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The Design and Simulation Patterns in Ultrasonic Wedges for Non-Destructive Testing

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Abstract- The design and simulation patterns in ultrasonic wedges for non-destructive testing are critical to the assessment and characterization of a material or structure. Its significance is the mitigation of failures in members. The approach is relevant mostly to non-destructive testing of very expensive and critical mechanical members requiring high level of reliability in operation. In this paper, the design and simulation of ultrasound through both straight and angle wedges are discussed. Also, the characterization of the material using pulse-echo and through-transmission ultrasonic methods is illustrated.

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I. INTRODUCTION

The performance and effectiveness of ultrasonic wedges in non-destructive testing cannot be optimised except appropriate design simulation approach is adopted. Design and simulation of the ultrasound will fix problems of wedge configuration and the interface angle [1]. Ultimately, this approach will enable the simulation of the sound wave into the test sample.

In ultrasonic testing, both longitudinal and shear waves can be transmitted into the specimen. However, refracted shear wave is exploited in angle beam inspection because of its low attenuation [2]. Most importantly, when refracted shear waves are utilized only in the inspection, the refracted longitudinal waves align with the material interface, enabling easy and accurate interpretation of signals [3]. The angle of the incident beam at which the parallel alignment of the longitudinal waves with the specimen surface occurs, is called the first critical angle.

Apart from the benefit of having one wave mode in the sample, the critical angle allows the inspection of sample surfaces such as weldments. For this mode-converted system, the transfer of energy is optimised in steel. Also the defect sensitivity is enhanced in the presence of shear waves [3].

II. WEDGE DESIGN

To optimally design an ultrasonic wedge, some basic specifications must be made. The following are the specifications that were used in the study.

a) Longitudinal waves are refracted into the test sample at 90^0.
b) Wedge is Rexolite with longitudinal sound velocity at 2362.2 m/s.
c) The test sample is made of alloy steel (X90CrMoV18) with shear sound velocity at 2478 m/s.

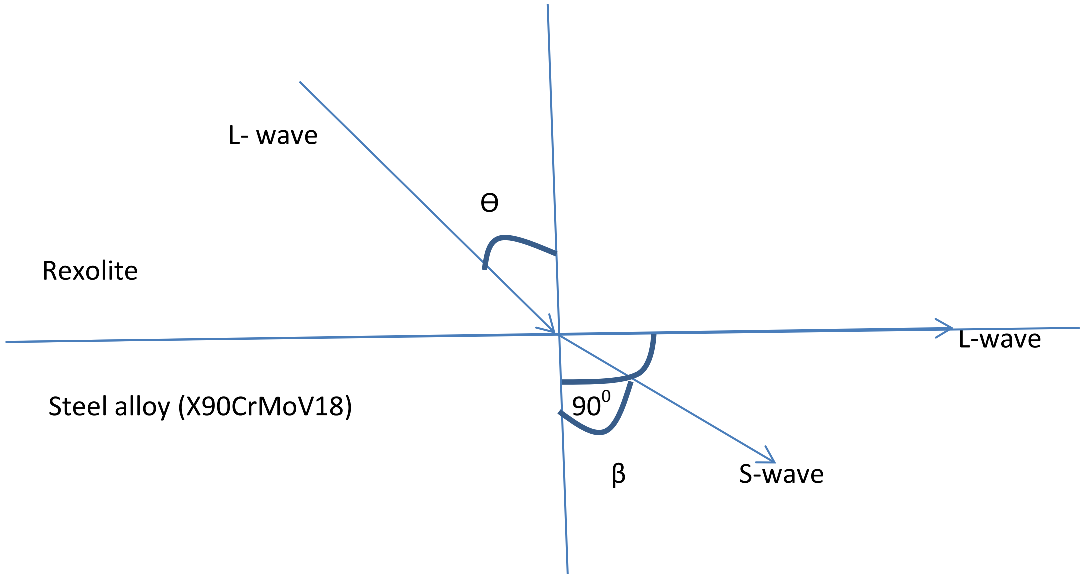

Fig. 1 : Refraction of shear waves into the sample

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From Fig.1, applying Snell's law:

$$\frac{\sin\theta}{\sin 90} = \frac{v}{u} \text{------------------------------}(1)$$

Where ϴ = incident wedge angle;

Longitudinal refracted angle = 90^0 at the interface;

v = longitudinal sound velocity in Rexolite;

u = Rayleigh wave velocity (2900 m/s).

Substituting in equation (1),

$$\frac{\sin\theta}{\sin 90} = \frac{2362.2}{2900}$$

ϴ = asin (2362.2/2900 sin90)

$= 54.54^0$

Hence, ϴ is beyond the first critical angle in steel (i.e. 27.5^0). However, it is below the second critical angle (i.e. 57^0). Therefore, only shear waves would be refracted into the unit under test.

Also, the refracted shear angle β in the specimen can be estimated as follows:

$$\frac{\sin 54.54}{\sin\beta} = \frac{2362.2}{2478}$$

$$\beta = \text{asin}\left(\frac{2478}{2362.2}\sin 54.54\right)$$

$= 58.72^0$

III. MATERIAL CHARACTERIZATION

The sound velocity of the specimen was measured using pulse-echo and through- transmission ultrasound. With this approach, the sound velocity of the specimen of known thickness can be found. Conversely, the sample thickness can be tested for material of known sound velocity especially in stress corrosion control [4].

As will be shown subsequently, the pulse-echo method gives more accurate results than the through transmission. Another advantage with the pulse-echo technique is that it is more amenable to ultrasonic testing because it requires only one scanning surface of the specimen [5].

For a steel block of thickness 20.3mm, the longitudinal sound velocity, using the two ultrasonic techniques, is compared as follows:

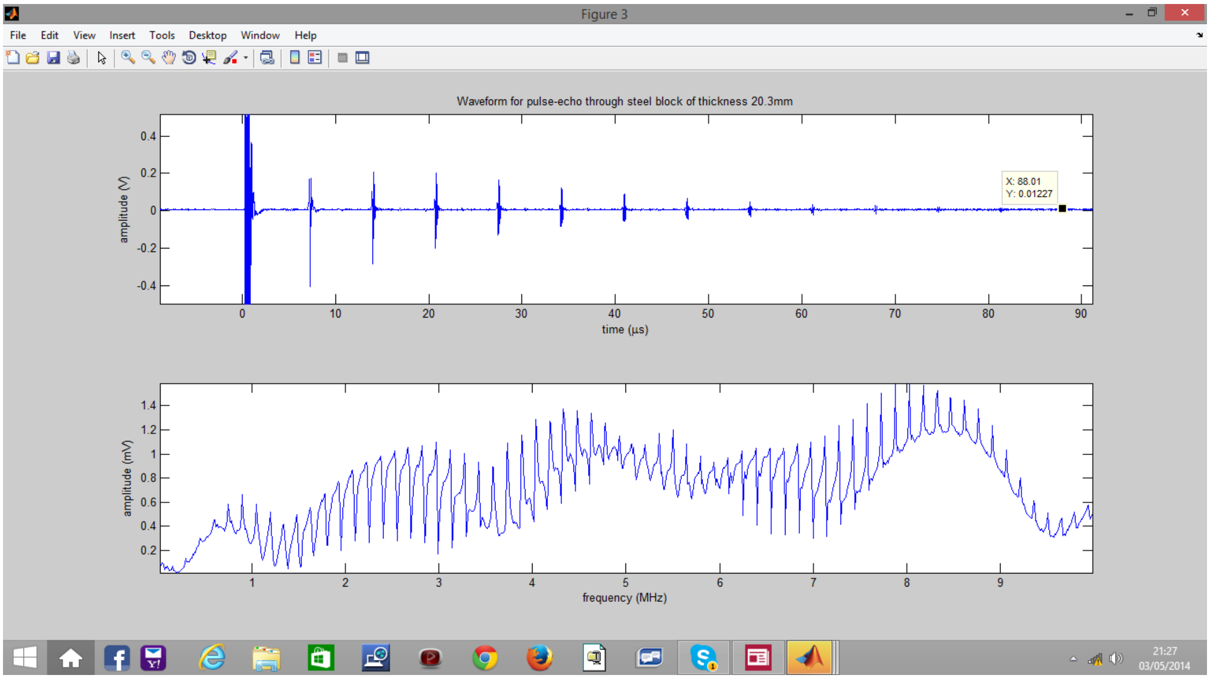

Fig. 2 : Waveform of pulse-echo ultrasound in the steel block

From Fig. 2, the time of flight is the time interval between the pickup and the first echo divided by 2.

$$\text{Hence, time of flight, } T_f = \frac{7.1-0.2}{2} = 3.45\mu s$$

$$\text{Sound velocity in the steel} = \frac{Thickness\ \ of\ steel\ block}{Time\ \ of\ flight}$$

$$= \frac{20300\,mm}{3.45s}$$

=5,884.1m/s

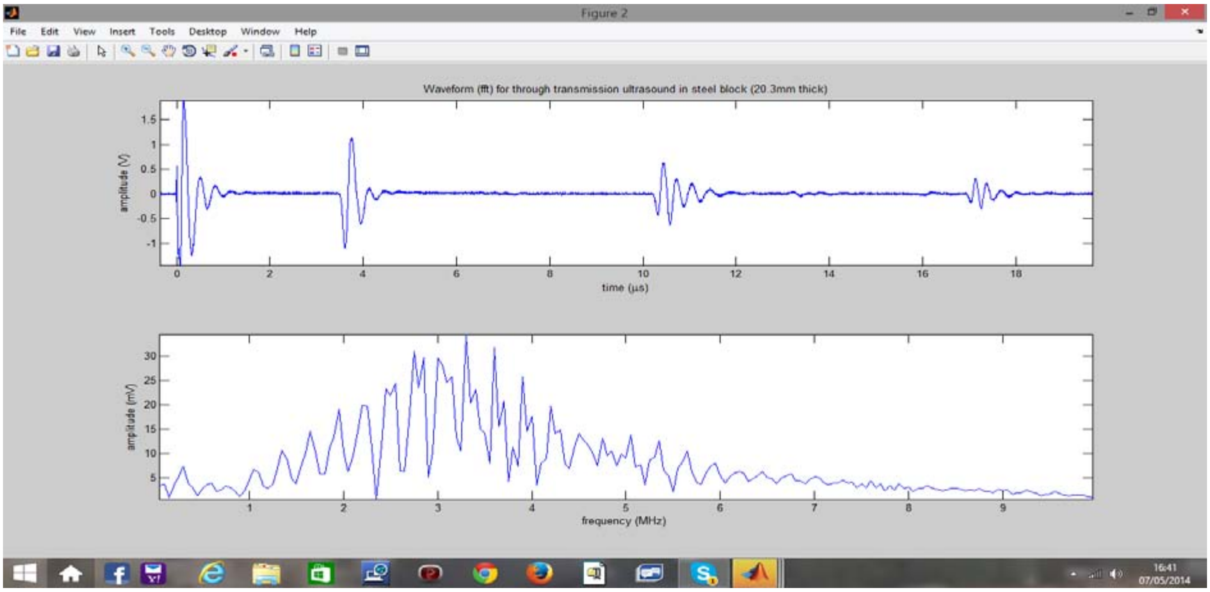

Fig. 3 : Waveform of through transmission ultrasound in the steel block

From Fig. 3, the time of flight is the interval between the pickup and the corresponding point on the first reflection.

$$\text{Sound velocity in the specimen} = \frac{Thickness\ \ of\ steel\ block}{Time\ \ of\ \ flight}$$

$$\text{From the graph, time of flight, } T_f = 3.48\mu s - 0.014\mu s$$

$$= 3.47\mu s$$

$$\text{Hence, longitudinal sound velocity in the steel} = \frac{0.0203\,m}{3.47e-6(s)}$$

$$= 5{,}850 m/s$$

IV. SIMULATION OF SOUND WAVE IN THE STEEL SAMPLE

A 10mm diameter piston transducer with a centre frequency of 1MHz was used to transmit ultrasound into the specimen through a Rexolite wedge of 0 and 20^0 interface angles. The directivity patterns for both longitudinal and shear waves were plotted in matlab using the directivity function.

a) Zero Degree Interface Angle

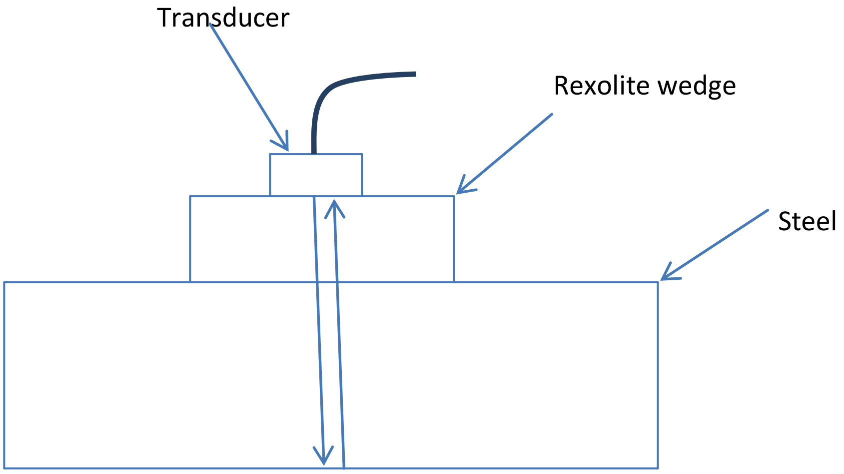

Fig. 4 : Ray propagation from Rexolite into steel at 0^0 Interface angle

The directivity patterns for Fig. 4 are displayed as follows:

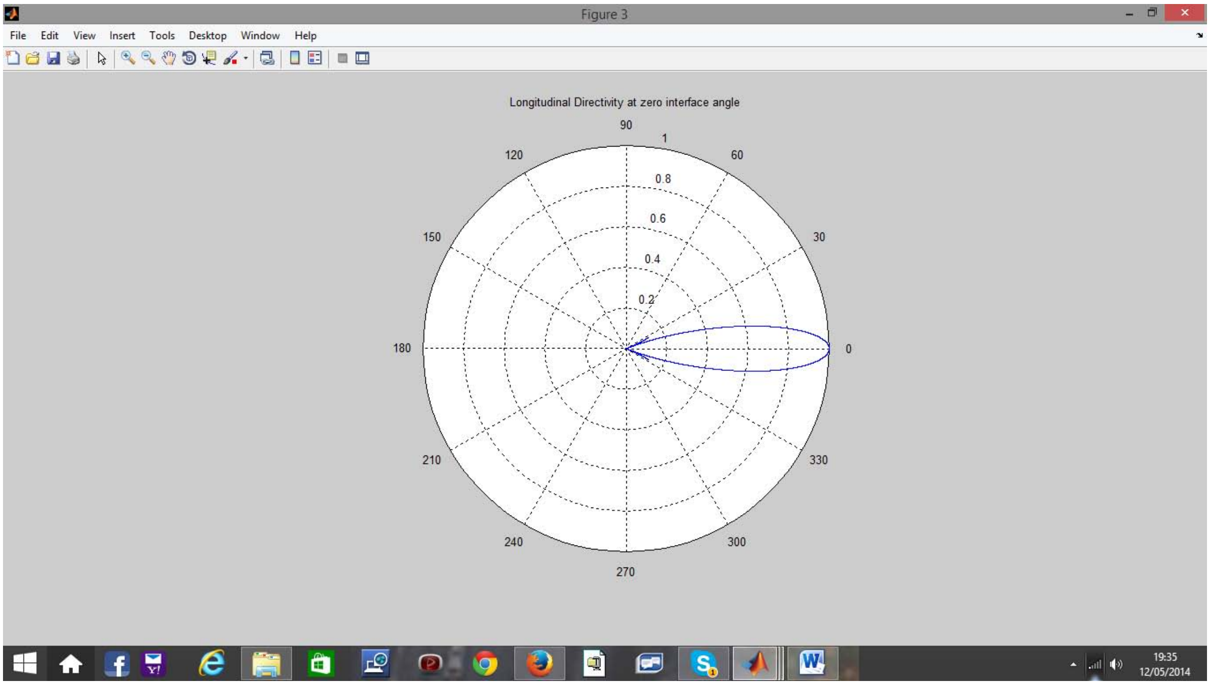

Fig. 5 : Directivity pattern of longitudinal wave in Steel/Rexolite at 0^0 interface angle

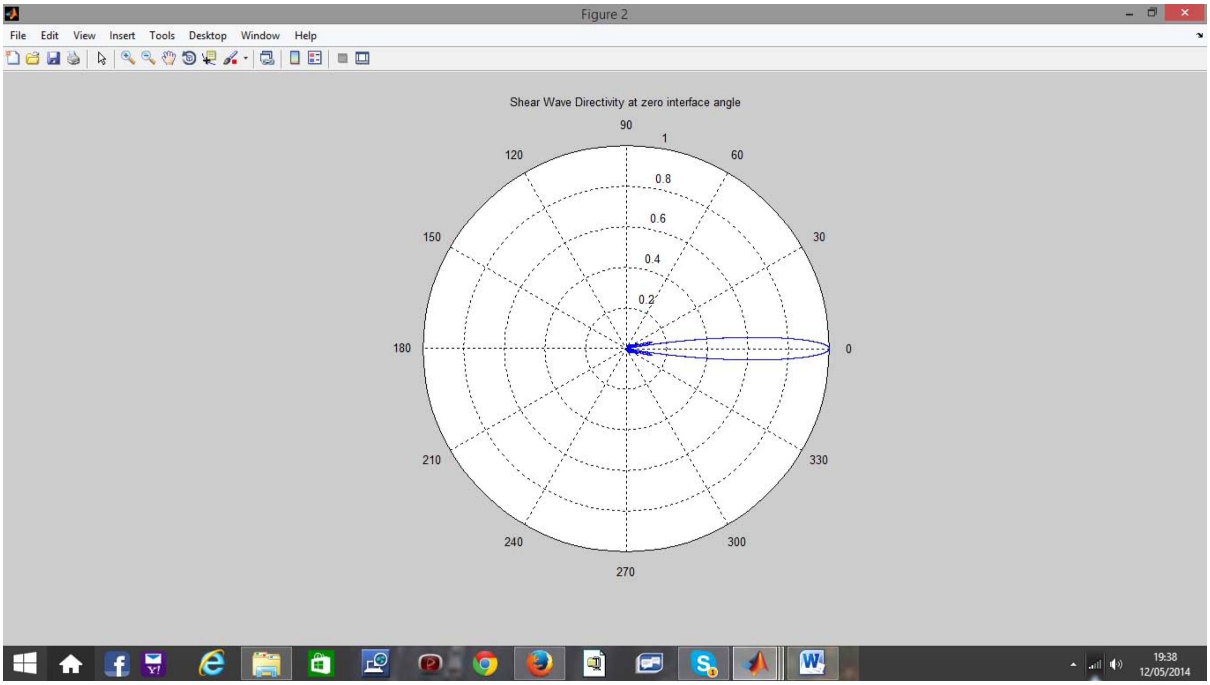

Fig. 6 : Directivity pattern of shear wave in Steel/Rexolite at 0^0 interface angle

b) Twenty Degree Interface Angle

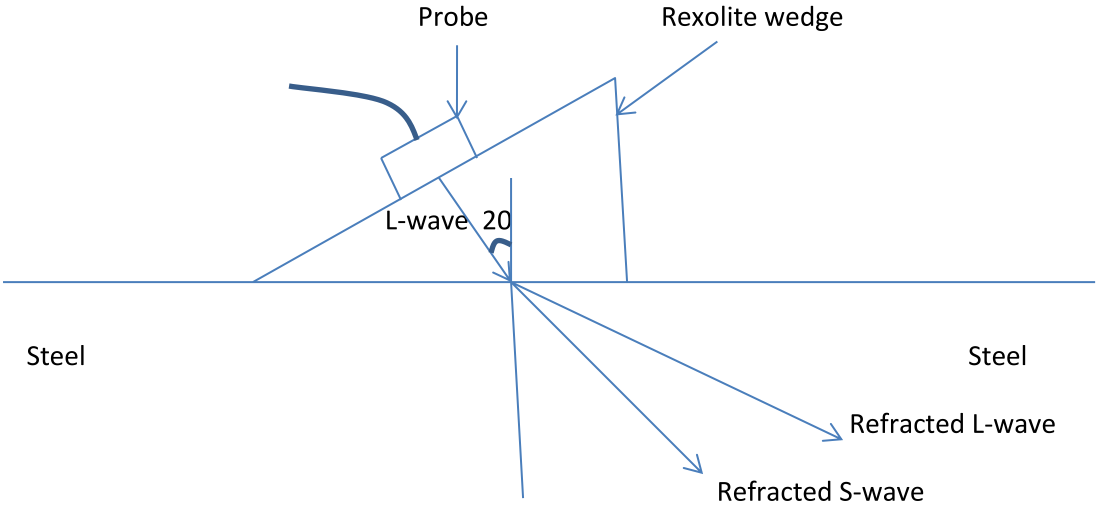

Fig. 7 : Ray propagation through 20^0 Rexolite wedge into Steel

The directivity patterns for Fig. 7 are shown below.

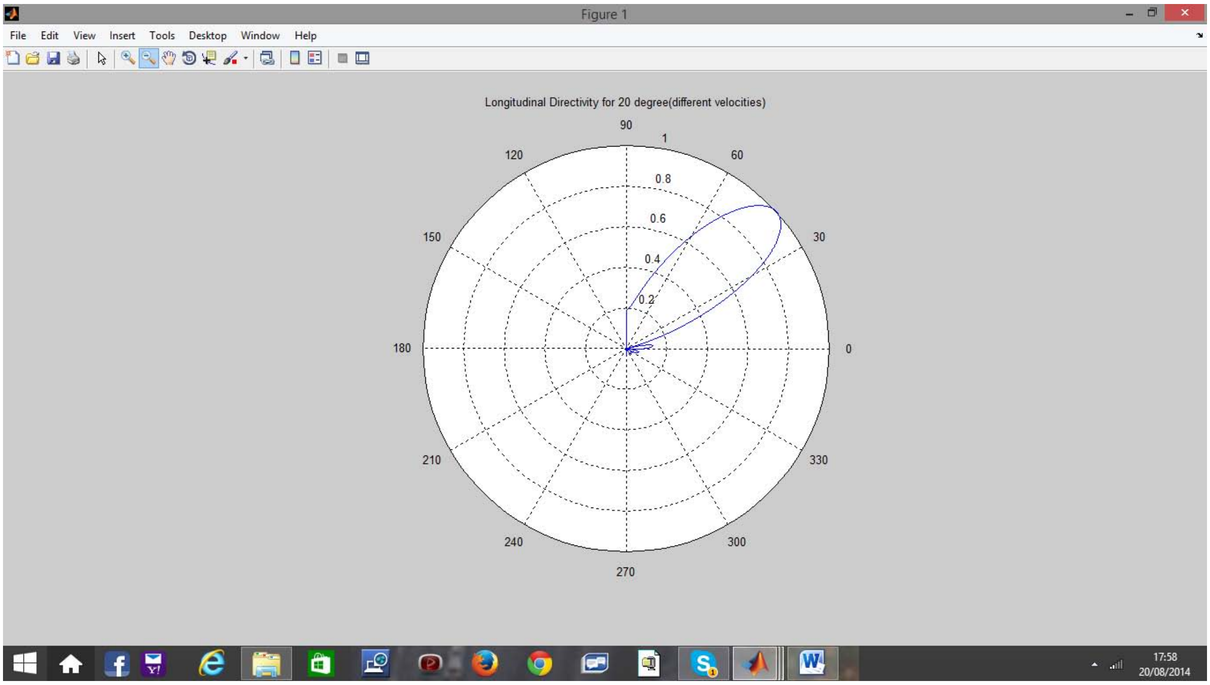

Fig. 8 : Directivity pattern of longitudinal wave in Steel/Rexolite at 20^0 interface angle, 1MHz

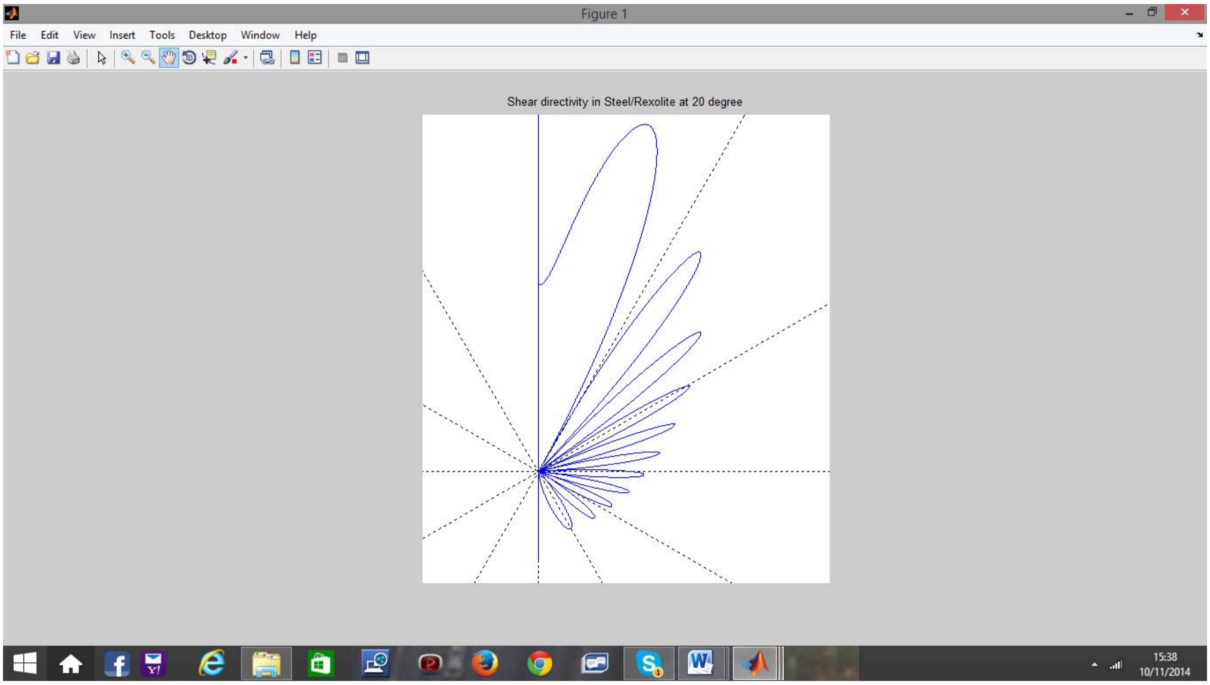

Fig. 9 : Directivity pattern of shear wave in Steel/Rexolite at 20^0 interface angle, 1MHz

c) Reducing The Centre Frequency of the Transducer From 1mhz To 0.5mhz.

The simulation patterns are illustrated below.

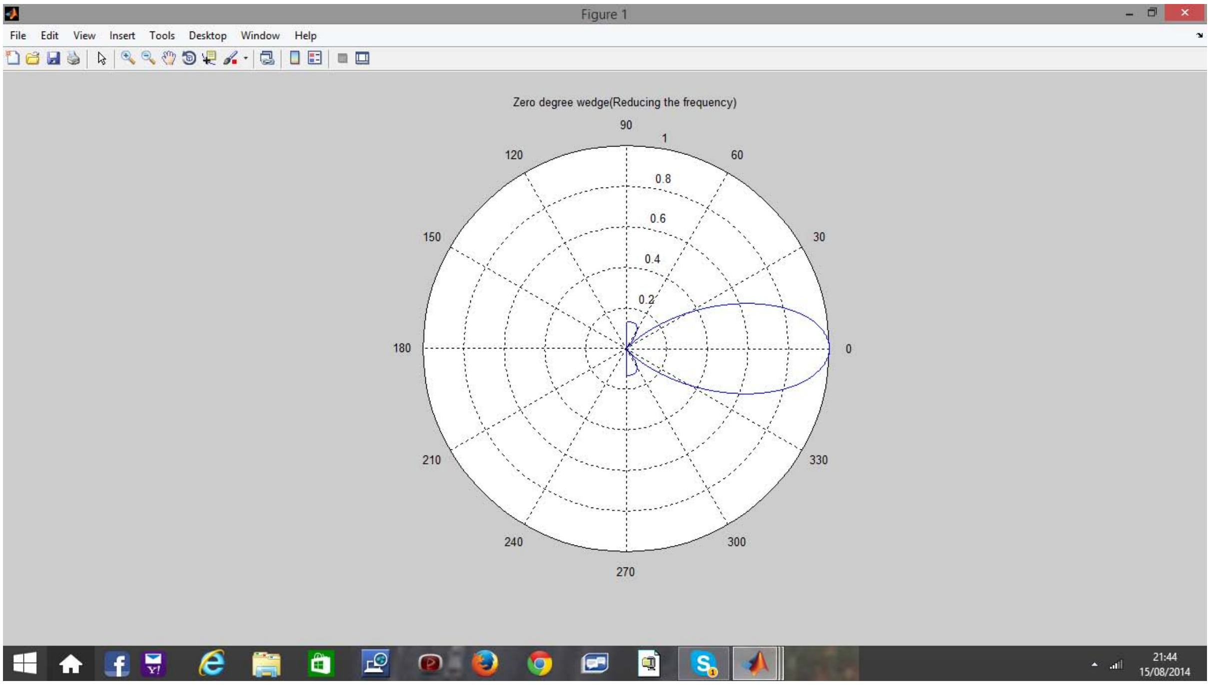

Fig. 10 : Directivity pattern of longitudinal wave in Steel/Rexolite at 0^0 angle and 0.5MHz

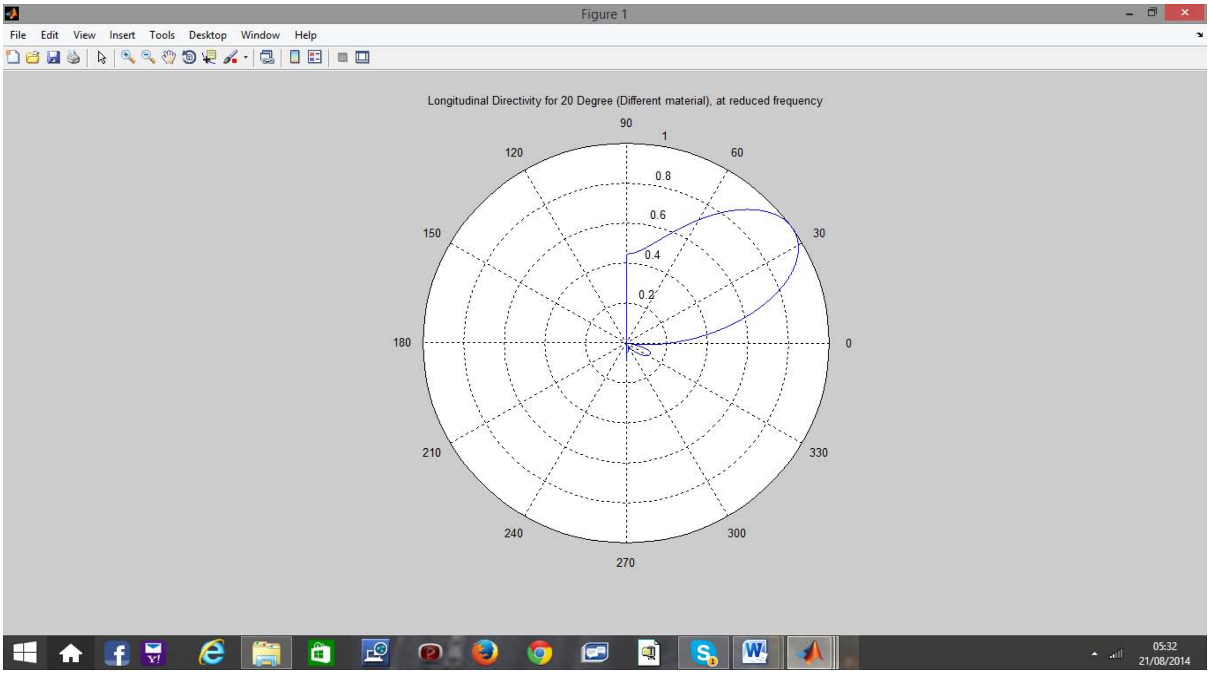

Fig.11 : Directivity pattern of longitudinal wave in Steel/Rexolite at 20^0 angle and 0.5MHz

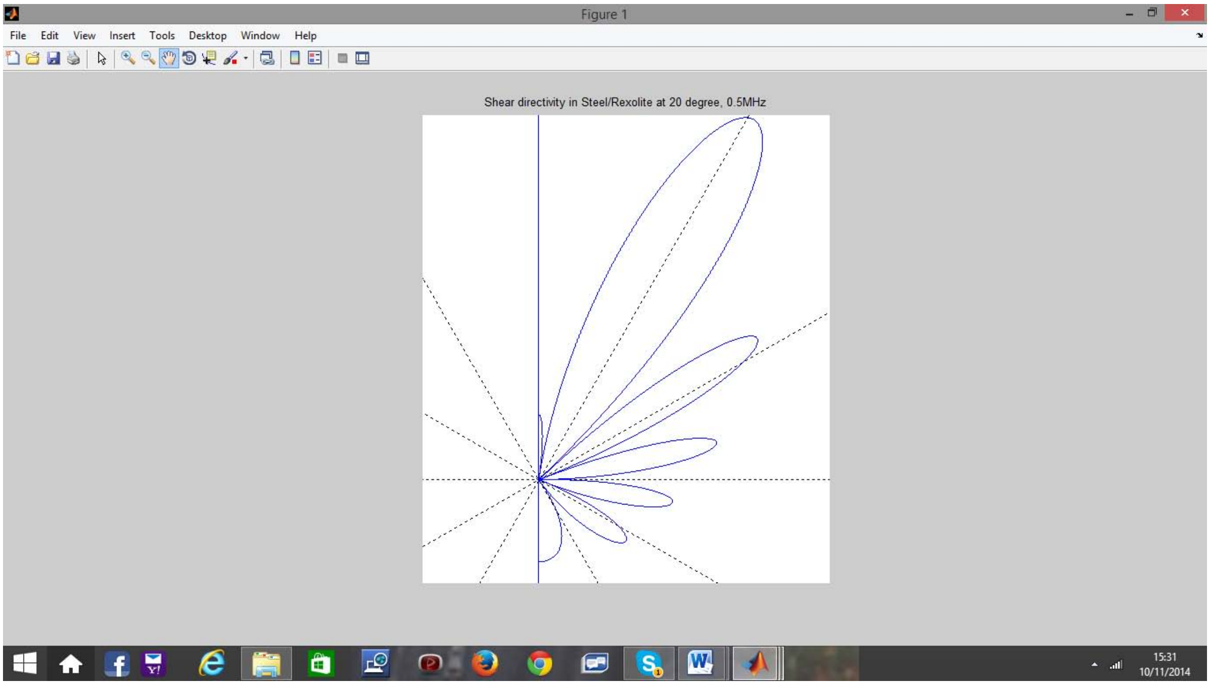

Fig.12 : Directivity pattern of shear wave in Steel/Rexolite at 20^0 angle and 0.5MHz

V. Discussion of Results

For the experiments on material characterization (see section 3), the ideal longitudinal sound velocity of steel is 5890m/s. This literature value could not be attained due to errors of instruments, operator and temperature variations. Also, the pulse-echo method gave more accurate measurement than the through transmission technique as seen from the small deviation when compared to the literature value.

From Fig. 5, the longitudinal directivity is less directional and less focussed than the shear directivity in Fig. 6. Moreover, both patterns are symmetrical, indicating absence of mode conversion. Directional ultrasonic signals are sensitive to small flaws and flaws parallel to the wave direction [6]. Hence, this informs why shear waves are mostly preferred in ultrasonic testing.

In Fig. 8, the longitudinal directivity pattern for the 20 degree wedge is asymmetrical and has a pronounced main lobe while in Fig. 9; the pattern is more distorted with many side lobes.

By reducing the centre frequency of the finite transducer, the following observations are made:

a) The longitudinal directivity patterns for the 0 and 20^0 interface wedges are more omnidirectional compared to the previous patterns in Figs. 5 and 8.

b) In Fig. 12, the shear directivity pattern for the 20 degree wedge is larger with fewer side lobes compared to that in Fig. 9.

Finally, it can be seen that the asymmetrical and distorted form of the patterns for the 20 degree angle wedge is due to mode conversion at the material interface. The directivity patterns for the straight wedge are symmetrical and on axis due the absence of mode conversion. Mode conversion is effected when the incident angle is not perpendicular to the interface in the presence of impedance mismatch [7].

VI. Conclusion

Appropriate wedge design and simulation will greatly facilitate the modeling of ultrasonic wedges. The approach will determine the critical incident angle which is one of the input parameters to numerical modeling.

Also, the analytical simulation done in this study can provide a reasonable picture of the numerical approach.

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