V. Conclusions

The objective of this paper was to develop a reliable chassis design according to standards and regulations in a simulation-based design approach. The weight of the A36 steel chassis currently in operation is around 12 kg. Considering the lightweight nature of the vehicle being around 70 kg in total excluding the driver, cutting a few kilograms from the chassis while maintaining stiffness will reap a lot of dividends. This study investigated a lighter-weight 6061 aluminum alternative to the current chassis A36 steel which can withstand the high stress collision scenarios. By using 6061 aluminum, the weight of the vehicle is expected to reduce significantly to approximately one third of the current weight. However, the accompanied aluminum ductility and softness could make it a daunting

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modification if not analyzed properly. A structural FEA was performed on the chassis body for static loading up to 1G equivalent acceleration. The analysis is based on linear elastic behavior of the vehicle chassis of both A36 steel and 6061 aluminum for the scenarios of bump, front impact, side impact and a rollover.

From the static stress analysis results, it was evident that steel possessed the higher safety factor in all load cases, and hence has a less likelihood of failure. However, aluminum chassis yielded unacceptable SF, given the same cross section tubes are used to that of steel. The SF was increased for aluminum by adding more material (thickness), but that has also resulted in higher mass. Overall, the final chosen geometry yielded an optimal design which provided the lightest possible chassis while still maintaining an acceptable SF of over 1.0.

An evaluation matrix procedure was attained to analyze the tradeoff between cost, weight and safety factor for the three chassis designs. Steel scored a total of 11 out of 15 points, while the original aluminum scored of 10 out of 15 points, and finally 12 out of 15 points for the modified aluminum. Although chassis safety is one of the most important aspects for the survival of the driver and the vehicle, weight reduction is a critical race-winning factor. Hence, with a little compromise in steel SF, an advantageous weight reduction is achieved. Nevertheless, caution and care are required when exceeding the anticipated loading conditions of 1G.

In the future, factors like the difficulty and aggressiveness of the racetrack in terms of turns radii, surface roughness and berms steepness will be considered. These factors will either decrease or increase the likelihood of failure, and hence will necessitate conservative or non conservative design decisions.

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Efficient Visualization Method of Buckling Region in Dynamic Transient Analysis of Cable Network Structures

By Shoko Arita & Yasuyuki Miyazaki
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Abstract- Deployable structure system using flexible members is necessary to construct a large structure in the space. The flexible members easily buckle as seen in wrinkles and slack. Therefore, it is available at designing of spacecraft to grasp when, where and how large the buckling occurs in the entire structure during the deployment. When dynamic analysis of large flexible structures which can ignore bending is conducted, the truss element and the membrane element, which do not consider the bending of an element, are often used from the viewpoint of calculation cost. Therefore, this paper proposes a comprehensive and efficient visualization method of buckling occurrence region and buckling magnitude during dynamic response analysis using the truss element to progress convenience in design. The method proposed in this paper is based on two previous studies. The proposed method is verified by a simple truss model, and an application example is shown.

Keywords: deployable structures, buckling, visualization, fem, truss element, dynamic structural analysis, transient response.

GJRE-J Classification: FOR Code: 090199

Efficient Visualization Method of Buckling Region in Dynamic Transient Analysis of Cable Network Structures

Shoko Arita [α] & Yasuyuki Miyazaki [σ]

Abstract- Deployable structure system using flexible members is necessary to construct a large structure in the space. The flexible members easily buckle as seen in wrinkles and slack. Therefore, it is available at designing of spacecraft to grasp when, where and how large the buckling occurs in the entire structure during the deployment. When dynamic analysis of large flexible structures which can ignore bending is conducted, the truss element and the membrane element, which do not consider the bending of an element, are often used from the viewpoint of calculation cost. Therefore, this paper proposes a comprehensive and efficient visualization method of buckling occurrence region and buckling magnitude during dynamic response analysis using the truss element to progress convenience in design. The method proposed in this paper is based on two previous studies. The proposed method is verified by a simple truss model, and an application example is shown.

Keywords: deployable structures, buckling, visualization, fem, truss element, dynamic structural analysis, transient response.

I. Background

A deployable structure largely deforms from moment to moment in the deployment process, and the flexible member easily buckles as seen in wrinkles and slack of the membrane surface, for instance. Buckling such as unexpected wrinkle or slack has a problem of deteriorating the surface accuracy of the deployed film surface. On the other hand, a folded structure made of flexible member is usually easier to deploy than rigid member because stress concentration occurring at a corner of fold is mitigated by out-of-plane deformation, which is easier to occur in a flexible member such as slack on a membrane. That is a major reason to use flexible members as deployable space structures.

Analysis of the dynamic behavior of flexible structures is necessary for the design and development of such deployable structures. Flexible members such as membranes and tethers often can be applied an approximation that ignores bending in the modeling.

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From the viewpoint of calculation cost, truss element and membrane element, which do not consider the bending of an element, are often used for analyses of large-scale dynamic FEM (Shirasawa et al., 2011; Ono et al., 2014).However, there are few studies that efficiently detect buckling from the entire structure during response analysis using the element model which does not consider bending. Because solution of buckling analysis is generally acquired from equation of bending moment. Therefore, the authors have proposed and developed a method to detect wrinkle and slack using the membrane elements (Arita et al., 2014) and a method to detect snap through buckling during the dynamic analysis using the truss element (Arita and Miyazaki, 2018). This paper proposes a comprehensive and efficient visualization method of buckling occurrence region and buckling magnitude during dynamic response analysis by using these two theories to progress convenience in actual design of gossamer spacecraft. By visualizing the buckling region, it is expected at actual designing that it will be easier to specify the part where buckling easily occurs, and to control or deal with the buckling part. A general method of visualization of buckling is to display the buckling mode shape in order to examining the buckling load and the shape after buckling (Noguchi and Fujii, 2000; Ikeda dt al., 2003). On the other hand, the purpose of the method proposed in this paper is not to obtain the mode shape but to grasp comprehensively when and what area the buckling displacement occurs during transient response of the deployment. Visualization based on such a concept is a unique point of this research. In a previous study, a method using tension field theory has been proposed as a method of calculating the amount of deformation after buckling (Conci, 2007).However, it is pointed that the assumption of tension field theory does not establish for the buckling of flexible structures (Iwasa et al., 2004).Therefore, the method proposed in this paper is to calculate the buckling displacement amount without using the tension field theory.

The theory of the visualization method is shown in Section 2. Section 3 shows the results of verification of the proposed method by a simple truss model, and Section 4 shows an analysis example assuming development of flexible membrane.

II. Theories of Buckling Analysis and Visualization

In the proposed method, the dynamic response of the entire structure is analyzed by the truss element, and the amount of the snap through buckling displacement of the node is visualized by color contour. However, since the truss element cannot express the deformation other than in the axial direction, it is necessary to calculate the long column buckling of the element itself in order to grasp the comprehensive buckling of the entire structure. Since a flexible member such as a membrane has a characteristic that compression rigidity is very small compared with tension and it is easy to buckle, it is necessary to devise modeling of the compressive stiffness in post buckling analysis. Hence, we adopt the theory called Mod-SRM, which models appropriately such features, to detect and visualize the buckling of each truss element. In other words, this paper proposes the method to visualize the comprehensive buckling of the entire structure by displaying the color contour of the snap through buckling of nodes and the long column buckling of elements with respect to the dynamic transient response diagram of the truss element. In this chapter, the detection and visualization method of the snap through buckling of nodes is explained in Section 2.1, and the detection and visualization method of the long column buckling of elements by Mod-SRM is explained in Section 2.2.

a) *Snap through Buckling of Nodes in Truss Elements*

i. *Introduction of Buckling Detection and Quantification Method*

Only the snap through buckling of the node is detectable in the truss element. Since detection and quantification of the snap through buckling are described in detail in the previous work (Arita and Miyazaki, 2018) by the authors, in this section, a schematic view of the method is shown in Fig.1 and the outline is explained below.

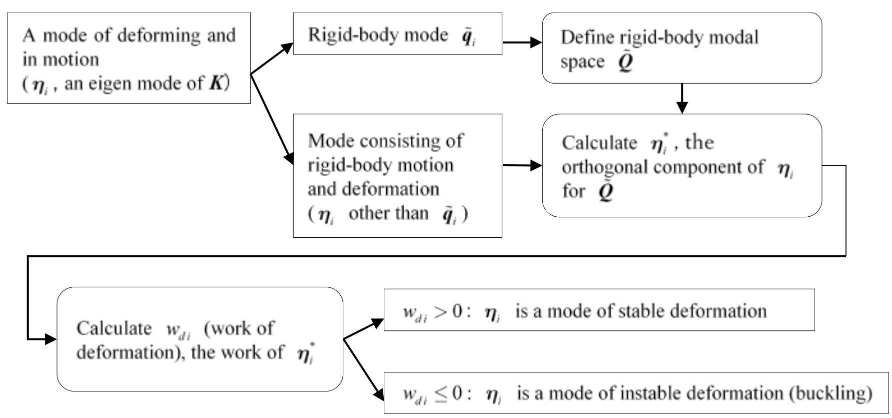

Fig.1: Buckling detection method. After extracting the orthogonal component to the rigid-body modal space $\tilde{\boldsymbol{Q}}$ from each eigen mode of the stiffness matrix $\boldsymbol{K}$, the eigen mode is judged if buckling or not according to the work of deformation.

Multiple buckling modes often appears at the same time. In such a case, quantification is carried out in order to determine the most likely buckling mode considering the motion state of the structure. Assuming that buckling displacement $\Delta\boldsymbol{x}$ is caused by external disturbance force $\Delta\boldsymbol{F}$, $\Delta\boldsymbol{F}$ is obtained by solving the equation of motion. Then, the norm of the obtained $\Delta\boldsymbol{F}$ is defined as a validation parameter "DF value". It is determined that the mode with the smallest DF value is the most likely buckling mode. Moreover, the norm of the buckling displacement $\Delta\boldsymbol{x}$ is also defined as another validation parameter "BD value".

ii. *Visualization of Buckling of Nodes Based on Buckling Displacement*

In this section, the authors propose a method of visualization using the detected buckling mode and the BD value explained above. The visualization method is to display the amount of the snap through buckling displacement of each node is visualized by color contour for the most likely buckling mode.

The element used in this theory is a two-node truss element having three degrees of freedom of x, y, z per node. We define n as the number of nodes of the entire structure, and define $\boldsymbol{h}$ as the most likely buckling mode. $\boldsymbol{h}$ is a normalized vector, in which the proportion of x, y and z displacements of each node is arranged. Then, the component corresponding to (x, y, z) of the j th node in $\boldsymbol{h}$ is defined as (x_j, y_j, z_j), and $\boldsymbol{h}_j$ is defined as follows.

$$\boldsymbol{h}_j \equiv [x_j, y_j, z_j]^T \qquad (1)$$

Likewise, a subscript j is written with respect to values of j th node. Here, we extract only buckling nodes from the buckling mode in order to extract local buckling by calculating the work for each node. Nodes of which deformation work becomes 0 or less are considered as buckling nodes because the displacement proceed by negative deformation work. To calculate the deformation work, it is necessary to extract only the deformation component from the mode that includes rigid-body motion. The orthogonal component $\boldsymbol{h}^*$ to the rigid-body modal space $\tilde{\boldsymbol{Q}}$, which means the deformation component, is extracted by Eq. (2). The deformation work of each node w_j^* in the buckling mode $\boldsymbol{h}_j$ is calculated by using the stiffness matrix $\boldsymbol{K}$ as Eq. (3).

$$\boldsymbol{h}^* = \boldsymbol{h} - \sum_{k=1}^{n} \frac{(\boldsymbol{h}\cdot\tilde{\boldsymbol{q}}_k)}{(\tilde{\boldsymbol{q}}_k\cdot\tilde{\boldsymbol{q}}_k)}\boldsymbol{q}_k \tag{2}$$

$$w_j^* = \boldsymbol{h}_j^* \cdot \left(\boldsymbol{K}\boldsymbol{h}^*\right)_j \tag{3}$$

Buckling displacement amount (BD value) is calculated for the node of which w_j^* is 0 or less by Eq. (4). α is a scalar giving the magnitude of the displacement in the buckling mode direction, and the details are explained in the previous study (Arita and Miyazaki, 2016). Therefore, only the results are shown here.

$$BD = \alpha\left|\boldsymbol{h}_j\right| \tag{4}$$

$$\alpha = \frac{\boldsymbol{a}\cdot\boldsymbol{b} + \boldsymbol{a}\cdot\boldsymbol{c}}{|\boldsymbol{a}|^2} \tag{5}$$

where

$$\begin{aligned} \boldsymbol{a} &= \frac{1}{\beta\Delta t^2}(\boldsymbol{I} - \tilde{\boldsymbol{Q}}[\tilde{\boldsymbol{Q}}^T\tilde{\boldsymbol{Q}}]^{-1}\tilde{\boldsymbol{Q}}^T)\boldsymbol{M}\boldsymbol{h} \\ \boldsymbol{b} &= \frac{1}{\beta\Delta t}(\boldsymbol{I} - \tilde{\boldsymbol{Q}}[\tilde{\boldsymbol{Q}}^T\tilde{\boldsymbol{Q}}]^{-1}\tilde{\boldsymbol{Q}}^T)\boldsymbol{M}\dot{\boldsymbol{x}}_0 \\ \boldsymbol{c} &= \frac{1}{2}(\boldsymbol{I} - \tilde{\boldsymbol{Q}}[\tilde{\boldsymbol{Q}}^T\tilde{\boldsymbol{Q}}]^{-1}\tilde{\boldsymbol{Q}}^T)\boldsymbol{M}\ddot{\boldsymbol{x}}_0 \end{aligned} \tag{6}$$

b is the coefficient of the Newmark-β method, *Dt* is the time step width in the time integration of the Newmark-β method, $\boldsymbol{M}$ is the mass matrix, $\dot{\boldsymbol{x}}_0$ and $\ddot{\boldsymbol{x}}_0$ are the velocity and acceleration of the previous time step respectively. Note that although Newmark-β method was used in the previous paper (Arita and Miyazaki, 2016), the concept of this method is also effective for other numerical integration methods, and similar equations can be derived by other methods. The magnitude of the displacement by the buckling is visualized by color contour display of nodes according to the BD value.

b) Long Column Buckling of Elements in Truss Elements

i. *Introduction of Mod-SRM*

A flexible member is easy to buckle because the compressive stiffness of the flexible member is very small compared to tensile stiffness. Therefore, methods that determine the compressive stiffness by multiplying the tensile stiffness by a coefficient smaller than 1 has been proposed for the element model that does not consider bending (e.g. Miyazaki, 2006). Mod-SRM, which is one of them, proposed to be able to determine the compressive stiffness ratio uniquely according to the amount of the out-of-plane buckling by introducing the stretchable elastic theory into the element model (Arita et al., 2014). Because Mod-SRM is based on the bending deformation of a beam, the visualization method proposed this paper is to apply Mod-SRM to the truss element. The outline of Mod-SRM and the derivation of physical quantities for the visualization are introduced in this section.

First of all, supposing one truss element of which total length is defined $l/2$ deforms like a slack of a cable, the equilibrium equation is expressed as Eq.(7) in an infinitesimal line element $\mathrm{d}\boldsymbol{x}$ subjected to the load $\boldsymbol{P}$ as shown in Fig. 2.Eventually, Eq.(8) and (9)are obtained from the equilibrium equation. Details of this derivation are written in the previous work (Arita et al., 2014).

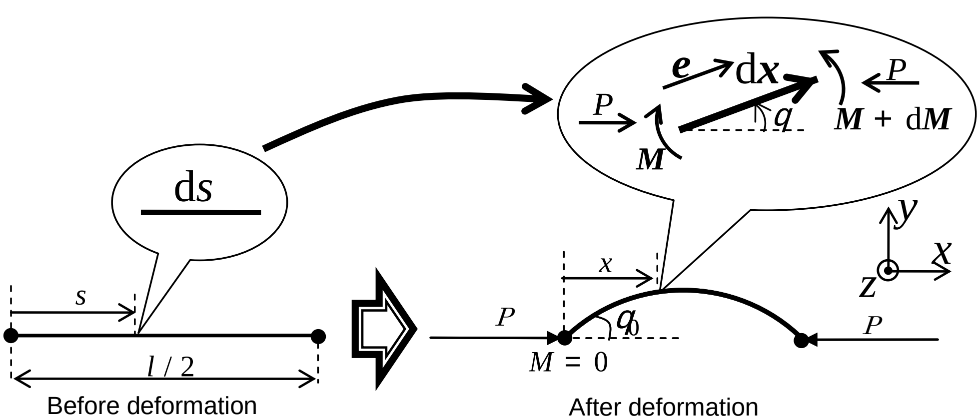

Fig. 2: Mathematical modeling of Mod-SRM. Supposing one truss element deforms like a slack of a cable, the equilibrium of forces and moments are obtained in an infinitesimal line element dx subjected to the load $\boldsymbol{P}$.

$$EI\frac{d^2\theta}{ds^2}+\left(1-\frac{P\cos\theta}{EA}\right)P\sin\theta=0 \tag{7}$$

$$\int_0^{\pi} f(t)\,\mathrm{d}t=\pi\sqrt{\frac{\eta}{2}} \tag{8}$$

$$\int_0^{\pi}(1-\eta\lambda C_\theta)C_\theta f(t)\,\mathrm{d}t=(1-\varepsilon)\pi\sqrt{\frac{\eta}{2}} \tag{9}$$

ε is the equivalent in-plane compressive strain, defined as shown in Fig.3. E^* means Young's modulus after buckling, and α denotes the ratio of stiffness in the compressive direction to the tensile direction. *l* is a material constant and is defined by Eq. (10). η is a non dimensional compressive load and is defined by Eq. (11). E means Young's modulus, A means cross-sectional area and I means moment of inertia of area. C_q and $f(t)$ are functions defined by Eq. (12) and (13) respectively. The compressive stiffness ratio α is obtained by Eq. (14):

$$\lambda\equiv\frac{EI\pi^2}{EAl^2} \tag{10}$$

$$\eta\equiv\frac{P}{\left(\frac{EI\pi^2}{l^2}\right)} \tag{11}$$

$$\cos\theta=\frac{1+\cos\theta_0}{2}-\frac{1-\cos\theta_0}{2}\cos t\equiv C_\theta(t)$$

$$\begin{cases}\theta:\theta_0\rightarrow 0\\ t:0\rightarrow\pi\end{cases} \tag{12}$$

$$f(t)\equiv\frac{1}{\sqrt{(1+C_\theta)\left[1-\frac{\eta\lambda}{2}(C_\theta+\cos\theta_0)\right]}} \tag{13}$$

$$\alpha=\frac{P}{EA\varepsilon}=\frac{\eta\lambda}{\varepsilon} \tag{14}$$

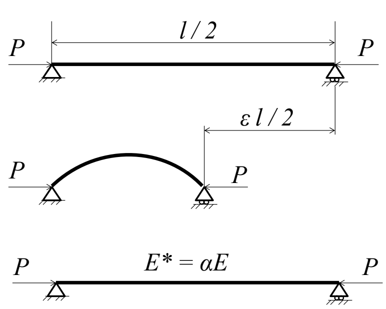

Fig. 3: Definition of symbols. ε is the equivalent in-plane compressive strain, E^* is Young's modulus after buckling, and α is the compressive stiffness ratio.

That is to say, given the equivalent plane compressive strain ε and the material constant *l* , the relation between the non-dimensional compressive load η and strain ε can be obtained when the load η and angle θ_0 are determined under Eq.(8) and (9).In the actual calculation, θ_0 is given and *h* is obtained by Newton's method so as to satisfy Eq. (8), and ε is obtained by Eq. (15):

$$\varepsilon=1-\frac{\int_0^{\pi}(1-\eta\lambda C_\theta)C_\theta f(t)\,\mathrm{d}t}{\int_0^{\pi} f(t)\,\mathrm{d}t} \tag{15}$$

It is convenient to calculate the approximation of η as the polynomial of ε by using the relation obtained by Eq. (15) in advance, and in the transient response analysis, η is calculated from the polynomial according to the value of ε at the time step. Hence, the compressive stiffness ratio α is decided every time step by Eq. (14).

ii. *Visualization of Buckling of Elements Based on Buckling Displacement*

In visualization, the buckling of each element is judged and the buckling elements are displayed in color contour according to the magnitude of ε.

The calculated value of compressive buckling load is used for the judgement of the buckling. In general, when an axial compressive load P is applied to a simply supported beam at both ends of bending stiffness EI and length l shown in Fig. 4, the Euler buckling load P_{0cr} is obtained as Eq. (17) from Eq. (16), which is the equilibrium equation assuming no expansion, contraction and shear deformation.

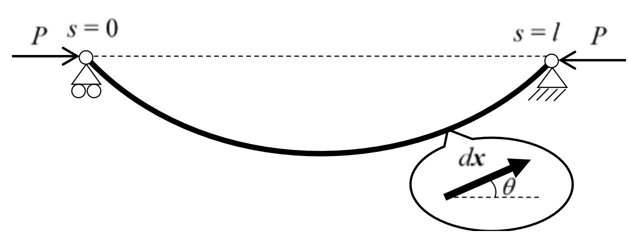

Fig. 4: Model of beam buckling

$$EI\frac{d^2\theta}{ds^2}+P\sin\theta=0 \tag{16}$$

$$P_{0cr}=\frac{EI\pi^2}{l^2} \tag{17}$$

On the other hand, considering expansion and contraction and shear deformation, if the equilibrium equation can be written as Eq. (18), the buckling load P_{cr} is written as Eq.(19).

$$EI\frac{d^2\theta}{ds^2}+Pf(\theta)\sin\theta=0 \tag{18}$$

$$P_{cr}=\frac{P_{0cr}}{f(0)} \tag{19}$$

This is proved as follows;

Multiplying both sides of Eq. (18) by $\frac{d\theta}{ds}$ gives the following equation;

$$EI\frac{\mathrm{d}^2\theta}{\mathrm{d}s^2}\frac{\mathrm{d}\theta}{\mathrm{d}s}+Pf(\theta)\sin\theta\frac{\mathrm{d}\theta}{\mathrm{d}s}=0 \tag{20}$$

Determining θ_0 as the θ at the point where the bending moment becomes 0, the following is obtained by integration by θ of Eq. (20);

$$\begin{aligned}&\frac{1}{2}EI\left(\frac{d\theta}{ds}\right)^2+P\int_{-\theta_0}^{\theta}f(\theta)\sin\theta d\theta=0\\&\Rightarrow\frac{d\theta}{ds}=\sqrt{\frac{2P}{EI}\int_{-\theta_0}^{\theta}-f(\theta)\sin\theta d\theta}\end{aligned} \tag{21}$$

The integral term in the Eq. (21) can be written as below;

$$\begin{aligned}\int_{-\theta_0}^{\theta}-f(\theta)\sin\theta d\theta&=\cos\theta f(\theta)-\cos(-\theta_0)f(-\theta_0)-\int_{-\theta_0}^{\theta}f'(\theta)\cos\theta d\theta\\&=\cos\theta f(\theta)-\cos\theta_0 f(-\theta_0)-\int_{-\theta_0}^{\theta}f'(\theta)\cos\theta d\theta\\&\quad+\cos\theta_0 f(-\theta_0)-\cos\theta_0 f(\theta)+\int_{-\theta_0}^{\theta}\cos\theta_0 f'(\theta)d\theta\\&=(\cos\theta-\cos\theta_0)f(\theta)-\int_{-\theta_0}^{\theta}(\cos\theta-\cos\theta_0)f'(\theta)\cos\theta d\theta\end{aligned} \tag{22}$$

Here, the following variable transformation is defined;

$$\begin{aligned}&\cos\theta=C(u)=\frac{1+\cos\theta_0}{2}+\frac{1-\cos\theta_0}{2}\cos u\\&\begin{cases}\theta:-\theta_0\to\theta_0\\u\ :-\pi\to\pi\end{cases}\end{aligned} \tag{23}$$

The following equation is obtained from Eq. (23);

$$\frac{\mathrm{d}u}{\mathrm{d}\theta}=\frac{\sqrt{1+C(u)}}{\sqrt{C(u)-\cos\theta_0}} \tag{24}$$

Using Eq. (21), (22) and (23), the following relation is obtained:

$$\begin{aligned}\frac{\mathrm{d}u}{\mathrm{d}s}&=\frac{\mathrm{d}u}{\mathrm{d}\theta}\frac{\mathrm{d}\theta}{\mathrm{d}s}\\&=\sqrt{\frac{2P}{EI}(1+C(u))\left\{f(\theta)-\frac{1}{C(u)-\cos\theta_0}\int_{-\theta_0}^{\theta}(C(u)-\cos\theta_0)f'(\theta)d\theta\right\}}\\&\equiv\sqrt{\frac{2P}{EI}(1+C(u))\{f(\theta)-h(u)\}}\end{aligned} \tag{25}$$

Furthermore, using Eq. (23) and (24), the $h(u)$ is written as below;

$$\begin{aligned}h(u)&=\frac{1}{C(u)-\cos\theta_0}\int_{-\theta_0}^{\theta}(C(u)-\cos\theta_0)f'(\theta)d\theta\\&=\frac{2}{(1-\cos\theta_0)(1+\cos u)}\int_{-\theta_0}^{\theta}\frac{(1-\cos\theta_0)(1+\cos u)}{2}f'(\theta)d\theta\\&=\frac{1}{1+\cos u}\int_{-\pi}^{u}(1+\cos\upsilon)f'(\theta(\upsilon))\frac{\sqrt{C(\upsilon)-\cos\theta_0}}{\sqrt{1+C(\upsilon)}}d\upsilon\\&=\sqrt{\frac{1-\cos\theta_0}{2}}\int_{-\pi}^{u}\frac{(1+\cos\upsilon)^{\frac{3}{2}}}{1+\cos u}\frac{f'(\theta(\upsilon))}{\sqrt{1+C(\upsilon)}}d\upsilon\end{aligned} \tag{26}$$

Because $\theta_0 \to 0$ in the case of buckling, the values of $C(u)$, θ and $h(u)$ are as follows;

$$C(u) \to 1\ ,\quad \theta \to 0\ ,\quad h(u) \to 0 \tag{27}$$

Thus, Eq. (19) is derived by Eq. (25) as follows;

$$\begin{aligned} \frac{2\pi}{l} &= \sqrt{\frac{2P^{cr}}{EI}2f(0)} \\ \Rightarrow P^{cr} &= \frac{EI\pi^2}{l^2 f(0)} \end{aligned} \tag{28}$$

Q.E.D.

In the case of Mod-SRM, the equilibrium equation is Eq. (7). Therefore, P_{cr} is below;

$$\begin{aligned} f(0) &= 1-\frac{P\cos\theta}{EA} = 1-\frac{P_{cr}}{EA} \qquad (\because \theta = 0 \text{ at the buckling}) \\ \Rightarrow P_{cr} &= \frac{EA(1-\sqrt{1-4\lambda})}{2} \end{aligned} \tag{29}$$

where P_{cr} is smaller of the two solutions. From Eq. (11), η_{cr} is below;

$$\eta_{cr} = \frac{2}{1+\sqrt{1-4\lambda}} \tag{30}$$

The same solution is obtained by setting $\theta_0 = 0$ in Eq.(8) and (13).When $\theta_0 = 0$,

$$C_\theta = \cos\theta_0 = 1 \tag{31}$$

Therefore,

$$f(t) = \frac{1}{\sqrt{2(1-\eta\lambda)}} \tag{32}$$

Thus, applying it to Eq.(8),

$$\frac{\pi}{\sqrt{2(1-\eta\lambda)}} = \pi\sqrt{\frac{\eta}{2}} \tag{33}$$

Solving this for η,

$$\eta = \frac{2}{1\pm\sqrt{1-4\lambda}} \tag{34}$$

Two solutions are obtained. Since the buckling load is the one with a smaller value, η_{cr} is obtained as Eq. (30).

Incidentally, the buckling strain ε_{cr} is obtained from Eq. (15) as follows.

$$\varepsilon_{cr} = \eta_{cr}\lambda = \frac{2\lambda}{1+\sqrt{1-4\lambda}} \tag{35}$$

III. Verification of Visualization of Buckling by Numerical Experiment

The authors verified the visualization method with a simple truss model consisting of 3 elements and 4 nodes. The truss model is shown in Fig.5, and its specifications are shown in Table 1. Before transient response and visualization, the relationship and polynomial approximation between η and ε were obtained in advance by Mod-SRM as shown in Fig. 6.The tensile strain is the positive value, and the compressive strain is the negative value. The buckling load of an element was obtained as η_{cr} = 1.000129 that is, P_{cr} = 0.005623[N] and ε_{cr} = 0.0001285 . Note that the compressive stiffness ratio ***a*** is calculated in each time step of the transient response analysis based on the polynomial approximation and Eq. (14). The relationship between α and ε, incidentally, is shown in Fig. 7.

The result of the buckling analysis is shown in Fig. 8. The horizontal axis is the time step. The first vertical axis at the left side is the strain of the element. The second vertical axis at the right side represents the detection result of the snap through buckling of the nodes. Since the nodes ① and ④ are fixed, they are excluded. Figure 8 shows the sharp fluctuation of the

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strain after Step 750. It can be considered that the drastic decrease of element stiffness due to compressive buckling causes the sharp fluctuation of the strain. Figure 8 also shows that snap through buckling of the nodes occur from Step 794 onwards. Figure 9 is the enlarged figure of Fig. 8 from Step 794 to Step 805 regarding the strain of the elements. Figure 10 is also the enlarged figure of Fig. 8 regarding the nodes, however, the vertical axis shows not the detection result but the BD value of the buckling nodes. Transient response is shown in Fig.11 as a result of visualization of the buckling. Comparing Fig. 9, 10 and 11, it can be confirmed that the color contour is properly visualized in the response diagram corresponding to the strain of the elements and the BD value of the nodes where the buckling occurred.

In the previous study, Mod-SRM only defined the compressive stiffness ratio for the post buckling analysis of a membrane. The study of the dynamic buckling of a truss element only quantified the ease of buckling and degree of buckling deformation as representative values for the entire structure. On the other hand, the method proposed in this paper enables visually recognizing where and how large the buckling occurs in a transient analysis by calculating the magnitude of buckling displacement for each node and element.

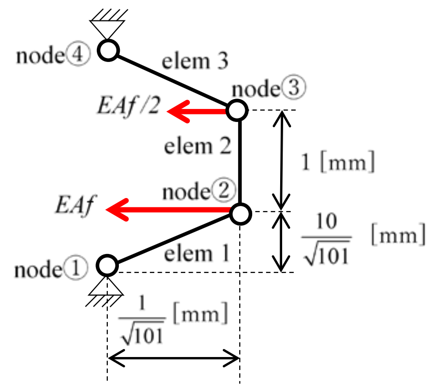

Fig. 5: Truss model for verification.

Table 1: Specifications of the analysis for the truss model.

Parameter	Symbol	Value	Unit
time step size	dt	5×10^{-6}	[s]
stiffness of an element	EA	0.55	[N]
density of an element	ρ	1.42	[g/cm^3]
increment of external force parameter	$\varDelta f$	2.5×10^{-9}	[-]
condition of constraint:	x,y,z of node①, x,y,z of node④		
condition of loading:	Incresing f step-by-step by $\varDelta f$, node② is subjected to $-EAf$ in the direction of x axis, and node④ is subjected to $-EAf/2$ in the direction of x axis.		

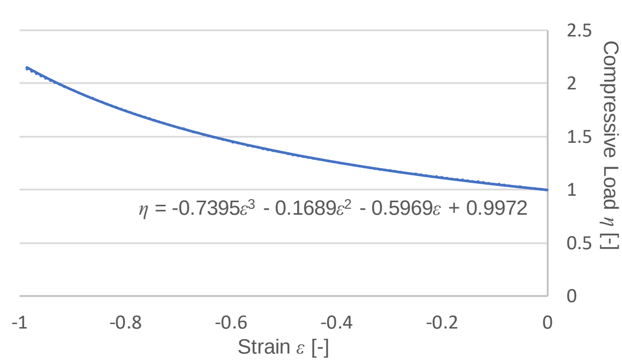

Fig. 6: Relation and polynomial approximation between η and ε. η at each time step in transient response is determined by the polynomial according to ε.

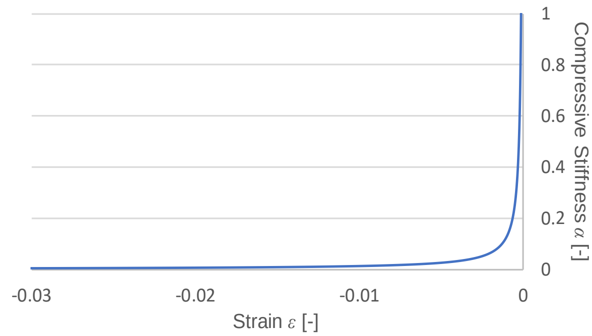

Fig. 7: Relation between α and ε. The compressive stiffness decreases according to the compressive strain.

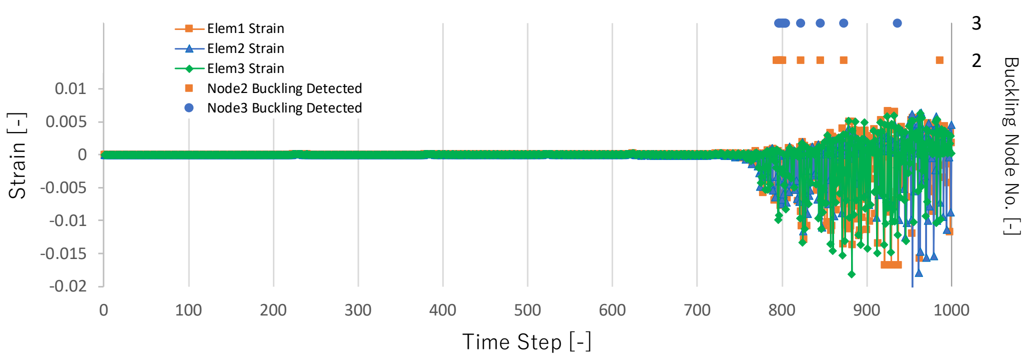

Fig. 8: Result of the buckling analysis. The first vertical axis at the left side is the strain of the element. The second vertical axis at the right side represents the detection result of the snap through buckling of the nodes. The drastic decrease of elements tiff ness due to compressive buckling causes the sharp fluctuation of the strain after Step 750. The snap through buckling of the nodes occur from Step 794 onwards.

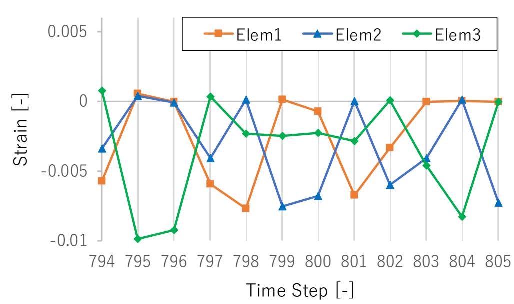

Fig. 9: The strain of the elements from Step 794 to Step 805. Color contour of each element in Fig. 10 is based on the magnitude of the strain.

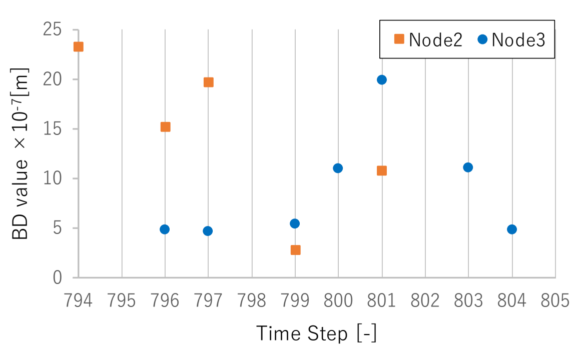

Fig. 10: BD value of the buckling nodes from Step 794 to Step 805.Color contour of each node in Fig. 10 is based on the magnitude of the BD value.

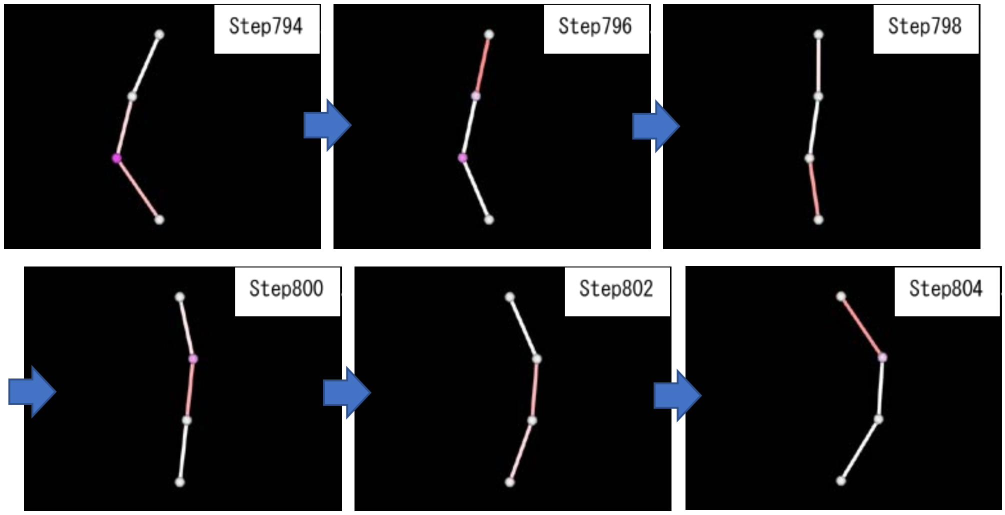

Fig. 11: Transient response and the result of the visualization. Comparing with Fig. 8 and 9, it can be confirmed that the color contour is properly visualized corresponding to the strain of the elements and the BD value of the nodes where the buckling occurred.

IV. Application Example of Membrane Structure

The authors conducted a calculation as an application example with a model assuming that the triangular membrane deploys with booms. The triangular membrane folded into a bellows deploys as shown in Fig. 12 and Table 2. The transient response is shown in Fig. 13. Buckling occurring at the nodes and the elements are visualized, indicating that we can confirm when, where and how large the buckling occurs in the structure.

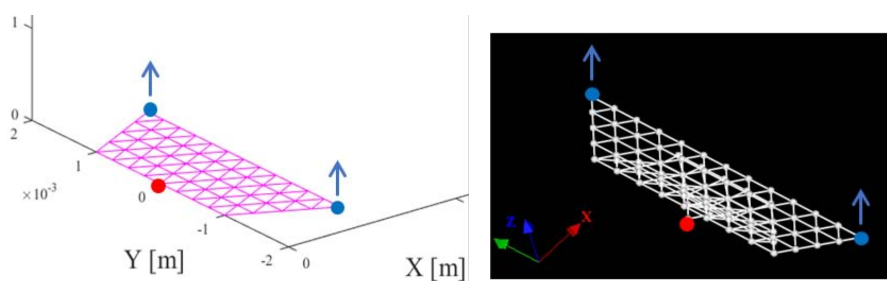

Fig. 12: Membrane structure model. The red node is fixed and the blue nodes are forcibly displaced every time step. At first, the membrane is folded into a bellows.

Table 2: Specifications of the analysis

Parameter	Symbol	Value	Unit
time step size	*dt*	5×10^{-6}	[s]
Young's ratio	*E*	3.5×10^{9}	[Pa]
Length of an element	*l*	1×10^{-3}	[m]
Thickness of an element	*h*	12.5×10^{-6}	[m]
Density of an element	ρ	1.42	[g/cm^3]
Boundary Cindition	Fix the red node and forcibly displace the two blue nodes by 0.75×10^{-7} per time step in the +z direction.		

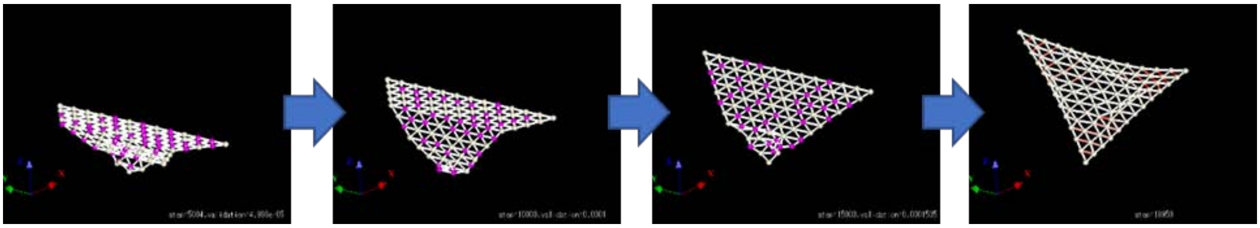

Fig. 13: Transient response and the result of the visualization. Snap through buckling occurs everywhere on the membrane, and the buckling of the element occurs intensively at the corners at the end of the deployment.

V. Conclusions

The authors proposed a comprehensive and efficient visualization method of buckling region during dynamic response analysis based on two previous studies to progress convenience in actual design of gossamer spacecraft. The proposed method is verified by a simple truss model, and the calculation of an application example is conducted. The result indicates that using this method, we can confirm when, where and how large the buckling occurs in the structure.

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Contrivance of 5s System to Effectuate Higher Productivity in Apparel Industries

By Jaglul Hoque Mridha, A.M. Riasat Alam, Tanvir Mahmud & Tanvir Ahmed

Northern University Bangladesh

Abstract- Bangladesh is the second largest exporter of readymade garment (RMG) products in the world after China. Above 80% of its total export earning is contributed by the RMG sector which has a huge impact on the economy of the country. At present this RMG sector is facing many threats and challenges to hold its flourishing position because of the entrance of new competitors both in the national and international market. To overcome these challenges continuous improvement is required to a great extent. This paper experiments execution of 5S approach to a production scenario in a garments industry. 5S method should be improved to ensure ergonomics in the workplace, to reduce defects and increase cleaning and productivity growth. It is one of the fundamental tools to intensify continuous improvement process in organizations and represents a transformation in 5 steps of a job, which is characterized by maximum efficiency at the micro level and minimum loss. Any company applying the 5S methodology will have reduction of different types of waste, efficient workflow due to lesser machine breakdowns, lower defect rates, reduced inventory and effective problem visualization, visible and swift results in an efficient way.

Keywords: productivity growth, apparel industry, inventory, visual control management.

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CONTRIVANCEOF5SSYSTEMTOEFFECTUATEHIGHERPRODUCTIVITYINAPPARELINDUSTRIES

Strictly as per the compliance and regulations of:

Contrivance of 5s System to Effectuate Higher Productivity in Apparel Industries

Jaglul Hoque Mridha [α], A.M. Riasat Alam [σ], Tanvir Mahmud [ρ] & Tanvir Ahmed [Ѡ]

Abstract- Bangladesh is the second largest exporter of readymade garment (RMG) products in the world after China. Above 80% of its total export earning is contributed by the RMG sector which has a huge impact on the economy of the country. At present this RMG sector is facing many threats and challenges to hold its flourishing position because of the entrance of new competitors both in the national and international market. To overcome these challenges continuous improvement is required to a great extent. This paper experiments execution of 5S approach to a production scenario in a garments industry. 5S method should be improved to ensure ergonomics in the workplace, to reduce defects and increase cleaning and productivity growth. It is one of the fundamental tools to intensify continuous improvement process in organizations and represents a transformation in 5 steps of a job, which is characterized by maximum efficiency at the micro level and minimum loss. Any company applying the 5S methodology will have reduction of different types of waste, efficient workflow due to lesser machine breakdowns, lower defect rates, reduced inventory and effective problem visualization, visible and swift results in an efficient way.

Keywords: productivity growth, apparel industry, inventory, visual control management.

I. Introduction

The apparel industries in Bangladesh are mainly export-oriented. Knit and woven garments are the main products. During the past two decades, the success of readymade garment exports from Bangladesh has exceeded the most optimistic standards. In terms of country employment, foreign exchange earnings and its contribution to real GDP, this RMG sector has rapidly gained immense importance. To sustain this rapid growth and satisfy customer demand, the companies need to create some new work practices instead of traditional practices. Applying LEAN techniques like the 5S system can result in improved productivity, cost savings, and workflow efficiency.

a) Objectives:

- To identify the 5S principles in Apparel Industry to find out the desired Productivity & Improve efficiency in Production line of apparel Industry.
- To identify the factors influencing in Productivity in Apparel Industry.
- To analyze the effect of 5S Principles on Apparel Productivity.
- To contemplate the pursuance in terms of manufacturing and environmental key performance indicators namely productivity, efficiency, quality, work in progress among 5S initiated and non- 5S initiated apparel units.
- Elimination of waste like and create an action plan for continuous improvement.

II. Literature Review

5S is a simple tool of the LEAN management for organizing your workplace in a clean, efficient and safe manner to enhance productivity, visual management and to ensure the introduction of standardized working of an organization.

The 5 phases are:

- Sort (Seiri)– "When in doubt, throw it out".
- Straighten (Seiton) –"A place for everything, and everything in its place".
- Shine (Seiso) – "The best cleaning is to not need cleaning".
- Standardize (Seiketsu) – "See and recognize what needs to be done".
- Sustain (Shitsuke) – "The less self-discipline you need, the better".

The system creates an environment where all objects are easier to find and any deviation from the normal situation becomes apparent by visual management methods. In the same time, 5S techniques maintain quality, promote a significant costs reduction by eliminating the losses and provides the best framework for progress throughout the organization.

These five phases of 5S system has a great impact in reducing the seven deadly wastes or MUDAS of an organization. These seven deadly wastes are:

1. Defect
2. Inventory
3. Processing
4. Waiting
5. Motion
6. Transportation
7. Overproduction

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III. Methodology

This section describes different areas related to the study and also the tools and techniques used in this study. It is a basic technique to enhance workplace appearance and give a pleasant work environment.

During our research on the project, we have visited some renowned garments manufacturing companies named Epyllion Styles Ltd. There we have met with the authority to perform our research on the 5S system. There we follow some of the steps to implement the research work:

- Discussed with the top management about the ways they follow to implement 5S system in their apparel industry.
- Used survey method and questionnaire method to collect necessary data and information from the IE department for the research work.
- Made effective analysis and survey of each department to gather some valuable data and photos which is needed for the project research work.
- Made some search from these company's web sites to collect necessary information, comparable data etc.
- All the necessary task were done for the project work during the time period from June to August, 2016.

a) *Data collection and analysis*

The five concepts, which have to be checked, introduced and implemented in the workplace by the garments industries, where we have made our research are:

i. *Seiri (Sort)*
 - Take some photos which are needed to analyze the study.
 - Segregate wanted & unwanted materials in all Zones.

ii. *Seiton (Set in Order)*
 - Identify all materials by Name/Number/Colour code, etc.
 - Design a suitable storage place/parking slots and fix the place for storing each item depending on the frequency of usage

iii. *Seiso (Shine)*
 - Prepare cleaning schedule for all zones covering.
 - The areas of cleaning
 - The items of cleaning

iv. *Seiketsu (Standardise)*
 - Make a list of the various activities of 5S for implementation.
 - Follow the significant guidelines for floor marking in the industry.
 - The following things to be standardized.

v. *Shitsuke (Sustain)*
 - Monitor all the activities of 5S continuously.
 - Create work discipline with the help of employees working in the particular area in order to suit the requirement

b) *Case study*

We have found some problems in different sections of the garments industry and found some actions required to solve the issues which are given below in the table:

Problems	Sample Dept.	Stores	Cutting	Stitching	Finishing	Packing	Office Area	Action Required
Unnecessary Items	Yes	Yes	No	Yes	Yes	Yes	Yes	Seiri
Leftover Present	Yes	Yes	Yes	Yes	Yes	Yes	No	Seiri
Rejection On Floor	No	Yes	Yes	Yes	No	Yes	No	Seiri
Floor Marking	Partial	No	Partial	Partial	No	No	No	Seiton
Labels	No	No	No	No	No	No	No	Seiton
Trolleys	Partial	Yes	No	Partial	No	No	No	Seiton
Sub Store	No	No	No	No	No	No	No	Seiton
Visual Controls	No	No	No	No	No	No	No	Seiton
Pathways Defined	No	No	No	No	No	No	No	Seiketsu
Racks And Bins	Yes	Yes	No	No	No	Yes	Yes	Seiton
Dust And Stains	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Seiso
Visible Sops	No	No	No	No	No	No	No	Seiketsu
Workers Training Over 5s	No	No	No	No	No	No	No	Shitsuke
Files Arrangement	No	No	No	No	No	No	No	Seiton

We divided the whole space available into six zones and then we identified the unwanted materials in those zones using red tags. After removing those unwanted items from the zones, can save 51.21 m^2 space. Table 1 Shown the improvement in saving space on the factory floor.

Table 1: Zone wise saving space

Zone	Space saving (m^2)
Zone 1	0.06
Zone 2	3.1
Zone 3	2.83
Zone 4	0.69
Zone 5	21.39
Zone 6	23.14
Total saving space	51.21 m^2

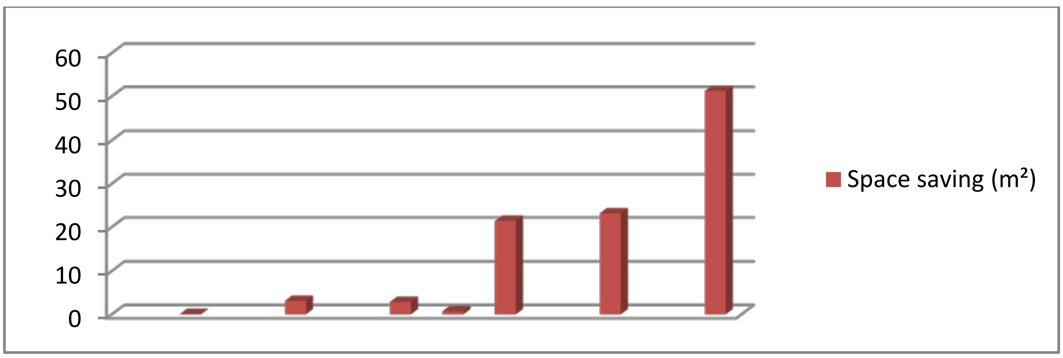

Figure 1: Different zone wise saving of apace in square meter

In zone 1, save no space due to the removal of small quantities of items from that zone which occupied a little space. Allocate all store rooms to zone 5 and zone 6. Found the most unwanted items in those store rooms. A comparatively a massive amount of space had been saved from zone 5 and zone 6. This saving space resulted in an additional cost savings of 4764.09US dollars or 376363.11 Taka, which is shown in a table.

Table 2: Zone wise saving cost

Zone	Total cost (USD)	Total cost (BDT)
Zone 1	12.58	993.82
Zone 2	162.08	1204.32
Zone 3	123.67	9769.93
Zone 4	21.32	1684.28
Zone 5	3455.91	273016.89
Zone 6	988.53	78093.87
Total saving cost	4764.09	376363.11

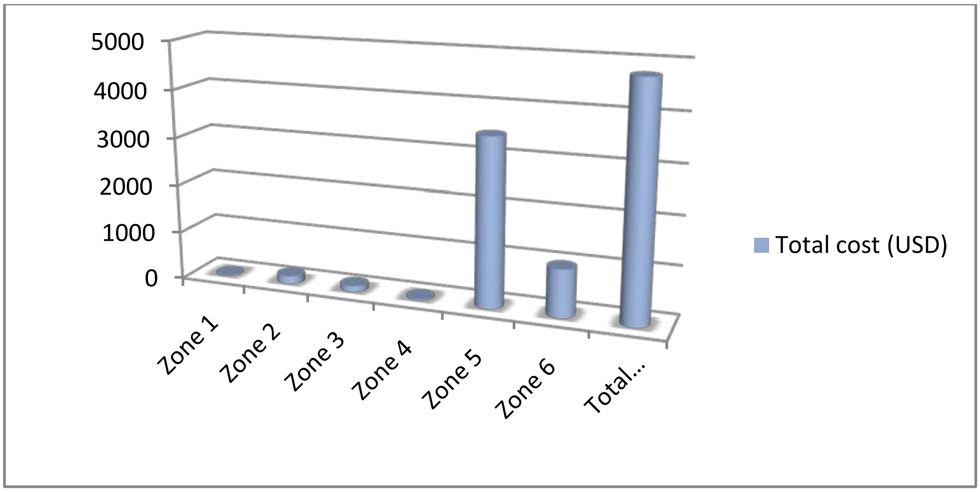

Figure 2: Zone wise total cost (USD)

Set in order was also applied in the fabric store. Before the implementation of 5s, there was no sequence of arranging the racks for storing fabrics. But during the study period, racks were rearranged according to the order volume of the buyer. Fabrics of higher quantity ordered were placed in initial racks while fabrics of lower quantity ordered were placed in last racks so that fabrics could be delivered with least delivery time. Rack allocation was subjected to change each month with change of buyer and order quantity. This resulted in a reduced movement of 22.95%. Table 3 gives a clear representation of this scenario.

Table 3: Rack allocation for buyers (Before and after set in order)

Buyer Order	Quantity(piece)	Rack (before)	Rack(after)
M&S	15630	1,2	12
H&M	35500	3	4,510
C&A	60000	4,5,6	1,2,3
Celio	12000	7	11
RAW	25000	8	9
S.Oliver	30000	10	8
River Islands	15000	9,12	6,7

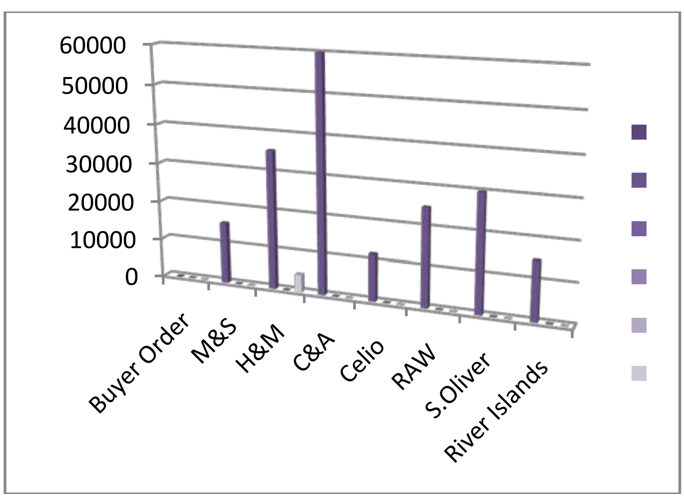

Figure 3: Different buyers and their order quantity

The same experiment done in the accessories store; a new layout was proposed and implemented based on the average quantity required/day. This experiment also resulted a reduction in overall movement of 27.13%. The previous and new allocation of the accessories in the store is shown in table 4.

Table 4: Rack allocation for accessories (Before and after set in order)

Items	Average quantity required/day (bag)	Rack(before)	Rack(after)
Thread	3340	1,2,3	10,11
Wash elastic	70	4,5,6,7	1,2,3
Elastic tape	90	8,9	4,5,6
Button	800	10,11	7,8
Zipper	426	12	9,10,11
Organic fabric	215	13,14	12,13,14

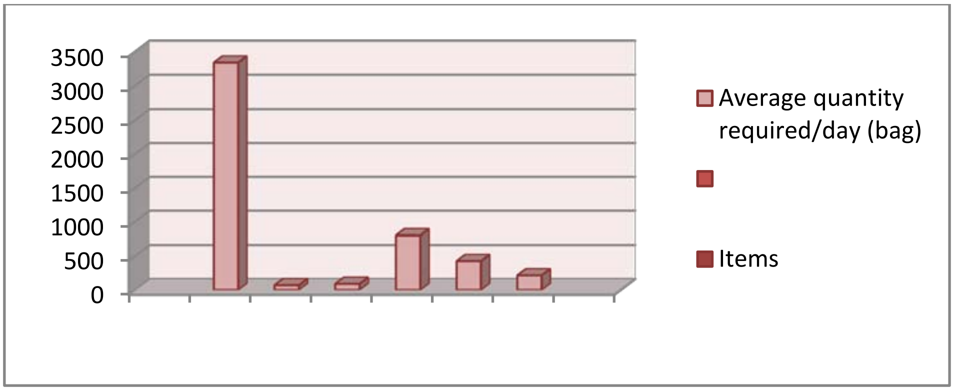

Figure 4: Rack allocation for various accessories

c) *Time Consuming Analysis*

Time utilization took each time the personnel or staff needed the tools or any item from the inventory places. To know how long it carry looking for the different sizes of tools before running 5S, Table 1 used to collect time in looking for a different amounts of threads. Table 2 is the data collection chart used for looking for sewing section. This data collected by the average number of 2 cycles.

Table 5: Time consumption in looking for threads of different sewing machine before 5S

Thread of various machines	M/C 1 (sec)	M/C 2 (sec)	M/C 3 (sec)	M/C 4 (sec)	M/C 5 (sec)	M/C 6 (sec)
Staff 1	50 sec	110	50	74	65	50
Staff 2	45 sec	115	65	70	69	35
Staff 3	40 sec	110	60	85	61	51
Staff 4	50 sec	125	55	65	60	50
Staff 5	35 sec	111	70	60	62	55
Staff 6	44 sec	115	75	75	75	30
Staff 7	40 sec	130	65	70	67	45
Staff 8	42 sec	125	62	65	60	40
Total(average)	43	117	62	70	64	119

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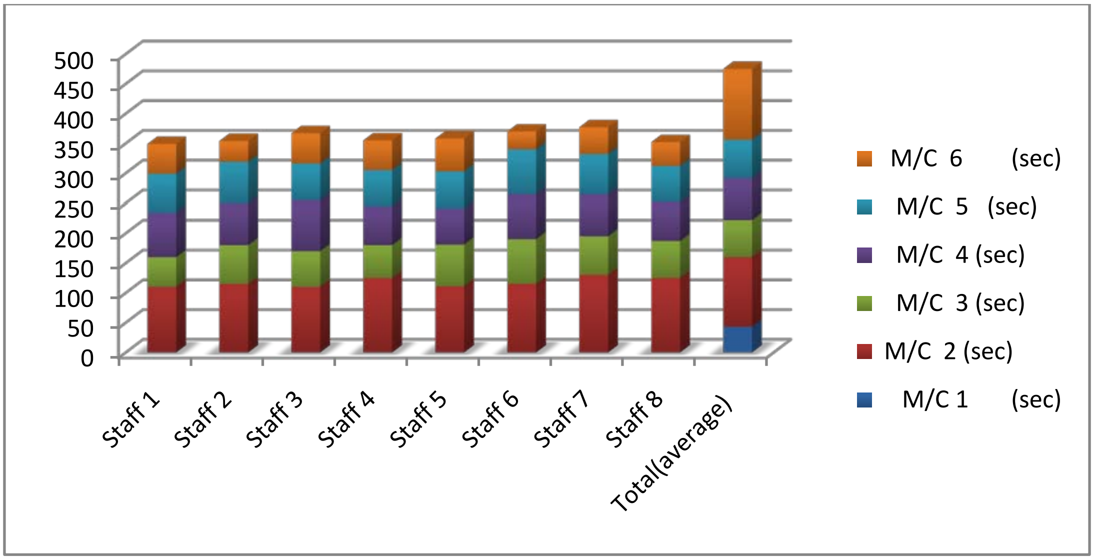

Figure 5: Time consumption to collect threads of different items of different sewing machines before implementing 5S

Table 6: Time consumption in looking for threads of different sewing machine after 5S

Thread of various machines	M/C 1 (sec)	M/C 2 (sec)	M/C 3 (sec)	M/C 4 (sec)	M/C 5 (sec)	M/C 6 (sec)
Staff 1	15 sec	30	15	33	25	20
Staff 2	13 sec	35	12	30	23	18
Staff 3	12 sec	25	25	28	28	22
Staff 4	18 sec	40	23	42	33	21
Staff 5	15 sec	25	22	30	33	29
Staff 6	18 sec	28	27	32	35	29
Staff 7	15 sec	42	28	38	25	21
Staff 8	12 sec	25	30	35	39	15
Total(average)	14	31	22	33	30	21

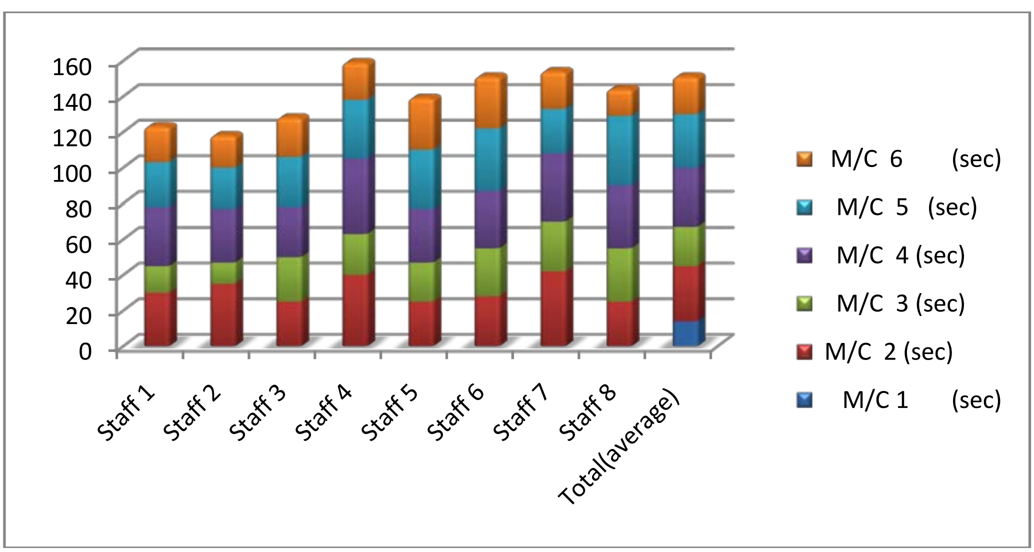

Figure 6: Time consumption to collect threads of different items of various sewing machines after implementing 5S

IV. Results and Discussions

After the implementation of 5S, from the proposed improvement proposal, 51.21-meter square space was saved, which resulted in a cost savings of 376363.11 Taka. Overall reduced movement of almost 25% was achieved in the fabrics and accessories room resulting in more than a 13% increase in multifactor productivity.

After the implementation of 5S on the factory floor, it resulted in average labor productivity from 3.46 to 7.66. This experiment showed an overall improvement of 45.17%. Labor productivity calculated for one month period before, and after the implementation of 5S and the result shown in the following figure:

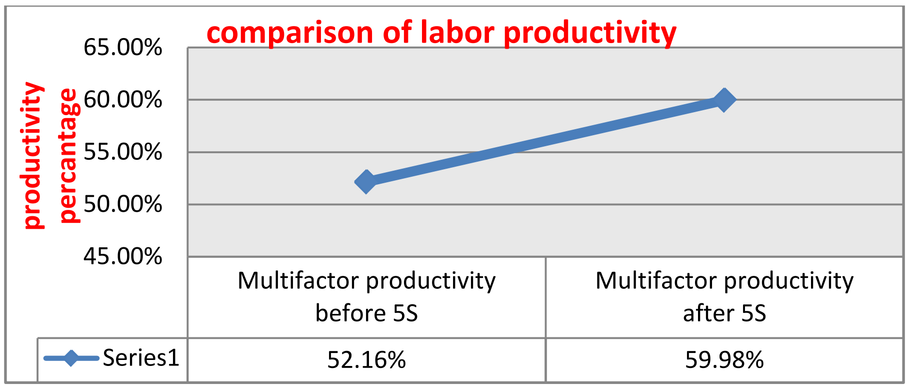

Figure 7: Comparison of labor productivity

Material productivity remained almost constant over the study period though it slightly peaked after the implementation of 5S. Average material productivity increased from 2.69 to 2.92 over the study period and resulting in a more than 15 % increase in multifactor productivity. Before the implementation of the 5S system, the multifactor productivity of EPYLLION STYLES LTD. was 52.16%, and after the implementation of 5S, the multifactor productivity assumed 59.98%.The reason behind it was that implementation of 5S during the study mainly focused on making tools and materials more easily accessible to workers, which enhanced labor productivity rather than trying to reduce the wastage and material cost.

This slight increase in material productivity came as by the implementation of 5S as labor productivity became significantly high after the application of 5S in the factory it had a positive impact on the multifactor productivity of the factory. The result shown in the following figure:

Figure 8: Comparison of multifactor productivity

V. Conclusion

The above activity performed on some of the renowned garments factories, and through 5S Japanese principles, some great results come in very short period. It is required to continue the audit activity on a regular basis and allocated resources and budget to maintain the 5S. The 5S committee needs to propagate the philosophy to every employee by training and awareness program, and a continuous improvement activity is required to enhance the production and reduce the wastages. It can also be a part of the yearly appraisal. The Japanese 5S System is a very essential system for ensuring systematic discipline. Moreover, this is a world-wide acceptable formula which helps in a great deal in solving the managerial level problems. 5S can be considered a philosophy, a way of life, which can raise morale and create a good impression to customers and enhance efficiency. 5S is a proven methodology and gives remarkable results all over the world. Bangladesh's industry needs to adopt it as an initial step toward modern management approaches.

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Análisis De La Gestión Y Manejo De Residuos Sólidos Basados En La Educación Ambiental En El Rio T´Ororcocha De La Ciudad De Juliaca, Puno – Perú

By Rubén Wilfredo Jilapa Humpiri & Jesús Luzmila Benique Carreón
Universidad Nacional de Juliaca

Abstract- The solid waste found in the T´orococha riverbed affects the inhabitants that live on its banks. Being important to improve the management services of urban solid waste in the area and create environmental awareness, this research work aims to determine how much an intercultural environmental education plan influences the willingness to pay for the appropriate service in the management and solid waste management, in the sectors affected by the contamination of the T´orococha river of the city of Juliaca, The methodology used is organized based on the determination of the factors influencing the willingness to pay and the cost of disposal to Pay for the proper service of solid waste management and management, for which purpose interviews have been conducted, and surveys in each sector.

Keywords: solid waste, environmental education, willingness to pay (DAP) and interculturality.

GJRE-J Classification: FOR Code: 090799

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Análisis De La Gestión Y Manejo De Residuos Sólidos Basados En La Educación Ambiental En El Rio T´Ororcocha De La Ciudad De Juliaca, Puno – Perú

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Abstract- The solid waste found in the T´orococha riverbed affects the inhabitants that live on its banks. Being important to improve the management services of urban solid waste in the area and create environmental awareness, this research work aims to determine how much an intercultural environmental education plan influences the willingness to pay for the appropriate service in the management and solid waste management, in the sectors affected by the contamination of the T´orococha river of the city of Juliaca, The methodology used is organized based on the determination of the factors influencing the willingness to pay and the cost of disposal to Pay for the proper service of solid waste management and management, for which purpose interviews have been conducted, and surveys in each sector. Applying the Logit model in the econometric estimation, it has been determined that the willingness to pay (DAP) is S /. 5.00 Soles, achieving an increase with respect to (DAP) before the implementation of the environmental education plan, it has also been determined that knowledge of interculturality, higher family income, preference for communication in the Quechua language positively influence the (DAP) while the increase in price, the respondent's older age, the greater number of inhabitants per dwelling and communication preference in Aymara language negatively influence the (DAP). Among the area with the highest (DAP) is zone I and III with 39% and 50% respectively.

Keywords: solid waste, environmental education, willingness to pay (DAP) and interculturality.

Resumen- Los residuos sólidos encontrados en el cauce del río T´orococha afectan a los pobladores que habitan en sus riveras. Siendo importante mejorar los servicios de manejo de los residuos sólidos urbanos en la zona y crear conciencia ambiental, el presente trabajo de investigación tiene como objetivo determinar en cuánto influye un plan de educación ambiental intercultural en la disposición a pagar por el adecuado servicio en la gestión y manejo de los residuos sólidos, en los sectores afectados por la contaminación del río T´orococha de la ciudad de Juliaca, La metodología utilizada está organizada basada en la determinación de los factores influentes en la disposición a pagar y el costo de la disposición a pagar por el adecuado servicio de la gestión y manejo de residuos sólidos, para cuyo efecto se ha realizado entrevistas, y encuestas en cada sector. Aplicando el modelo Logit en la estimación econométrica, se ha determinados que la disposición a pagar (DAP)es de S/. 5.00.Soles, logrando un incrementocon respecto a la (DAP) antes de la implementación del plan de educación ambiental, así mismo se ha determinado que el conocimiento de interculturalidad, mayores ingresos familiares, preferencia de comunicación en el idioma quechua influyen de manera positiva en la (DAP) mientras que el aumento de precio, mayor edad del encuestado, mayor cantidad de habitantes por vivienda y preferencia de comunicación en idioma aymara influyen negativamente en la (DAP). Entre la zona con mayor (DAP) se encuentra la zona I y III con el 39% y 50% respectivamente.

Palabras Claves: residuos sólidos, educación ambiental, disposición a pagar (DAP), interculturalidad.

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I. Introducción

El trabajo de investigación se fundamenta sobre la base de la gestión de los residuos sólidos generados por los habitantes aledaños al RìoT´orococha, cuyo afluente atraviesa la ciudad de Juliaca.

La contaminación del río T´orococha en los últimos años se ha agravado a consecuencia del constante crecimiento demográfico de la ciudad de Juliaca, la baja cobertura en sus servicios de agua, desagüe y servicio de recojo de residuos sólidos ha generado la proliferación de insectos, paracitos y microorganismos patógenos que ponen en riesgo constante riesgo a la población.

La contaminación del río T´orococha, es un problema para las poblaciones deCoata, Huata y Capachica porque sufren los efectos negativos sobre las fuentes de abastecimiento de agua y producción agropecuaria, de tal modo que ha ocasionado un conflicto socio ambiental.

Mediante la propuesta del plan de educación ambiental se busca desarrollar las capacidades de los involucrados para generar una culturade gestión de los residuos sólidos autogestionaria con la disposición de pago para lograr un desarrollo local sustentable. Se considera que la educación ambiental juega un papel importante como instrumento de transformación social, generando cambios de actitud, creencias y valores de la sociedad respecto al medio ambiente, sin embargo, se requiere del apoyo de los involucrados para lograr la resolución de los problemas ambientales, así como la participación de todos los actores sociales (Acevedo *et al* 2018).

El manual de educación ambiental, está orientado al proceso de la adecuada gestión de los residuos sólidos, incidiendo en la valoración de los residuos orgánicos e inorgánicos la cual contribuiría a la disponibilidad de pagar por la adecuada gestión de los residuos sólidos.

Es de mucha importancia el análisis consiente, del buen vivir, y en armonía con el ecosistema y el medioambiente, resultando de carácter prioritario el adecuado al uso, usufructo de los recursos y su conservación; buscando un equilibrio coherente y amigable; la problemática del rio T´orococha, considerando como un tema reciente o de poca importancia ya que se trata de la micro cuenca que ha dispuesto ancestralmente del recurso agua a los pobladores y la crianza de animales.

Hoy se tiene un serio problema de contaminación por los pobladores aledaños, y no es posible el consumo directo del agua, sin embargo, la población alternativamente extrae el agua del sub suelo y esto se constituye en un peligro para la salud pública. La educación ambiental es la herramienta elemental para que todas las personas adquieran conciencia de la importancia de preservar su entorno y sean capaces de realizar cambios en los valores, conducta y estilos de vida, así como ampliar sus conocimientos para impulsarlos a la acción mediante la prevención y mitigación de los problemas existentes y futuros (Espejel & Flores, 2012).

La Agencia Europea de Medio Ambiente (EEA) define la conciencia ambiental como el "crecimiento y desarrollo de la comprensión, la percepción y el conocimiento sobre el medio ambiente biofísico y sus problemas, incluida la interacción humana y sus efectos. Pensar 'ecológicamente' o en términos de una conciencia ecológica" (citado en Gómez, 2011). El trabajo de investigación ha definido como finalidad principal determinar en cuánto influye un plan de educación ambiental intercultural en la disposición a pagar por el adecuado servicio en la gestión y manejo de residuos sólidos, en sectores afectados diferenciados del río T´orococha.

II. Materiales y Métodos

a) Materiales

Instrumentos de campo:Encuestas, Entrevistas, Fichas Técnicas, Formatos de recolecciónde datos y Registros visuales (video y fotografías).

Materiales de laboratorio (análisis de agua y suelos):Probetas graduadas, Matraces, Estufa, Refrigeradora, Refractómetro, Bazos de precipitado, Balanza de precisión, Pipetas, pH metro, Cinta de rotulación, kits de análisis de agua y kits de análisis de suelo.

b) Métodos

El método aplicado está basado en la valoración de la voluntad del contingente afectado como causa principal de la contaminación por los residuos sólidos; para determinar la DAP, la misma que consiste en la aplicación de los instrumentos de recojo de información; (encuestas, entrevista y evaluación in situ del problema) cuyos instrumentos están estructurados de acuerdo a los objetivos del estudio incidiendo en cuatro ejes temáticos fundamentales: Socioeconómico, Interculturalidad, Medio ambiente y Disposición a pagar.

- Determinación de la (DAP) Valoración compensada o equivalente

En la etapa de la determinación de la disponibilidad de pago, basada en la valoración contingente es encontrar el valor compensatoria o variación equivalente asociada al cambio en la provisión del bien natural como es el caso del río T´orococha, la cual está siendo afectada por la aglomeración de residuos sólidos, la posibilidad de desarrollar la voluntad de su mejora se expresan en unidades monetarias como una forma intuitiva de entender la diferencia entre las variaciones en el actual contexto. En efecto se ha realizado la caracterización de los residuos domiciliarios con la finalidad de determinar y valorar la generación de los residuos reciclables con el propósito de generar recursos económicos como resultado de la venta de los residuos reciclables. Para la determinación de la (DAP) se ha establecido el modelo LOGIT la misma que considera las variables establecida en la investigación.

- Determinación de la DAP por zonas afectada

Para contar con la determinación del desprendimiento de pago de los sectores identificados es importante contar con la información de la voluntad de mejorar las condiciones ambientales en el ámbito de intervención de parte de los involucrados, cuyos datos han sido procesados con la estadística cuantitativa con la finalidad de identificar las divergencia basada en la variable del mayor interés de pago por el proceso de mejora de las condiciones ambientales, en consecuencia para este proceso se ha aplicado la estadística de la distribución de Pearson, llamada también (Chi-cuadrado) para el procesamiento de los datos de la encuesta, con los cuales se determina y evalúa la relación a la mayor disponibilidad de pago.

III. Resultados y Discusiones

Disposición de pago por el adecuado servicio en la gestión y manejo de residuos sólidos, en los sectores afectados por la contaminación del río T´orocoча

- Disposición a pagar por mejorar el servicio de limpieza y recojo de basura

En la figura 1, se observa, que el 20% está en del desacuerdo en pagar, antes de la intervención y después de la intervención esta disminuye al 11%, mientras que las personas que han asimilado incrementa del 79% al 89 %, cifras que muestran el compromiso de los afectados en aras mejorar el sistema de gestión de los residuos sólidos ymejorar las condiciones de medioambientales.

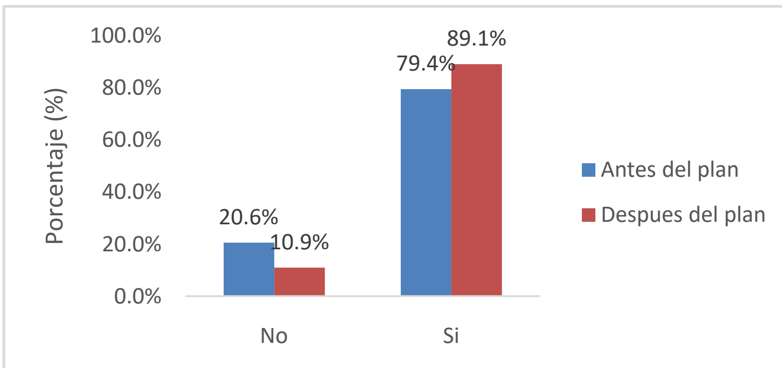

Figura 1: Disposición a pagar por servicio de limpieza y recojo de residuos sólidos

- Monto a pagar como una contribución monetaria para mejorar el servicio de limpieza y recojo de residuos sólidos

En la figura 2, se presenta la evaluación del monto a pagar por el servicio, la misma que tiene el siguiente detalle: antes de la intervención el monto a paga antes del plan fluctúa de 32.6% y 36.2% quienes pagarían de 1 a 5 soles respectivamente, después de la intervención el 26.3% pagaría 1 sol y el 37% contarían con la disponibilidad de pago de 5 soles.

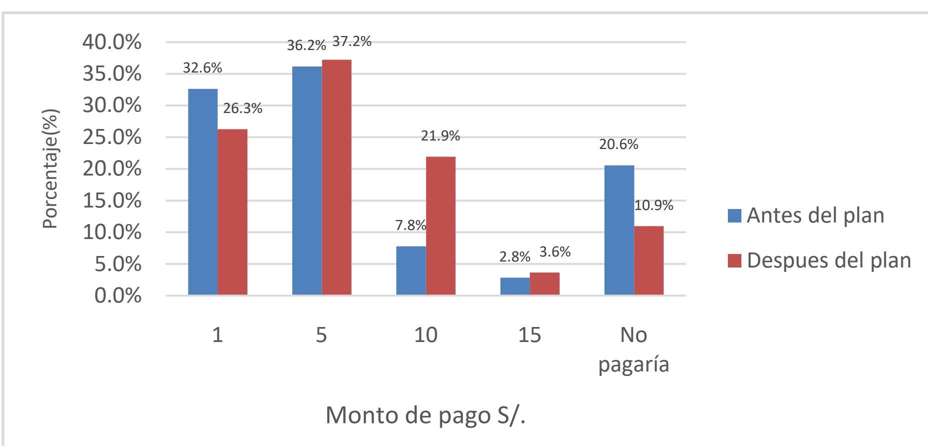

Figura 2: Monto a pagar como una contribución monetaria para mejorar servicios de limpieza y recojo de residuos sólidos

- Modelos de probabilidad de Logit antes de la implementación del plan de educación ambiental

Aplicado el modelo Logitse muestran interés por el tema las de mediana edad, los miembros de la familias, las que conocen de interculturalidad y los que conocen los idiomas como el quechua y el aymaray tienen el interés (DAP) por la adecuada gestión de los residuos sólidos domiciliarios mientras que los encuestado que no estarían dispuestos a para en esta etapa se ha determinado las condiciones que no son favorables para este caso el tema de educación, la cantidad o monto de pago; cuyas condiciones iniciales se presentan en la tabla 1.

Tabla 1: Modelos de probabilidad de logit antes de la implementación del plan de educación ambiental

DispP	Coef	Std	Err	z	P>|z|	[95% Conf. Interval]
Edad	0105007	1975755	0.53	0.595	-282233	492246
Educ	-9183867	5951549	-1.54	0.123	-2.084869	2480955
Miem	1340859	1886083	0.71	0.477	-2355795	5037514
Ingres	-26061	2855928	-0.09	0.927	-5858127	5336907
Intercul	4808764	6183961	0.78	0.437	-7311577	1.69291
Comuni	2287326	2347524	0.97	0.33	-2313736	6888388
Cons	1.593004	1.650267	0.97	0.334	-1641464	827468

- Modelos de probabilidad de Logit después de la implementación del plan de educación ambiental

Aplicado el modelo Logit después del plan de educación ambiental, sobre las variables consignados se interpreta lo siguiente: a mayor edad mayor es la disponibilidad de pago, a mayor concientización o educaciónincrementa la disposición de pago, a mayor consenso del monto de pago la disponibilidad de pago es mayor, a mayor miembros por familia la intención de pago es menor, a mayor conocimiento de interculturalidad menor es la disposición de pago y a mayores ingresos la disponibilidad de pago es menor. Cuyos resultados se muestran en la tabla 2.

Tabla 2: Modelos de probabilidad de Logit después de la implementación del plan de educación ambiental

DispP	Coef	Std	Err	t	P>|t|	[95% Conf. Interval]
Edad	0013369	0021256	0.63	0.53	-28674	0055412
Educ	0719012	0666287	1.08	0.282	0598877	2036902
Miem	-0291217	0185928	-1.57	0.120	-0658975	0076542
Intercul	-780376	0731428	-1.07	0.288	-2227182	066643
comuni	0.169292	0258428	0.66	0.514	0341869	0680453
Ingres	-0527604	0296806	-1.78	0.078	0.078	0059467
Monto	0.603991	0089408	6.76	0.000	0427146	0780836
Cons	652186	1918315	3.40	0.001	2727508	1.031621

Lo principal de esta experiencia, es que la implementación del plan de mejora de medio ambiente, ha contribuido de manera significativa al 0,05 de margen de error, las intenciones de disponibilidad de pago es un indicador valorable. Por lo que se debe valorar cuán importante es la acción de la demostración que si se puede cambiar la actitud de las personas con iniciativas de esta índole.

Hanemann*et al*. (1991). Considera que el componente principal de los datos dicotómicos es la cantidad umbral ofrecida como pago por la mejora de la gestión de los residuos domiciliarios, que generan impactos medioambientales negativos que afectan a los poblaciones, al contrario de los modelos logit o probit ordinarios donde este valor umbral es cero.

Amemiya, (1981).El método aplicado para estimar el modelo Logit es el Método de Máxima Verosimilitud. Este método estima los parámetros del modelo maximizando la función de verosimilitud con respecto a los parámetros del modelo, encontrando los valores de los parámetros que maximizan la probabilidad de encontrar las respuestas obtenidas en las encuestas estructuradas sobre la base del fin de la investigación.

- Disponibilidad de pago por zonas afectadas (antes de la intervención)

Antes de la intervención la (DAP) es de 1.00 con una relativa tendencia de pagar 5.00 soles entre las zonas I y II. Cuyos resultados se presentan en la tabla 3.

Tabla 3: Disponibilidad de pago por zonas afectadas (antes de la intervención).

Monto estimado / %	Zona-I	Zona-II	Zona-III	Zona-IV
	Los geranios, Villa médica y aledaños		San Santiago, Sol de oro y aledaños	
1	34,9	31,6	22,0	28,1
5	32,6	37,8	29,3	40,6
10	11,6	6,1	26,8	19,8
15	4,7	2,0	4,9	3,1
No pagaría	16,2	2,5	17,0	8,4
Total	100	100	100	100

- Disponibilidad de pago por zonas afectadas (después de la intervención)

Para el análisis de la (DAP), después de la intervención se observa en la tabla 6, las cuales se mantiene entre 1.00 – 5.00 soles esta última siendo la más razonable. La (DAP), después de la intervención se observa un incremento en promedio de 37 % entre las zonas I y II, mientras que en las zonas III y IV se ha alcanzado 38 % en promedio.

Tabla 4: Disponibilidad de pago por zonas afectadas (después)

Monto estimado / %	Zona I	Zona II	Zona III	Zona IV
	Los geranios, Villa médica y aledaños		San Santiago, Sol de oro y aledaños	
1	24,2	29,3	25,0	25,8
5	39,4	34,1	50,0	25,8
10	24,2	19,5	12,5	32,3
15	3,1	4,9	3,1	3,2
No pagaría	9,1	12,2	9,4	12,9
Total	100	100	100	100

IV. Conclusiones

Los factores influentes en la disposición a pagar son condiciones en las que los involucrados deben de desarrollar conciencia, conocimiento y prácticas medioambientales, con el propósito de concientizar a los afectados, mediante la socialización del plan de educación ambiental intercultural validada mediante la información previa, esta ha sido aplicada a la población (muestra) representativa en un numero de 141, viviendas (familias). Para determinar la disposición a pagar por el adecuado servicio en la gestión y manejo de los residuos sólidos, en los lugares afectados por la contaminación.

La valoración del bien; sobre la (DAP), mejora del 79% al 89 %, como resultados de la intervención cuya cifra muestra el compromiso de los afectados en aras mejorar el sistema de gestión de los residuos sólidos y mejorar las condiciones de medioambientales. Del análisis de la intervención el monto a paga antes del plan fluctúa de 32.6% y 36.2% quienes pagarían de 1 a 5 soles respectivamente, después de la intervención el 26.3% pagaría 1 sol y el 37% contarían con la disponibilidad de pago de 5 soles.

Antes de la intervención la (DAP) es de 1.00 con una relativa tendencia de pagar 5.00 soles entre las zonas I y II. Para el análisis de la (DAP), después de la intervención se mantiene entre 1.00 – 5.00 soles esta última siendo la más razonable. En la (DAP), después de la intervención se observa un incremento en promedio de 37 % entre las zonas I y II, y en las zonas III y IV se ha alcanzado 38 % en promedio.

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Experimental Investigation on CI Engine with Hydrogen Peroxide as an Alternate

By B. Murali Krishna
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Abstract- The current automotive emission norms and environment protection measures are motivating to find alternative techniques and fuels. In this work, experimental investigations are carried out to study the performance characteristics of single-cylinder, four-stroke Direct Injection (DI) Compression Ignition (CI) engine using diesel with hydrogen peroxide (H2O2) as an additive with different proportions i.e. 5, 10, 15, 20, 25 (% by volume basis) and compared with conventional diesel fuel performance. The performance parameters like brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), Mechanical efficiency (ME), Volumetric efficiency (VE), Exhaust gas temperature (EGT) and Smoke are evaluated to find optimum blend. From the experimental investigations, it is found that diesel engine with $D_{85}H_{15}$ shown reduction in BSFC, Exhaust gas temperature, Smoke and increase in BTE in comparison with conventional diesel operated engine.

Keywords: *diesel, efficiency, blends, emulsion, hydrogen, oxygen.*

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EXPERIMENTALINVESTIGATIONONCIENGINEWITHHYDROGENPEROXIDEASANALTERNATE

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Experimental Investigation on CI Engine with Hydrogen Peroxide as an Alternate

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I. Introduction

The dependency on fuel imports, limited reserves of petroleum and its pollution leads to find an alternative solution/fuel. In view of this, attempts must be made to develop the technology of alternate clean burning fuels. The alternative, which satisfies all these requirements, is diesel with hydrogen peroxide (H_2O_2). Hydrogen peroxide is viable, alternative energy storage medium, competing with hydrogen gas, biogas, biodiesel and alcohol. H_2O_2 is an energy-dense fuel that burns as cleanly as H2, but requires no oxidizer as it is included inside the fuel. Actually, it does not burn; it decomposes violently into water and oxygen if heated above 80^0C with a release of tremendous energy, close to the energy per mole of H_2. It also decomposes in light and in the presence of metal ions. One volume of H_2O_2 releases ten volumes of oxygen when it decomposes. It is like water, so it does not need a pressure vessel to contain it. When it breaks down into water and oxygen it does not form any persistent, toxic residual compounds. It is completely soluble in water. Pure H_2O_2 is a colorless, when it used to produce energy, creates only pure water and oxygen as a by-product, so it is considered as a clean energy like hydrogen. However, unlike hydrogen, H_2O_2 exists in liquid form at room temperature, so it can be easily stored and transported. H_2O_2 has been around for a long time, so there is a long history of industrial handling and storage. Andrea Bertola et al [1] reported that the dominating factor of introduction of water in the diesel combustion has been found to be the lower peak combustion temperature that is responsible for lowering NOx emissions. Additional advantages of water-diesel fuel emulsions are considerable lower particulate emissions. Niranjan Kumar et al [2] observed water in oil emulsions are engineered to provide emissions with reduced carbon particulate, lower opacity and lower nitrogen oxide levels. From the previous work, it is observed that the H_2O_2 and diesel blends as a viable alternative to use in the CI engines without any major modifications. In addition, H_2O_2 is available in many parts of the world and appears to be very attractive to use in CI engines. The presence of additional oxygen atom in H_2O_2 molecule enhances the combustion process and effects exhaust emissions. The heat release rate at the beginning of the combustion stage is high in a diesel engine and is a major source of pollutants like NOx. Various methods are being tried to control these emissions. Unfortunately most of the methods that control NOx, affect smoke and particulate emissions adversely. Use of H_2O_2 and diesel emulsion in diesel engines is one of the methods that can be used for the simultaneous reduction of both NOx and smoke without any penalty in fuel consumption. In this work, H_2O_2 and diesel blends are used to study the performance of diesel engine to find optimum keeping in emission and performance concern. It is essential to study the various properties of any fuel for implications in engine use, storage, handling and safety [1-4] and the details are described in the following sections.

Hydrogen peroxide properties

- Chemical properties-The principal byproduct of H_2O_2 reactions is water, since it does not create hazardous wastes, it is a preferred oxidizer.
- Physical properties- H_2O_2 is denser than water, but is miscible with water in all proportions. It is a noncombustible liquid, but heat and oxygen released during decomposition can ignite combustible materials.
- Stability and decomposition- H_2O_2 is exothermically decompose into pure water and oxygen gas with evolution of heat reference temperature and concentration, as well as presence of impurities and stabilizers.

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- Storage and handling equipment-preferred metals and plastics are containers like drums, tanks, tank trucks or railcars etc which are of atmospheric vessels with properly designed continuous vent to release the small amounts of oxygen liberated from H_2O_2

Table 1: Properties of Diesel and H_2O_2

Properties	Diesel	H_2O_2
Specific gravity	0.84	1.1
Density (kg/m3)	840	1110
Boiling Temp. (°C)	210	225
Viscosity (cP)	2.6	1.8

II. Experimental Work

In this study, experiments were conducted on a single-cylinder, four-stroke, water-cooled, DI CI engine. The specifications of engine are given in Table2. The photograph of experimental setup is shown in the Figure.1. The test engine was coupled to a calibrated rope brake dynamometer for loading purpose. Fuel consumption was measured by a calibrated burette and a stopwatch. Air consumption was measured using an orifice meter connected through an air-box and U-tube manometer. A Hatridge smoke meter was used for the measurement of smoke density. Exhaust gas temperature was measured using K-type thermocouple. In this work, all the experiments were conducted at a constant speed of 1500 rpm with load varying from zero to full in steps of 20%.

Investigations were done using diesel with hydrogen peroxide (H_2O_2) as an additive with different proportions i.e. 5, 10, 15, 20, 25 (% by volume basis) to determine optimum blend. For example, D90H10 fuel contains 90% Diesel and 10% of H_2O_2 by volume. The diesel is mixed with H_2O_2 in a glass flask; mixture is stirred for about 45 minutes by using a magnetic stirrer, depicted in Figure.2. As the density of H_2O_2 is greater than that of diesel continuous stirring is made. This is achieved by magnetic stirrer set up and the fuel mixture is allowed to pass through the fuel pipe to the engine, proper care is taken while stirring. Initially base tests with diesel are conducted for different loads and time taken for consumption of 10cc fuel are recorded for comparison with proposed blends. The blended fuel is fed to the engine by using an aspirator bottle provided with an arrangement for holding a mechanical stirrer. The mechanical stirrer consists of 12 volts DC motor welded to a vertical spindle with rotor blades attached to it. The stirring is done in the aspirator bottle in order to maintain a homogeneous mixture during the test. The stirring should be done without fail to get accurate results. Important features of diesel and H_2O_2 blend fuel are: i). results in substitution of depleting fossil fuels, ii). Due to introduction of H_2O_2 into combustion chamber results in fall of peak temperatures further results in reduction of NOx, iii). No major modification to engine is required, iv).Results in higher thermal efficiency and very low smoke level, v). OH radicals are produced when water is introduced near a flame this suppresses NOx levels due to chemical kinetic effects.

Table 2: Engine Specifications

Type	Single cylinder, 4-stroke, direct injection, CI
Cooling	Water cooled
Bore	80 mm
Stroke	110 mm
CR	16.5:1
Rated speed	1500 rpm
Rated Power	3.7 kW

Experimental test procedure followed in this work starts with warming up the engine using test fuel from the fuel tank. The required engine load percentage is adjusted by using dynamometer. Instrument readings for a particular test case are recorded after a sufficiently long time that ensures steady state engine operation.

Figure 1: Photograph of the experimental setup

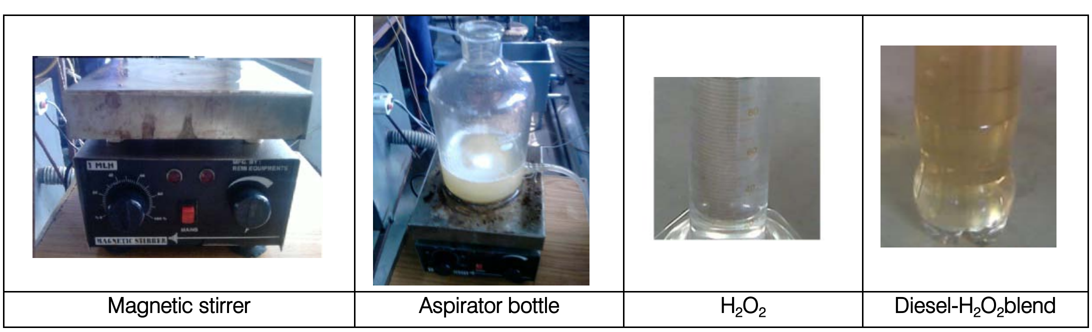

Figure 2: Photograph of magnetic stirrer set up for Diesel-H_2O_2 mix

III. Results and Discussion

The engine was operated with diesel and H_2O_2 blends. The experimental data presented here using appropriate graphs.

a) Specific fuel consumption (SFC)

The variation of brake specific fuel consumption (kg/Kw.hr) with load different blends of hydrogen peroxide with diesel is presented in Figure 3. For the fuels tested, brake specific fuel consumption is found decrease with increase in the load. This is due to the higher percentage increase in brake power with load as compared to the increase in fuel consumption. Fig.3 shows the fuel consumed for different fuels, D85H15 (15% H_2O_2) fuel shows least fuel consumption compared to other blends and diesel.

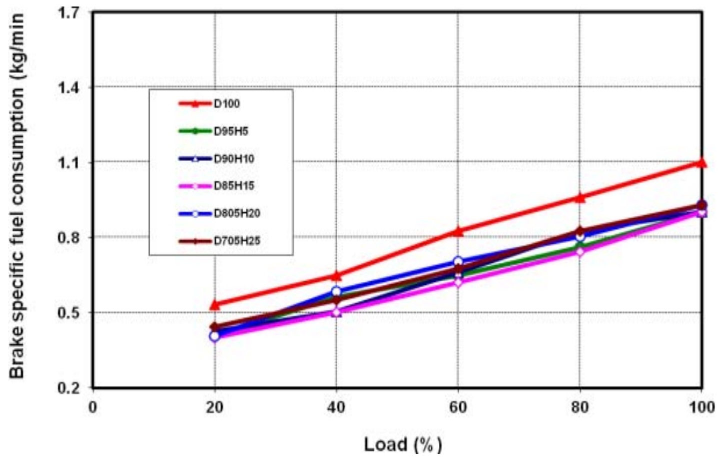

Figure 3: Brake specific fuel consumption with load

b) Brake Thermal Efficiency

Figure 4 shows the variation of brake thermal efficiency (BTE) with load for different blends of hydrogen peroxide with diesel. From Fig.4, it is observed that, BTE increases with increase in load for all the fuels. The break thermal efficiency $D_{85}H_{15}$ (15% H_2O_2) is higher compared to other blends and diesel. It is found that as the concentration of hydrogen peroxide is increased, the brake thermal efficiency of the engine has increased. The hydrogen peroxide which is present in the diesel fuel starts decomposing and releases very large amount of oxygen. This oxygen is helpful to reduce the ignition lag as well as assist the complete combustion of the fuel.

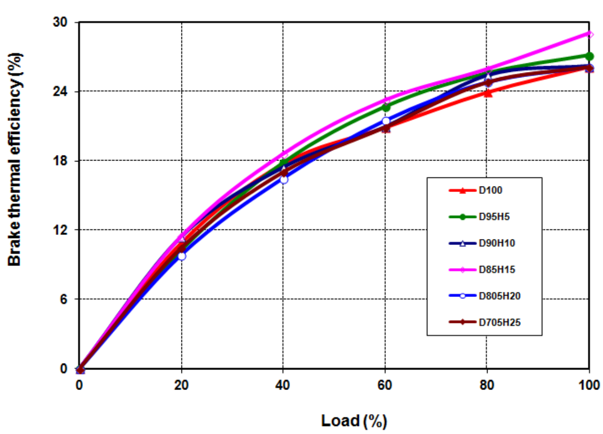

Figure 4: Brake thermal efficiency with load

c) Mechanical Efficiency

To determine mechanical efficiency (ME), initially friction power was estimated based on Willan's line method [6]. Figure 5 shows the variation of mechanical efficiency with load for different blends of hydrogen peroxide with diesel. The trends showed an increase in efficiency with load, similarly increasing for all the fuels considered. All the blends shown close to the neat diesel operated engine.

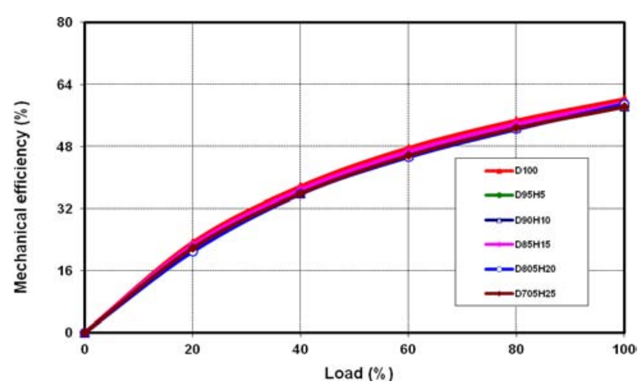

Figure 5: Mechanical efficiency with load

d) Exhaust Gas Temperature (EGT)

The variation of exhaust gas temperature with load for different blends of hydrogen peroxide with diesel is shown in Fig.6; it is observed that with increasing load the temperature of the combustion chamber increased as expected. The rise in temperature is less for blend fuel due to content of H_2O_2; the

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dissociation of H_2O_2 decreases the temperature in the combustion chamber resulting in least exhaust gas temperature. From Fig.6; it is observed that the EGT is lower with 15% H_2O_2 blend compared to neat diesel. As the concentration of hydrogen peroxide is increased, the exhaust gas temperature of the engine decreased. This happens due to additional oxygen molecule released by hydrogen peroxide that leads to better combustion. The lowest value of exhaust gas temperature has found with 15% of hydrogen peroxide with diesel. Also, decrease in exhaust gas temperature with blends of hydrogen peroxide with diesel fuels, which is indication of reduction in NOx [3]

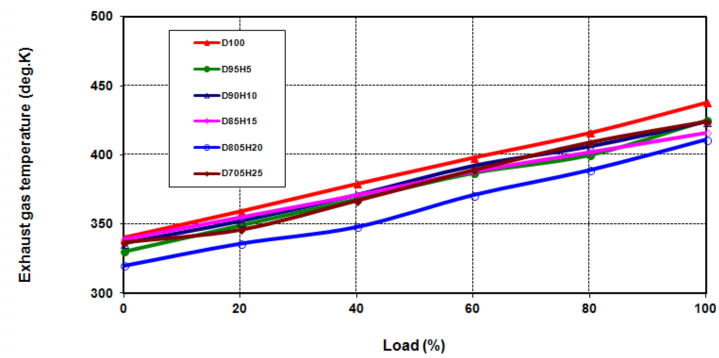

Figure 6: Exhaust gas temperature with load

e) Volumetric Efficiency (VE)

The variation of volumetric efficiency (VE) with load for different blends of hydrogen peroxide with diesel is shown in Fig.7. It is observed that there was no significant change in the volumetric efficiency throughout operating range concerning to individual fuels tested, which is good agreement with Anand et al [6].

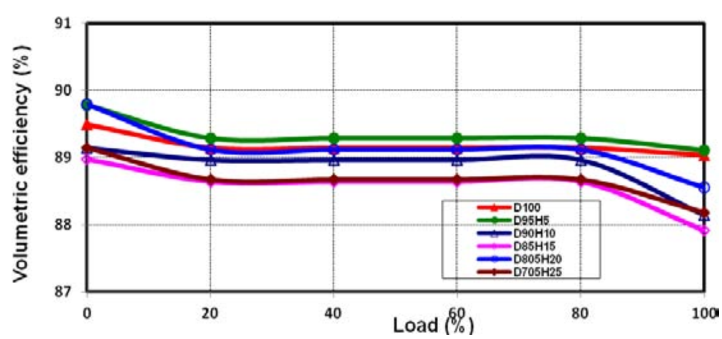

Figure 7: Volumetric efficiency with load

f) Smoke

For CI engines, the most important pollutants are smoke and NOx as it was stated earlier. The variation of smoke emissions with load for different blends of hydrogen peroxide with diesel is shown in Fig.8. From this, it was observed that the smoke emissions were increased with increase with load. Further, with 15% blend of hydrogen peroxide is less with neat diesel.

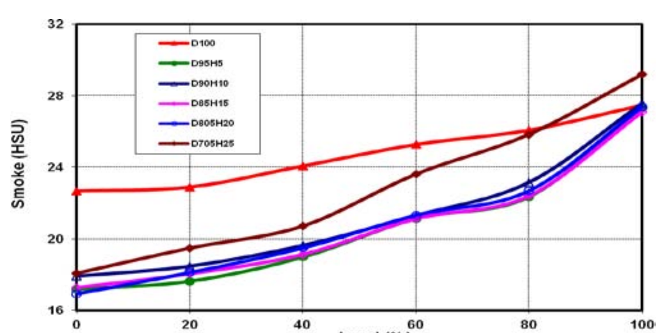

Figure 8: Smoke with load

IV. Conclusion

The following conclusions were derived from the experimental investigation over different blends of hydrogen peroxide with diesel on single cylinder Diesel Engine.

- D85H15 shown reduction in BSFC, Exhaust gas temperature, Smoke and increase in BTE in comparison with neat diesel operated engine.
- Based on experiments, it is concluded that D85H15 as an alternative fuel for existing conventional diesel engines without any major modifications.

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Theoretical and Numerical Analysis of Anterior Cruciate Ligament Injury and its Prevention

By Lixiang Yang
University of Cincinnati

Abstract- Anterior cruciate ligament (ACL) injury is one of major risks for most athletes. ACL injury can be caused by many risk factors such as anatomic risk factors, biomechanical risk factors and environmental risk factors. In this article, numerical and theoretical analysis is conducted to investigate biomechanical risk factors. An entire three-dimensional finite element knee model is built based on MRI data. Anterior Tibial Translations (ATT) at different knee flexion angles are simulated by finite element models. In the simulations, more attention is given to material properties of different knee components and their effects on ACL injury. Mechanical response of ACL during sport activities is highly determined by its viscoelastic properties. Unfortunately, viscoelastic properties of two bundles of ACL will change dramatically even with several hours' physical aging. As a consequence, ACL will experience mechanical ductile to brittle transition due to daily physical aging. Theory of physical aging from polymer science is, for the first time, introduced to understand ACL injury and its prevention. By analogy to physical aging of amorphous polymer materials, we think physical aging of two bundles of ACL will largely increase risk of ACL injury. Besides, physical aging will also build a heterogeneous stress and strain in ACL due to its natural anatomic structure, which is a large risk for athletes. The specific designed prevention programs for ACL injury such as plyometrics, strengthening and other neuromuscular training exercises [1] are believed to erase physical aging of ACL. ACL with less physical aging is less likely to get injured in sport activities. In this article, a virtual physical aging simulation is built to validate current hypothesis. Erasing physical aging of ACL may provide an accurate and quantitative way to prevent ACL injury.

Keywords: *ACL injury; Viscoelasticity; Physical aging; Prevention; Sports.*

GJRE-J Classification: *FOR Code: 091599*

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Keywords: ACL injury; Viscoelasticity; Physical aging; Prevention; Sports.

I. Introduction

There are more than 80,000 anterior cruciate ligament (ACL) tears annually in the United States. 70% of the injuries are the result of sports participation. An investigation of knee injuries in Iranian male professional soccer players shows that anterior cruciate ligament is the most commonly injured ligament of the knee [2]. A review of physical profiling for lacrosse players in the United States shows ACL injury is one of the most common injuries [3]. Global positioning systems (GPS) wearable technology was suggested to monitor athletes' physical profiles in sport fields. For volleyball players, a recent survey [4] shows ankles and knees are the most likely injury areas. Among all ligaments of knee, ACL is most likely to get injured. ACL injury can be caused by many risk factors. They can be listed as environmental risk factors, anatomic risk factors, and biomechanical risk factors [5]. Environmental risk factors include knee braces effect, shoe and surface interaction and so on. Anatomic risk factors include the differences in femoral notch and ACL size, joint laxity, hip-trunk position and muscle development. Biomechanical risk factors are related to neuromuscular control and proprioception in joint stability. All these risk factors can lead to high stress and strain in ligaments. If strain and stress built on ACL during sport activities are higher than that ACL can bear, ACL will be torn apart.

Many experiments and virtual simulations have been performed to understand knee injuries, especially ACL injury [6][7][8][9]. Although these research efforts have yielded much information, they have not resulted in a clear understanding of the cause of ACL injuries. Detail review of researches on ACL injury mechanics and mechanical properties of ACL was given by McLean et al [10].In the past several decades, studies of knee injury were mostly from anatomy aspects, for example, muscles, cartilage and tibia and femoral notch [11]. Recently DS Simulia Inc. built a whole knee simulator add-on in Abaqus to consider impacts of all kinds of anatomy components [12].

Besides anatomical effects, mechanical characterization of knee ligaments will be an important factor to understand knee injury. Stress and strain relationships for knee ligaments have been built for more than two decades. Since ligaments and tendons contain collagen fibrils, elastin, proteoglycans, glycolipids, water, and cells, mathematical modelling of mechanical behaviour of ACL is still in its infancy. Because of its complex components, mechanical behaviours of ACL need be modelled as anisotropic nonlinear materials. Recently Marchi et al. [13] built a hybrid constitutive model for medial collateral ligament (MCL) by superposing a slightly compressible, isotropic eight-chain Mackintosh network model with a phenomenological directional component. Since many knee injuries happen when attending sports, time dependent mechanical properties of ligaments cannot be ignored. Ligaments are normally under high speed stretch or twist when a football player jumps and falls on

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the ground. Time dependent property of ACL is usually modelled as viscoelasticity, a combination of time independent springs and time dependent dashpots. Therefore, viscoelasticity becomes one of the centre topics to understand ACL tearing during sports.

Generally speaking, viscoelasticity is the theory that tell how solid materials flow like liquids. Although it is hard to see by eyes, nearly everything in the world flows. Solid material flows are usually so tiny that no one notices their existence. Mountains flow in millions of years. Metals flow in hundreds of years. Since everything flows, there is no reason to believe human being's tissue is not flowing. The evidence of tissue flow can be seen by comparing kid's smooth face and old man's wrinkled face. Natural aging of human beings from baby age to the aged is related to how bio-tissues degenerate from elastic state to plastic state. Mechanical behaviours of tissues and bones are changed from ductile state to brittle state permanently during person's entire life [14]. This entire life aging from elastic state to plastic state is irreversible. However, physical aging which happens daily on ACL can be reversed due to its short time aging. This inverted process is related to exercises such as stretching and cyclic movements of arms and legs. Therefore, we will see daily exercises have a potential function to delay human being's getting older.

There is a long history to apply viscoelastic theory to understand mechanical behaviours of human tissues. Fung [15] is one of the pioneers who firstly formulated Quasi-Linear Viscoelasticity (QLV), which combines elastic and time dependent components of a tissue's mechanical response using a hereditary integral formulation. By inputting hyper-elastic model [16] into linear viscoelasticity model [17], QLV can model strain stiffing behaviour as well as time effects of many soft tissues [18]. QLV model has also been used to understand mechanical behaviours of ACL [19]. However, for lots of tissues, viscosity is a function of applied strain level which limits the application of QLV [20]. For instance, ACL is a double-bundle anatomic structure which is made of anteromedial (AM) and posterolateral (PL) bundle. Two bundles show very different time-dependent properties in daily stress-strain range [19]. Compared to PL, mechanical response of AM bundle is much stronger since it has a more uniform collagen alignment. Accurately measuring ACL viscoelastic property is challenging because of its two bundle structures and heterogeneous strain-stress distribution during tension tests. Mechanical properties of ACL should be modelled as nonlinear viscoelastic models where relaxation time and relaxation modulus are not constant during its deformation. However, no widely accepted nonlinear viscoelastic model can be used. Today, Quasi-linear viscoelastic model is still widely used although it is still based on linear viscoelastic theory. Recently a new mathematical stress-strain framework was built for amorphous polymers [21]. It can be used to model mechanical behaviours of soft tissues. Nonlinear viscoelasticity and hyper-elasticity models were illustrated by a single mathematical equation. Physical aging of ACL can be added into this model too. Unfortunately, during past several decades, physical aging has been ignored by most if not all researchers when they conducted researches on measuring viscoelastic properties of ACL. Physical aging of ACL means its viscoelastic properties will be shifted with aging time if let ACL rest for several minutes or hours. Accuracy of measured viscoelastic properties of ligaments or tendons without considering physical aging is questionable. Measurement with physical aging considered provides a new approach to study nonlinear viscoelasticity of bio-tissues such as ligaments.

In the following three sections, we will have an extensive discussion of ACL injury from numerical and theoretical perspective. In the first section we will introduce numerical modelling of ACL by finite element analysis. A full three dimensional knee model is built and run by using a commercial finite element code, Abaqus. Most of the simulation works are to understand material property effect of each knee component on ACL injury under anterior tibial translation. In the second section, limits of finite element analysis of ACL injury will be briefly discussed. In the last section, theoretical analysis of ACL injury will be discussed based on physical aging and viscoelastic theory. It will be demonstrated that initially built-in stress on ACL due to physical aging is a big risk for ACL injury. ACL injury prevention is related to erasure of initial stress on ACL. Finally, a conclusion is given at the end of the article.

Figure 1: Sketch of three dimensional finite element model of entire knee

II. Finite Element Analysis of ACL Injury

In order to understand mechanism of ACL injury, a complete virtual knee model was built. In this finite element model, most knee joint components such as lateral meniscus, medial meniscus, tibia, tibial cartilage, femur, femoral cartilage, anterior cruciate ligament, lateral collateral ligament, medial collateral ligament, patella, fibula, fibula cartilage are included. Two dimensional geometries of knee components are got from MRI segmentations. These MRI pictures are imported into a commercial image processing software, Mimics, to get 3D geometry. Singular points on the surface of geometry during 3D model generation are removed by using smoothening process in Mimics. After smooth 3D geometries of all components are created in Mimics, they are imported into Abaqus. Assembling of all ligaments, bones, cartilages and so on is conducted in Abaqus. Assembled three dimensional finite element model is shown in Fig. 1.

Mechanical responses of different components are modelled as different material constitutive models. For bones such as femur, tibia and fibula, linear elastic materials are used. ACL is modelled either as isotropic or anisotropic hyperelastic models [22] [23]. PCL is modelled by using Arruda-Boyce model [24]. Anisotropic hyperelastic statistical mechanics model [25] is used for constitutive relationship of femoral and tibial cartilage. A user subroutine VUMAT is written based on this nonlinear anisotropic material model. Linear viscoelastic model is used for material properties of meniscus [26]. It is well known that mechanical responses for different areas of tibial and femoral cartilages are not uniform. In this simulation, if the same material model is assigned to all sections of cartilages, it is called homogeneous model, shown on the left side of Fig.2a. If different sections of cartilages are assigned with different material properties, it is called heterogeneous model which is shown on the right part of Fig.2a. For heterogeneous cartilage, 21 regions are used for tibial cartilage and 29 regions are assigned with different materials for femoral cartilage. Homogeneous cartilage and heterogeneous cartilage are assembled with other knee components in Abaqus, shown in Fig 2b.

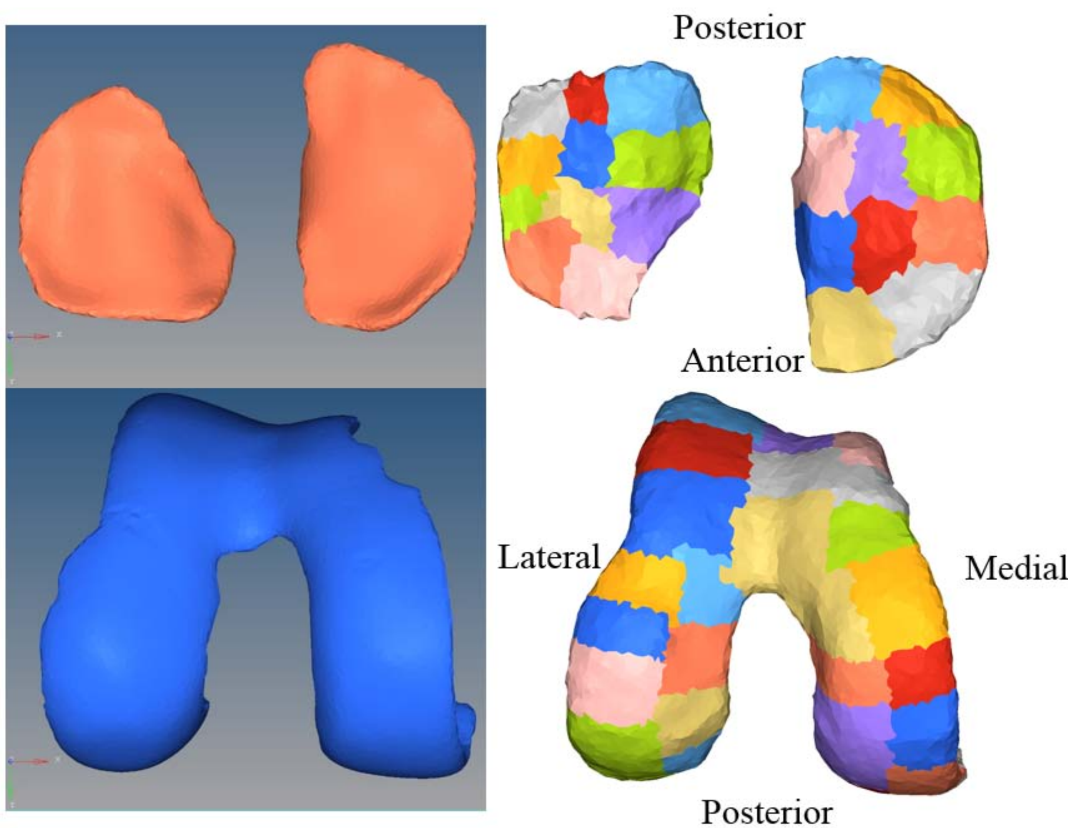

Figure 2a: Comparison of homogeneous cartilage (left) and heterogeneous cartilage (right) partition

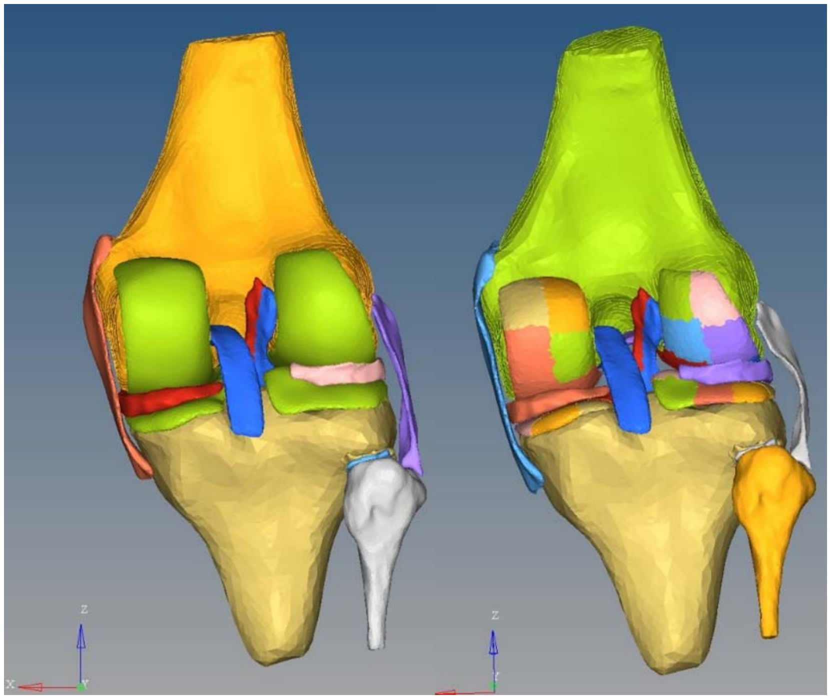

Figure 2b: Complete knee model with homogeneous cartilage (left) and heterogeneous cartilage (right)

One of key reasons that causes ACL injury is ATT. ATT will create a relative movement between femur and tibia. Velocity and acceleration due to this movement will build up a large strain and stress on ACL. In this numerical study, we will focus on modelling knee impact due to ATT. Simulation is performed in two steps. In the first step, femur is rotated by 30 or 45 degree related to tibia as shown in Fig. 3. In the second step, using the results from the first step, a 3g loading is applied to the top of femur which will create ATT. Simulations show ATT will not only create translations but also create certain rotations between femur and tibia. As a consequence, ACL will gain a large stretch force due to this translation. Shear and tensile strain will be built on ACL.

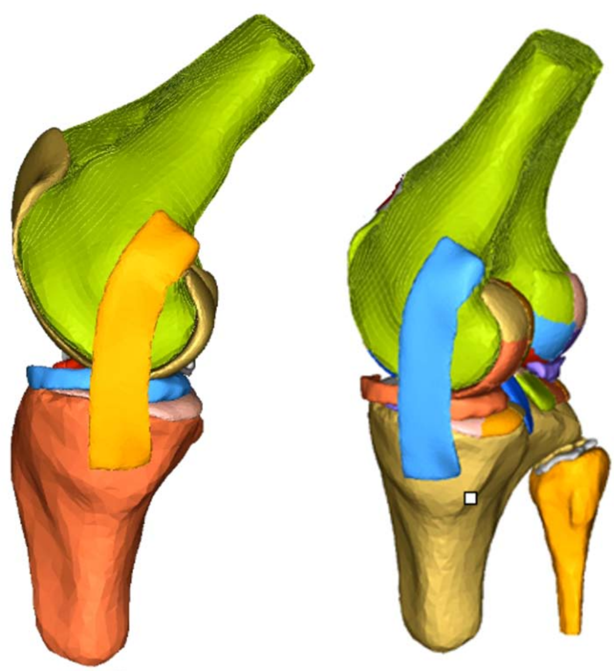

Figure 3: Sketch of 45 degree (left) and 30 degree knee (right) flexion angles before ATT is applied

Shear strain profile is shown in Fig. 4a for 3g loading when femur and tibia are in 30 or 45 degree flexion angles. The largest shear strain will happen at the end of ACL near to femur. Compared to maximum shear strain 18.4% in 30 degree angle, maximum shear strain for 45 degree angle is 24.1%. Shear strain around middle of ACL is small for both cases. The highest value near the centre of ACL is 7.5%.

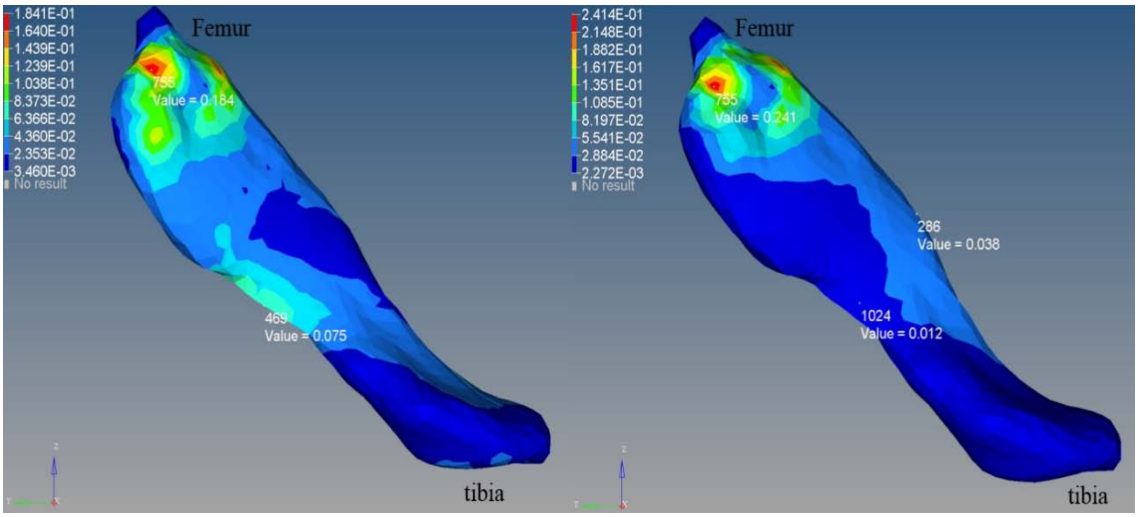

Figure 4a: S Shear strain in ACL upon 3g loading at 30 (left) and 45 (right) flexion angles

Tensile strains from 30 and 45 degree cases are comparable, as shown in Fig. 4b. They are following the same trends as shear strain profiles. The highest tensile strain happens at the end near to femur side. Maximum tensile strain in 30 degree, 11.9%, is comparable with that in 45 degree, 10.9%. At the centre part of ACL, tensile strain is 7.2% for 30 degree and 2.4% for 45 degree knee flexion angle.

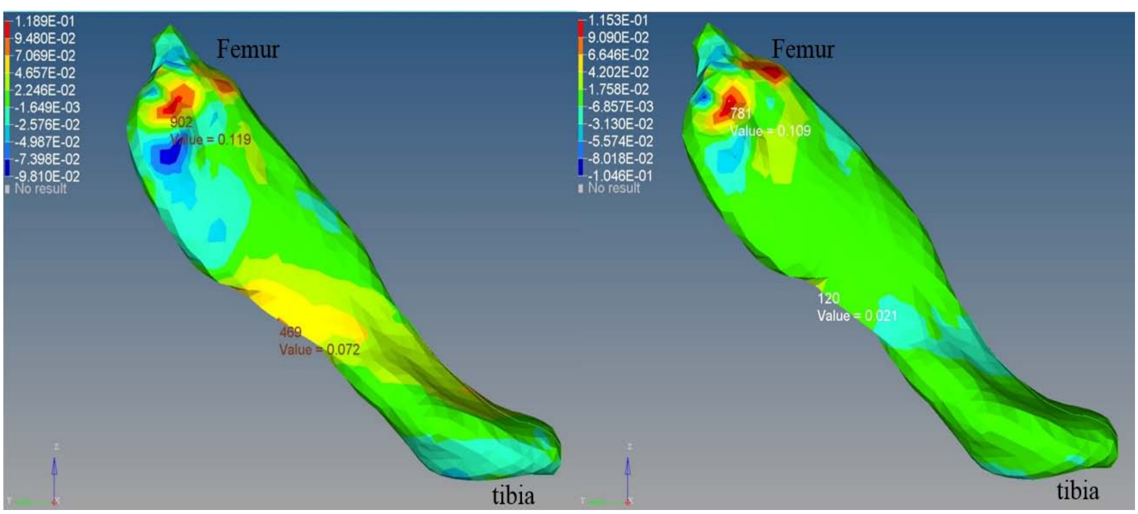

Figure 4b: Tensile strain in ACL upon 3g loading at 30 (left) and 45 (right) flexion angles

Since soft tissues such as femoral cartilage and tibial cartilage are generally heterogeneous, it is necessary to understand how heterogeneity affects ACL injury. In Fig. 5a and Fig.5b, tensile strain and shear strain profiles are compared for homogeneous and heterogeneous cartilage effects on ACL injury upon 3g loading impact. As shown in Fig. 5a, tensile strain in the center of ACL increases 30% in heterogeneous cartilage case where 7.2% for homogeneous cartilage and 9.7% for heterogeneous cartilage. For both cases, tensile strain near the end of femur side is 12%. Comparing to homogeneous case, shear strain in heterogeneous case has a dramatic increase in both middle and end part of ACL, as shown in Fig.5b. It increases from 18.4% to 40.8% at the end of ACL near to femur and 7.5% to 10.8% in the middle section of ACL. In general, after replacing homogeneous cartilage with heterogeneous cartilage, shear strain and tensile strain in ACL will increase from 30% to 110%.

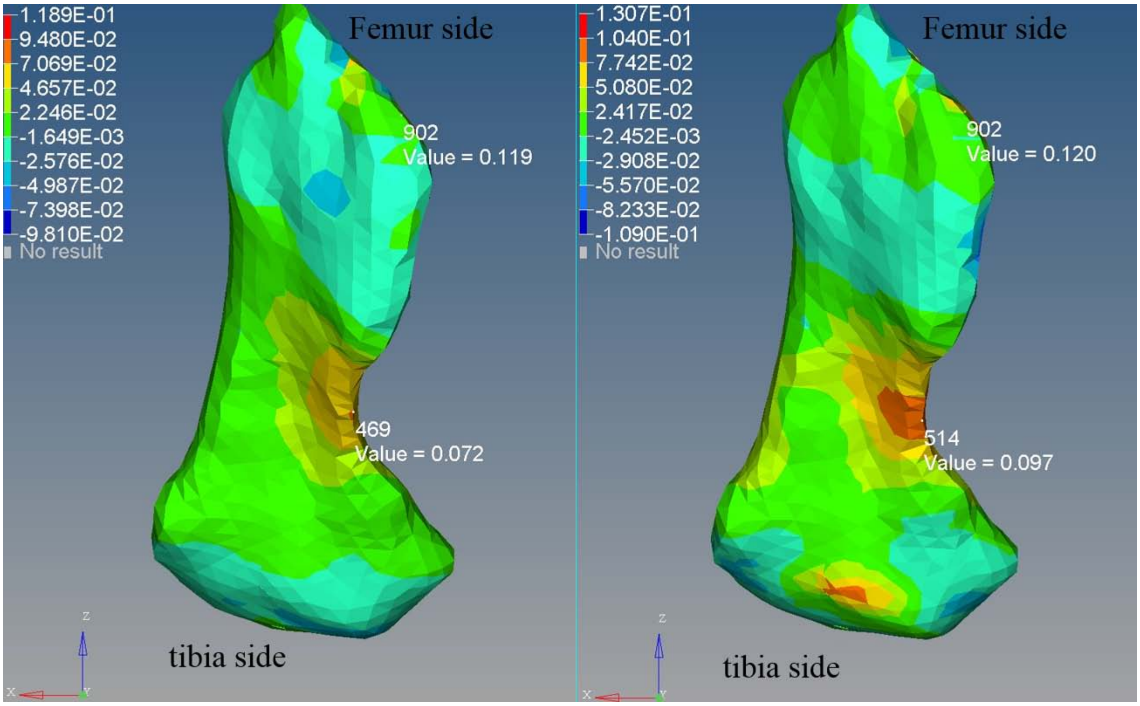

Figure 5a: Tensile strain in ACL for homogeneous (left) and heterogeneous cartilage (right) upon 3g loading

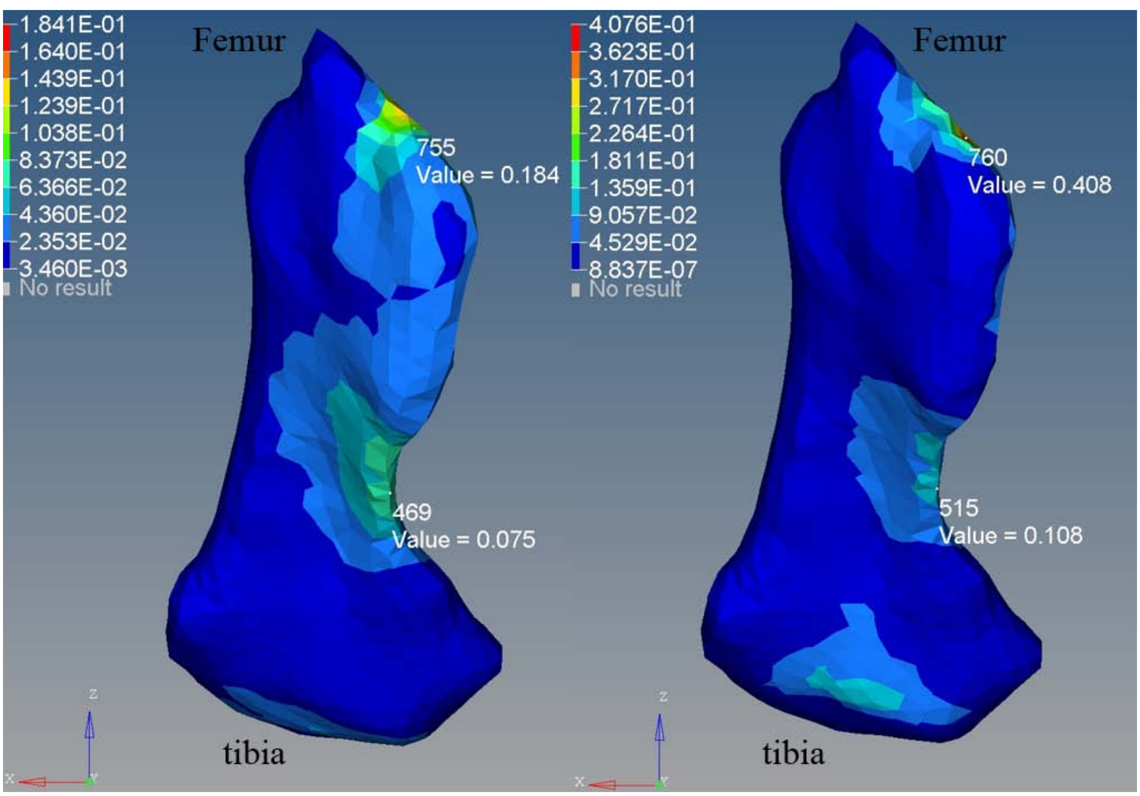

Figure 5b: Shear strain in ACL for homogeneous (left) and heterogeneous (right) cartilage upon 3g loading

III. Limitation of Finite Element Analysis of Knee Injury

Finite element analysis has been continuously used to understand ACL injury during sport activities. One reason is that knee injury experiments can only be conducted by using deceased animal knees. But animal knee structures are very different from human beings'. Therefore, finite element analysis becomes an excellent alternative way to understand physics behind ACL injury. In finite element analysis, geometry can be easily changed. Material models can be selected for different knee components based on experimental material characterizations. Impact analysis as well as static analysis can be performed based on study interests.

One advantage of finite element analysis is to handle very complex geometry structures. However, in knee injury analysis, since geometry is from MRI or CT scans, it is hard to get perfect geometry shape of ligaments, especially the connection area between ligaments and bones. A little difference in ACL shape can have a large impact on simulation results. The assembly of each knee component is also not perfect. In Abaqus, usually tie constraint is applied to connect different knee components. Two surfaces such as master surface and slave surface need be selected to connect to each other using tie constraint. Selection of nodes on the surfaces is mostly based on researchers' experiences. Different connection will largely affect accuracy of stress and strain in ACL. Another issue related to ACL geometry is that its two bundle structure cannot be modelled well. In reality, AM and PL bundles intertwine with each other. In MRI or CT scans, it is hard to tell which is which. Therefore, in the simulation, AM and PL bundles are modelled as a single piece and material properties are assigned to each of them based on stress-strain curves from experiments. This treatment will introduce additional deviation from real ACL geometry.

Material properties are another concern in modelling ACL injury by using finite element analysis. Material models for soft tissues are mostly taken from other research areas such as polymer mechanics and solid mechanics. Many material models are originally built for certain applications and certain materials. But they have been extensively used to study soft tissues with parameter fitting. It is often questionable whether these material models can be used for soft tissue analysis. To model anisotropic, nonlinear, time and temperature dependent mechanical response of soft tissues is still a challenge problem. Current material models such as hyperelastic model, linear viscoelastic or combination of these two may be the most choices for many soft tissue structure simulations. However, not only do complex mathematical structures of these models limit their usage, but also these models cannot fully capture physical behaviours of soft tissues. The reason why most researchers use these material models is because they are the only choices. Therefore, new material models for soft tissues need be built based on new mathematical structures. Currently the model built by Yang [21] is a good candidate material model which break up traditional material model framework. Anisotropic and hyperelastic property was illustrated by a novel and simple mathematical framework. Nonlinear viscoelastic effect is simply modelled by time dependent Young's modulus.

Another concern about material properties of soft tissues is their heterogeneity. Experimental characterizations of material properties of soft tissues are very limited. Most experimental methods can only get homogenous stress-strain relationship. However, based on high speed camera observation, during tensile tests, stress and strain distributions on ACL are not uniform [27]. This inhomogeneous stress and strain also happen on cartilages. Usage of a single material model for all potions of ACL or cartilages will introduce additional errors to simulation results.

Regarding stability of finite element analysis, in explicit dynamical analysis, time derivative is mostly discretized as central difference method. This numerical method is conditional stabilized. Time increment must be smaller than critic time increment to get physically accepted solutions. In Abaqus simulations, it is hard to calculate this stable time increment due to geometry nonlinearity, material nonlinearity, and contact nonlinearity. Simulation is easily abort due to stability or element distortion. To fix this stability issue is mostly based on investigators' personal experiences. Finite element stability of ACL modelling is also limited by contact between cartilage and meniscus. Contact penetration is one of main reasons leading to simulation failure. Numerical simulation of contact between soft materials such as cartilages is relate to element size adjusting, contact penalty setting, contact type and contact coefficient, and so on. It is time consuming and involves tremendous trial and errors to solve the problems.

In terms of numerical error of dynamical finite element analysis, numerical error will come from both time discretization, space discretization and artificial damping introduced to the model. It was suggested to use quadratic hexahedra element or quadratic tetrahedral element instead of linear tetrahedron element for static, contact and modal analysis [28]. Enhanced quadratic tetrahedral element is promising in terms of contact analysis and computational time [29]. However, it isn't proved that linear tetrahedron element is not good for explicit dynamic analysis. For high performance computation, numerical models are usually decomposed to many computational domains and assigned to different CPUs. Domain decomposition decreases computational time but introduces inconsistent results. That is, geometry shapes of deformed structures are not always consistent when a model is computed with different numbers of CPUs.

Another important limitation of finite element analysis of knee injury is that it is incapable to simulate physical aging and initially built-in stress and strain in ACL. We will talk this subject in the next section.

IV. Brief Introduction to Physical Aging of Polymers and ACL

People noticed physical aging firstly when studying amorphous polymers. In glass, and under isothermal conditions, volume of polymers evolve continuously towards their equilibrium value. During this volume evolution mechanical properties of polymers also change. It is the change in mechanical properties during this volume recovery that has come to be known as physical aging. The fundamental study of physical aging of amorphous polymers and other materials is to understand non-equilibrium glassy state, the molecular scale rearrangements, and how this relates to structural relaxation, which will not be discussed here.

To best of author's knowledge, physical aging of ACL has never been studied. However, physical aging of polymers has been investigated during past several decades. Due to lacking of studies of physical aging of tissues, this section is based on former studies of physical aging of polymers. Analogy between tissues and polymers is based on that both of them have macromolecular chain structures. For bio-tissues, actin is the most dominated protein filament in eukaryotic cells. It forms the cytoskeletal rim. This actin cortex is a polymer gel that provides mechanical supports to cells, and has an important impact in cell motion [32]. Actin forms viscoelastic network. Its basic viscoelastic properties were studied based on Mackintosh chain model. But physical aging of actin was never studied before. Based on this microscopic analogy between amorphous polymers and soft tissues, therefore, it is reasonable to assume physical aging of ACL is similar to that of polymers. In amorphous polymers, physical aging happens between glass transition temperature (α peak) and second relaxation peak (β peak) [33]. Ductility will decrease with physical aging. Physical aging of amorphous polymers is explained by free-volume concept. Transport mobility of particles in a closely packed system depends on the degree of packing on the free volume. After a polymer is cooled to some temperature below glass transition temperature, the mobility will be small, but not zero. This non-zero mobility will cause free volume inside polymers to gradually decrease to an equilibrium value. This non-zero mobility largely dominates viscoelastic property shift. On the other hand, it is widely accepted that ACL is a viscoelastic material. Mathematical representation of physical aging of ACL is given as a shift of relaxation modulus, shown in Fig.6, where α_E, t_R, t_e are horizontal component of shifts, reference aging time, current aging time respectively. As shown in the figure, physical aging shifts relaxation modulus horizontally to the right where relaxation time will be increased.

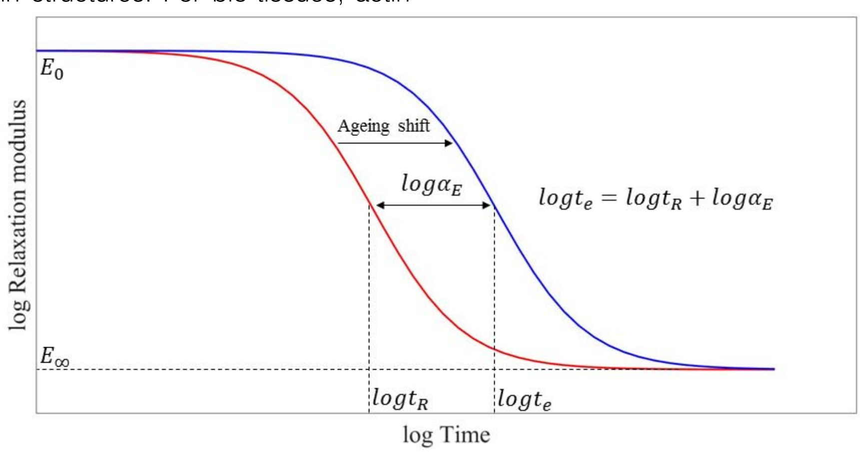

Figure 6: Schematic illustration of relaxation modulus of ACL with the aging shifts.

During this shift, relaxation modulus will become much stiffer than that before physical aging. During sport games, ACL movements of athletics usually happen in less than one second. Short time relaxation modulus will have a big impact on stress changes on ACL. As shown in Fig. 6, stiffening of ACL modulus due to physical aging will make ACL less ductile and have less flexible deformation before torn.

It is shown [30] that the double-logarithmic shift rate, μ is constant over wide ranges of aging time, t_e for most amorphous polymers. μ is defined as $\mu = -\frac{d\log \alpha_E}{d \log t_e}$,where α_E is the shift factor. This shift factor is almost unity up to glass transition temperature and will shapely decrease to 0 when temperature is higher than glass transition temperature. But there is no experimental data reported for ACL.

Regardless, for ACL, physical aging effects on other mechanical properties such as brittleness, Young's modulus, yielding stress, and modulus of resilience and toughness were rarely studied before. If physical aging happens, modulus of resilience and modulus toughness will become small. Therefore, less elastic strain energy can be absorbed by ACL before fracture starts. Ligaments will become brittle the same as aged polymer. Simultaneously, after several hours physical aging time, stress initially built on ACL will continue to develop.

V. Erasure of Physical Aging Induced Initial Stress on ACL

It was generally accepted that two bundle anatomic structures of ACL, the anteromedial bundle (AMB) and the posterolateral bundle (PLB), are time dependent materials or viscoelastic materials. Their viscoelastic properties such as relaxation time and relaxation modulus can be changed with aging time. It is well known that ACL is always loaded in any anatomical position [10]. There is no anatomical position that no stress is built on ACL. Therefore, initial stress in ACL will relax to its equilibrium state with time based on viscoelastic theory. During this ACL stress relaxation, unevenly distributed stress will build on two bundles of ACL with physical aging time. This stress is not homogeneous and will lead to certain high stress concentration areas which will largely increase ACL injury risks when athletes play football, basketball, baseball, soccer or other sports.

The other point that physical aging interests us for studying ACL injury is because physical aging of ACL can be removed by high level mechanical deformation and large mechanical stress. Particularly, in sports, warming up activities such as cyclically stretching legs and bending of knees before soccer or other games will create these high level mechanical deformations and stresses. As a consequence, these activities will remove physical aging and in turns to remove initial heterogeneous built-in stress and strain on ACL. Prevention programs such as plyometrics and strengthening are related to creating high level stress and strain in ACL in relatively slow stretch speed. Then initial stress concentration can be removed by these prevention programs. When athletes attend specific designed prevention programs for ACL injury before sports [31], physical aging effects of ACL are erased by high level stretch stresses to some degree. Actually stretching is an effective way to erasing physical aging, for example, calf stretch, groin stretch, and hamstring stretch. Muscle soreness and cramping can be reduced or eliminated by daily exercises. Activities such as dance, martial arts (aikido or karate), tai chi, or yoga are programmed stretches which are designed to reduce physical aging of bodies.

Historically, Struik [30] was the first to remark on what he referred to as erasure of physical aging due to the application of large deformations to a polymer sample. This apparent reversal of physical aging due to large mechanical or other stimulus has also been studied in structural glasses, colloidal systems, ferroelectric relaxors and spin glasses.

How physical aging can be erased by high level stress stretch is illustrated by Fig.7. Red solid line shows relaxation modulus at high stress without physical aging. Red dash line shows relaxation modulus of the same material at low stress without physical aging. If let both of them age for the same time, red line will shift to blue line and red dash line will shift to blue dash line. It is shown that a material under high stress is less likely to get physical aging. If we look at the curves in a different way, red dash line (low stress without physical aging) is shifted horizontally to the right a big amount of distance and become blue dash line (low stress with physical aging). At this moment, if stress in this material is raised to a higher level, the blue dash line will shift back to the left and become the blue solid line where the material is under high stress with most physical aging effect erased. As shown in the figure, the material becomes less stiff and more ductile after physical aging effect is erased.

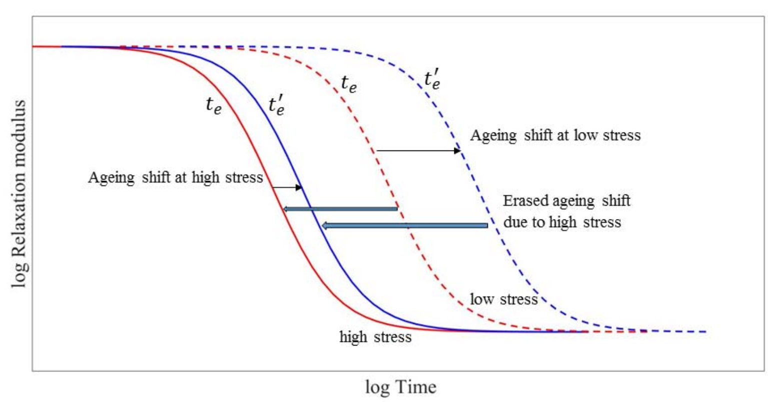

Figure 7: Schematic illustration of effects of physical aging and high stress effects on relaxation. t_e and t_e' are two different elapsed times.

VI. Numerical Modelling of ACL Stress Caused by Physical Aging

In this demonstrated example, ACL is virtually modeled by using finite element model, Abaqus 2016. It is to demonstrate how stress will change in ACL when physical aging happens. Real anatomy structure of ACL is very complex in shape and orientation. Anatomically, two bundles of ACL wrap about each other and vary in length and mechanical property. AM bundle averaged 39 mm in length. Its cross section is given as 5.1_0.7 mm in sagittal width, and 4.2_0.8 mm in coronal width. PL bundle, by contrast, is averaged 20.5_2.4 mm in length, 4.4_0.8 mm in sagittal width, and 3.7_0.8 mm in coronal width [11]. Based on this anatomy knowledge, a simplified geometry model of ACL is built for simulation. AM will be modeled to be 39 mm length and PL 20.5 mm length. They are attached to each other.

Material properties of ACL are adapted from literature. Linear viscoelastic model will be used for each of two ACL bundles. Standard linear solid model is used to fit the experimental data by Castile et al[19]. As shown in Fig. 8, stress relaxation happens in a very short time. The short term and long term moduli of AM are much stiffer than those from PL. In this simulation, physical aging will be modeled by shifting the relaxation curve to the right. Approximated shift factor is assumed be one for simplicity.

To proceed, ACL is pulled away by 8 mm for both sides in two seconds and relaxed for 5 seconds. Then ACL is let to age for some time by letting mechanical properties of AM and PL shift to the right. In this calculation, we assumed that relaxation time for both AM and PL increases 10 times due to physical aging where short term and long term moduli remain unchanged. Physical aging simulation starts at the time when original relaxation simulation is completed. Initial condition of physical aging simulation is then imported from original relaxation simulation with relaxation time changed. Stress comparison of two bundles of ACL before and after physical aging is shown in Fig. 9. Compared to original ACL, higher stress is created on both AM and PL by physical aging. Higher stress area is enlarged after physical aging. Stress near to the end of ACL is also increased. The maximum stress along the ligament direction is increased from 0.626 MPa to 0.7889 MPa because of physical aging. Therefore, in this simple demonstration, physical aging increases the risk of ACL injury. In reality, geometry and mechanical properties of two bundles are much more complex. Two bundles of ACL intertwine with each other. It will be expected more stress concentration areas exist due to physical aging.

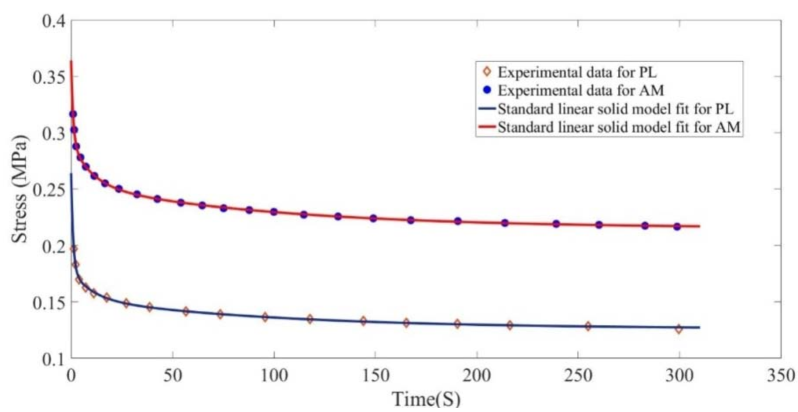

Figure 8: Standard linear solid models are used to fit relaxation modulus curves of AM and PL from experimental data given by Castile et al [19].

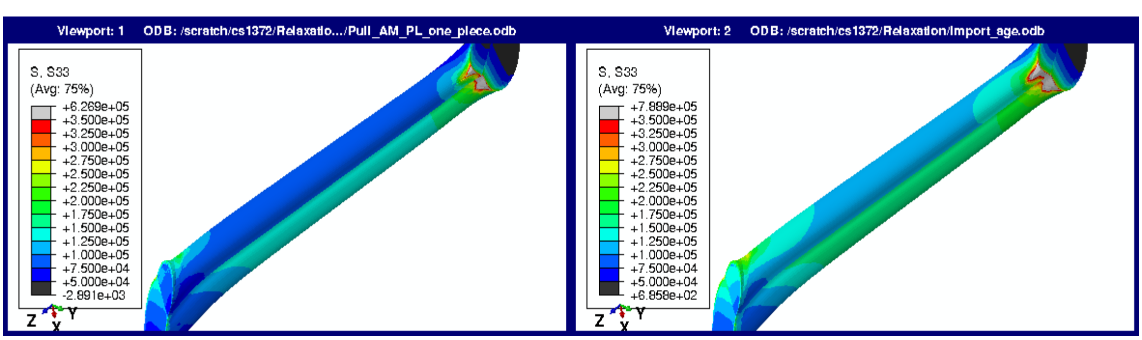

Figure 9: Comparison of tensile stress due to stress relaxation for ACL before physical aging (left) and after physical aging (right) by using finite element analysis.

VII. Conclusion

In this article, numerical and theoretical analysis of ACL injury is conducted. The results from finite element analysis show that ACL will have large shear strain in 45 degree flexion angle when it is under 3g loading, comparing with 30 degree flexion angle. Tensile strain is usually smaller than shear strain in both 30 and 45 degree flexion angles. Tensile and shear strain will increase from 30% to 110% if homogenous cartilage is replaced by heterogeneous cartilage. Since heterogeneity is existed in all kinds of soft tissues, a smoothed material property distribution is suggested to use in the future numerical simulations.

Physical aging of ACL is introduced to understand ACL injury in sport activities. It is shown in the simulation that internal stress on ACL will largely increase due to physical aging. Since physical aging of ACL has never been investigated in experimental and theoretical study before, this article opens a new door to understand ACL injury during sports activities. Unlike the simplified geometry of ACL used in current computation, real ACL anatomy and geometry are more complex. AM and PL are intertwined with each other. After physical aging, stress distribution should be much more heterogeneous than the one shown here. Since mathematical modelling and experimental tests of erasing physical aging of ACL were never attempted before, direct validation of physical aging erasure of soft tissues is not provided. However, it is widely accepted that risks of ACL injuries dramatically decrease if athletes attend specific designed prevention programs for ACL injury such as plyometrics, strengthening and other neuromuscular training exercises. In these programs, ACL will be under slowly loaded high stress state. Physical aging of ACL is believed to be erased and ACL is shifted back from brittle state to ductile state. Since ductile ACL can absorb more energy and brittle ACL is easy to fracture, detail investigations of physical aging caused ductile and brittle transition will be very interesting.

Although finite element analysis is a very promising way to study ACL injury, its usage and validation are limited by nonlinear and time dependent material models, contact analysis, accuracy of geometry, and numerical error accumulations.

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Acknowledgments

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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.

The Editorial Board reserves the right to make literary corrections and suggestions to improve brevity.

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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.

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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.

Numerical Methods

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

Abbreviations

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.

Tables, Figures, and Figure Legends

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

Techniques for writing a good quality engineering research paper:

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.

4. Use of computer is recommended: As you are doing research in the field of research engineering then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

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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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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:

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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.

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Mistakes to avoid:

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- Keep paying attention to the topic of the paper.

- 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.
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- Avoid use of extra pictures—include only those figures essential to presenting results.

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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:

- o Single section and succinct.
- o An outline of the job done is always written in past tense.
- o Concentrate on shortening results—limit background information to a verdict or two.
- o 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:

- o Explain the value (significance) of the study.
- o 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.
- o Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- o 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.

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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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

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