18th World Conference on Nondestructive Testing, 16-20 April 2012, Durban, South Africa

Effects of Various Couplants on Carbon Steel and Aluminium Materials Using Ultrasonic Testing

Ngeletshedzo NETSHIDAVHINI [1], Raymond B. MABUZA [2]

[1] Department of Nondestructive Testing & Physics, P/Bag X021, Vanderbijlpark, 1900, Johannesburg, South Africa; Phone: +27 16 950 9050, Fax: +27 16 950 9794; e-mail: ngeletshedzon@vut.ac.za

[2] Department of Nondestructive Testing & Physics, P/Bag X021, Vanderbijlpark, 1900, Johannesburg, South Africa; Phone: +27 16 950 9228, Fax: +27 16 950 9793; e-mail: raymondm@vut.ac.za

Abstract

Couplants are essential for providing the necessary link between transducers and materials in ultrasonic testing. In this paper, various couplants are used on aluminium and carbon steel materials to study the effects they have on the amplitudes of back wall echoes. The amplitudes of back wall echoes increase with increasing acoustic impedance of couplants. Reflection and transmission coefficients at the interface between media (crystal, couplant and specimen) and the acoustic impedance of materials also contribute to the amplitude of back wall echoes. Comparing steel to aluminium, the study has shown that aluminium has low acoustic impedance, thus resulting in back wall echoes of high amplitudes. This study also shows that couplants with high transmission coefficients are most effective for detection of defects.

Keywords: Couplant, reflection coefficient, transmission coefficient, amplitude, back wall echo, acoustic impedance

1. Introduction

For every contact ultrasonic testing to be successful, a couplant is required in between the material under test and the transducer. The couplant enables sound waves generated by the transducer to be efficiently transmitted into a material. A thin film of couplant is usually applied on the surface and should be uniform throughout. This thin film causes the error in the measurement of velocity and attenuation [1]. Couplants come in different forms, for example, oil, grease, pastes and many more and have certain effects [2, 3, 4] which will be discussed in this paper and also proved experimentally. A couplant may be liquid, semi-liquid or paste.

Important factors like hazard to the operator and the structure under test, wetting properties, availability and surface conditions of a structure to be tested should be taken into account prior to selection of a suitable couplant. Some critical properties of a good couplant are that it (i) must be easy to apply and easy to remove (ii) must be free from solid particles, air bubbles and any contaminants and (iii) must also be non-toxic.

When sound waves are emitted from the transducer, most of the sound waves are reflected at the interface of the face of the transducer, the couplant and the front surface of the material resulting in a little amount propagating into the material. This results in some portion of energy being reflected at the boundaries of the material. The reflected energy is received by the receiver and then converted into signals that are displayed on the screen of the flaw detector representing either the thickness of the material or anything encountered in the material by the sound waves. The amplitude of these signals are affected by the type of couplant [1, 5] used and will be discussed in detail in this paper. Few studies on the effect of couplant on contact ultrasonic testing have been done [6, 7].

For the purpose of this study, various couplants are used to investigate the effects they have on carbon steel and aluminium specimens. This is done through observing the amplitudes of first back wall echoes and the attenuation coefficients from the material.

2. Behaviour of sound waves at boundaries

The intensity of energy reflected and transmitted at a boundary is dependent on the acoustic impedance of the media involved. The resistance that a material has to the propagation of sound waves is known as acoustic impedance and is mathematically given by

$$\eta = \rho c \tag{1}$$

where ρ is the density of the material and c is its acoustic velocity. At an interface between the two media, the acoustic impedances of the media will determine what amount of the incident sound wave will be reflected and what amount will be transmitted into the second medium. Therefore, acoustic impedance is an important factor in determining the reflection and transmission coefficients in a material [8]. Various acoustic impedances of the couplants used in this study are determined and tabulated in table 1 below.

Table 1. Acoustic impedances of the couplants used

Couplants	**Acoustic impedance(MPa.m^{-2})**
Honey	2.89
Glycerine	2.43
Motor oil SAE 20	1.51
Sunflower oil	1.35
Baby oil	1.17
Ultrasound gel	-
Grease	-
Vaseline	-

As the sound waves impinge on the front surface of a material, the wave is reflected and some portion is also transmitted into the material. The amount of the energy reflected and transmitted at the interface is dependent upon the reflection and transmission coefficients. The reflection and transmission coefficients can be determined by using the following equations,

$$R = \left(\frac{\eta_1 - \eta_2}{\eta_1 + \eta_2} \right)^2 \tag{2}$$

$$T = \frac{4\eta_1\eta_2}{(\eta_1 + \eta_2)^2} \tag{3}$$

where R represents reflection coefficient, T stands for transmission coefficient, η_1 represents the impedance of the material in which the incident and reflected waves are travelling and η_2 stands for the impedance of the material in which the transmitted wave is propagating.

When sound waves propagate through a material, their intensities decrease with distance hence a reduction in the amplitude of the echoes from the back wall. This is the result of scattering and absorption of the wave. The resultant effect of scattering and absorption is called attenuation. The amplitude of an ultrasonic wave that has travelled distance y can be represented as

$$A = A_0 e^{-\alpha y} \tag{4}$$

where A represents the reduction of the amplitude after the wave travelled distance y, A_0 is the original amplitude of the travelling wave and α stands for attenuation coefficient of the material.

To obtain the attenuation coefficient (dB/mm), the ratio of two subsequent amplitudes are denoted by m and expressed in decibels:

$$m = 20 \log \frac{A_0}{A} \tag{5}$$

In pulse echo testing, the wave bounces back and forth in the material. A certain fraction is picked up by the transducer when reflection occurs, proving a measure of the amplitude between each round trip of the pulse. The attenuation coefficient between each round trip of the back wall echoes for this setup will be given by

$$\alpha = \frac{m}{2d} \tag{6}$$

where d is the thickness of the material.

3. Experiments

3.1 Experimental setup

Specimens made of carbon steel and aluminium with dimensions 200x150x30 mm and 150x60x30 mm respectively are used. An Olympus 4 MHz, 10 mm diameter longitudinal wave transducer is connected to a SIUI CTS 9009 ultrasonic flaw detector. Couplants such as glycerine, baby oil, motor oil SAE 20, grease, honey, margarine, vaseline and ultrasound gel are used. The layer (thickness) of couplant on the surface of the specimen is kept constant by applying the same pressure on the transducer throughout all experiments. For the purpose of our study, the pulse echo technique is used for all experiments.

In this study, two parts of the experiments are considered. The first part is concerned with the couplant (glycerine) being placed on the surface of the carbon steel specimen with a transducer directly on it. Here, the longitudinal wave transducer emits longitudinal waves that propagate through the couplant and the homogeneous specimen until they reach the rear end of the specimen. These waves are then reflected through the same path back to the transducer. The reflected waves are then displayed on the screen of the flaw detector as signals representing the initial pulse and the back wall of the specimen. In this case, there is no defect echo because there is no defect in the specimen. Since the aim of this experiment is to observe the behaviour of first back wall echoes, the amplitudes of the back walls are noted. The same procedure is followed for all the other couplants.

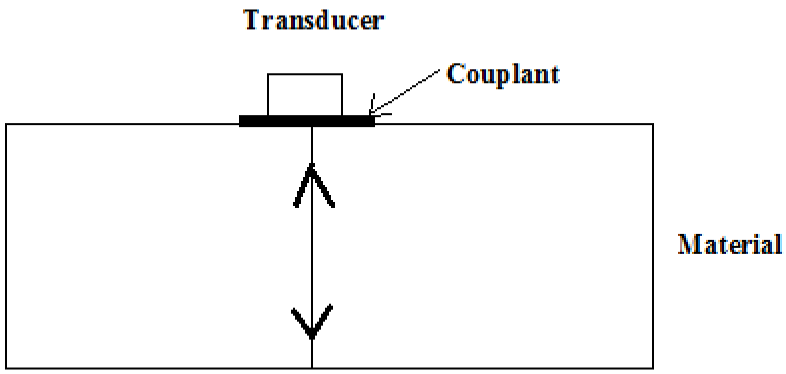


Figure 1. Schematic representation of the experimental setup

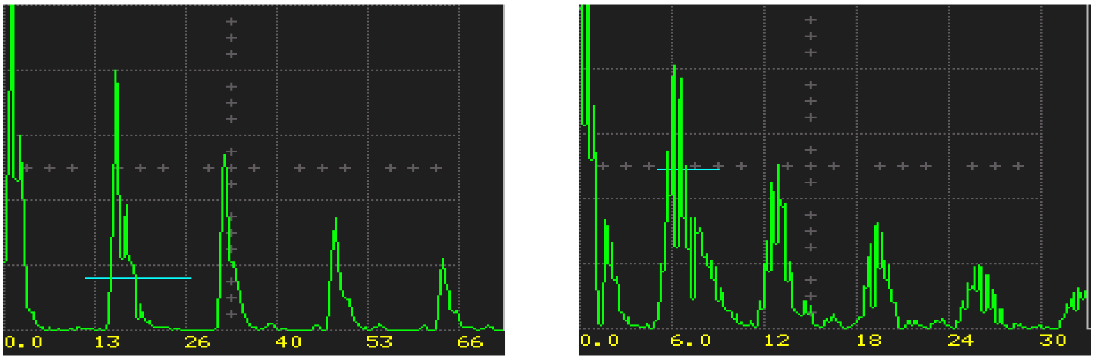
The second part of our experiment deals with specimens with defects and all the couplants used in part one. Here, the main objective is to observe the amplitudes of the signals resulting from defects. These signals are noted in all experiments.

3.2 Results and discussion

3.2.1 Part I

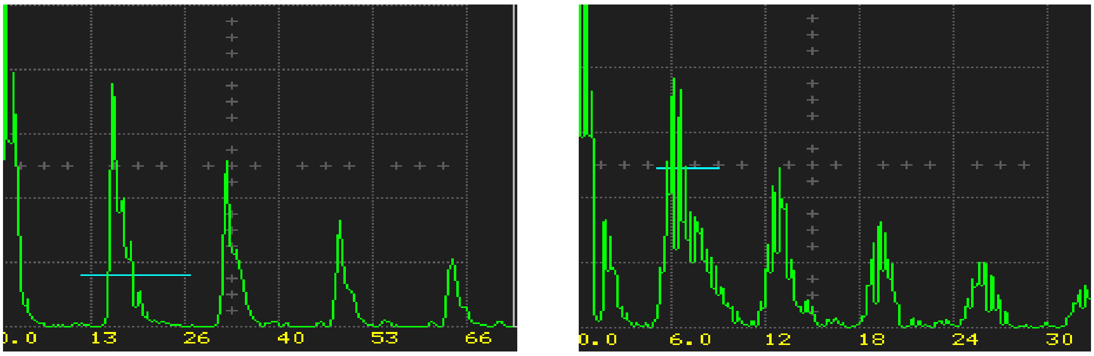
(i) Results

The flaw detector is adjusted to have three repetitions of the first back wall echo. All couplants are used on the carbon steel and aluminium specimens and the amplitudes of the first and second back wall echoes are considered. The flaw detector is set to have a gain of 31.5 dB when conducting the experiment on the carbon steel specimen. It is then reduced to 25.5 dB in the case of aluminium. This is so because of the low resistance the material (aluminium) has to the propagation of sound energy, hence, the sound velocity is faster than that of carbon steel. Figures 2 through 9 below show the results obtained in the experiments.



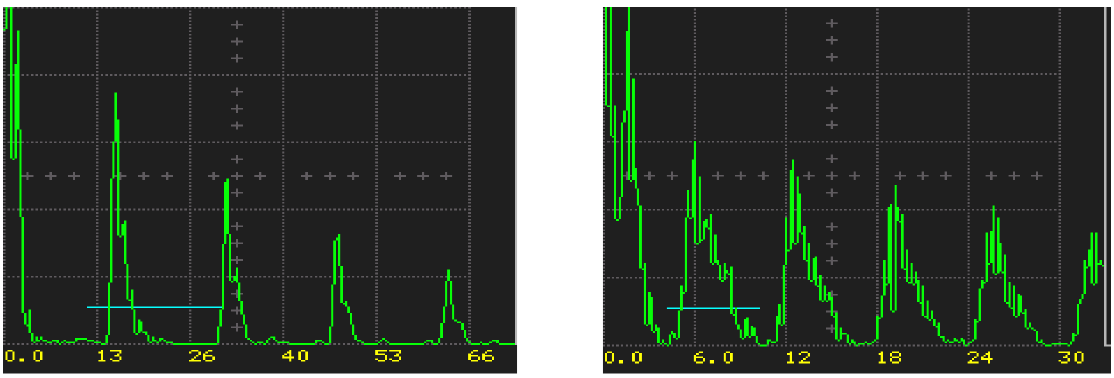
(a) (b)

Figure 2. Back wall echoes from (a) carbon steel (80%) and (b) aluminium (81) with honey used as couplant



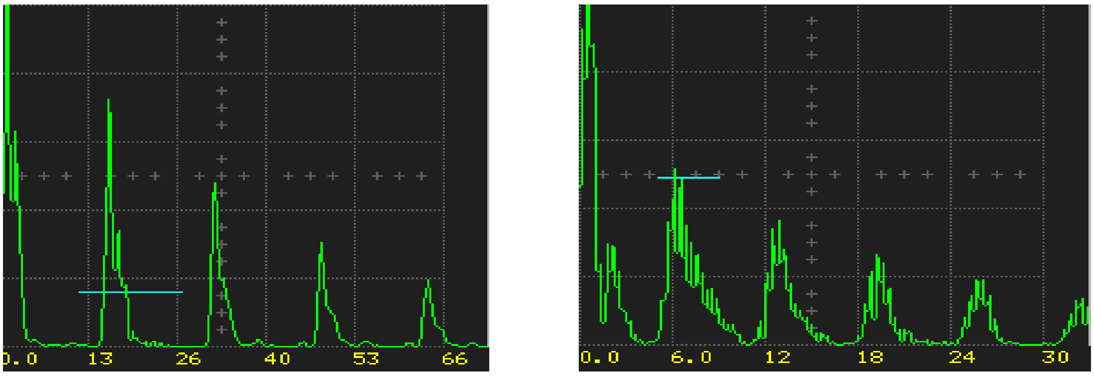
(a) (b)

Figure 3. Back wall echoes from (a) carbon steel (76%) and (b) aluminium (77%) with glycerine used as couplant



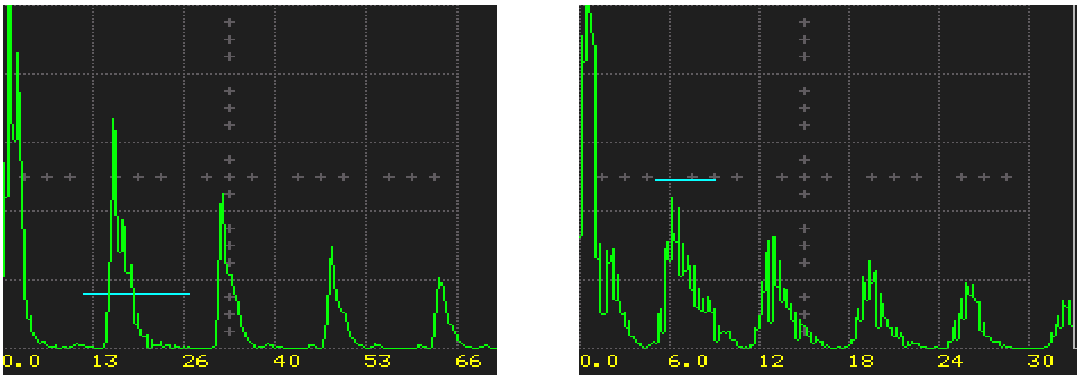
(a) (b)

Figure 4. Back wall echoes from (a) carbon steel (75%) and (b) aluminium (60%) with motor oil SAE 20 used as couplant



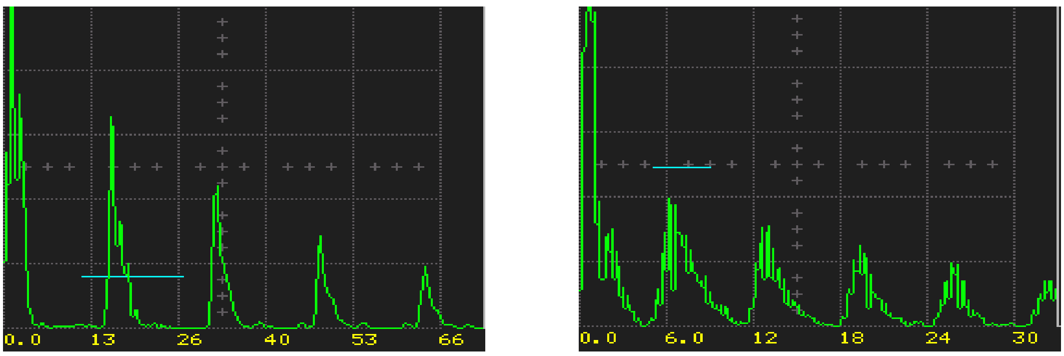
(a) (b)

Figure 5. Back wall echoes from (a) carbon steel (73%) and (b) aluminium (52%) with sunflower oil used as couplant



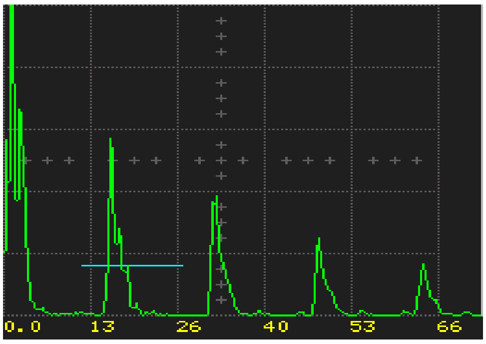
(a) (b)

Figure 6. Back wall echoes from (a) carbon steel (71%) and (b) aluminium (44%) with baby oil used as couplant

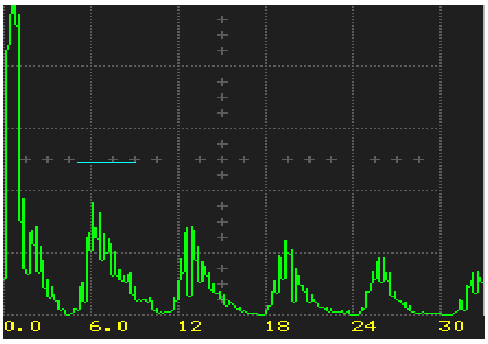


(a) (b)

Figure 7. Back wall echoes from (a) carbon steel (66%) and (b) aluminium (40%) with ultrasound gel used as couplant

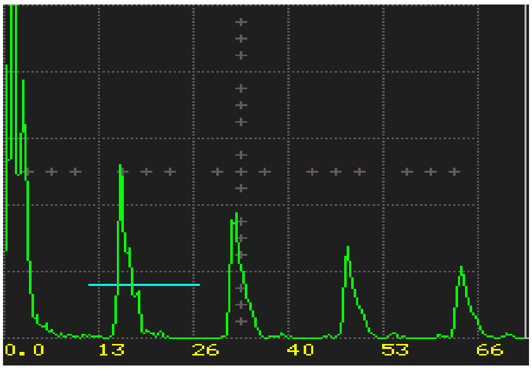


(a)

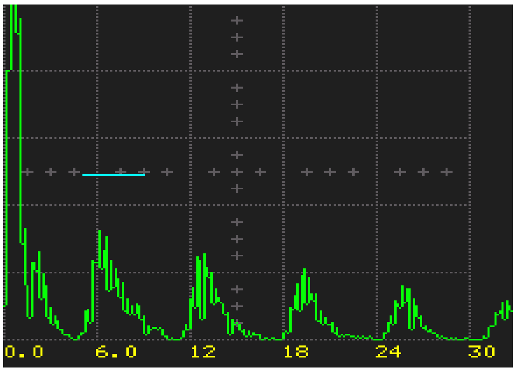


(b)

Figure 8. Back wall echoes from (a) carbon steel (58%) and (b) aluminium (36%) with grease used as couplant



(a)



(b)

Figure 9. Back wall echoes from (a) carbon steel (52%) and (b) aluminium (33%) with vaseline used as couplant

(ii) Discussion

(a)

In figure 2, honey is used as a couplant on carbon steel and aluminium specimens. The first back wall echoes for both specimens resulted in amplitudes of 80% and 81% respectively. These amplitudes are obtained by placing a gate across the echo on the screen of the flaw detector. The gate automatically reads the amplitude which is then displayed on the screen. Honey is very viscous and its viscosity is highly affected by temperature and water content. The high viscosity contributes to its acoustic impedance. Aluminium has low resistance to the propagation of sound energy; hence, the sound velocity is faster than that in carbon steel. Carbon steel has high acoustic impedance as compared with aluminium.

When glycerine is used as a couplant, (figure 3), the first back wall echo for carbon steel is 76% and 77% for aluminium. Glycerine provides high acoustic impedance and therefore produces better transmission of sound waves into the material. It also has relatively low viscosity, which makes it better at permitting trapped air out from the contact region with a little amount of force on the transducer.

The table below summarizes results obtained in the experiments together with the acoustic impedances of various couplants used. The acoustic impedances for carbon steel and aluminium are 46.32 $MPa.m^{-2}$ and 17.21 $MPa.m^{-2}$ respectively.

Table 2. Amplitudes of first back wall echoes resulting from carbon steel and aluminium specimens using various couplants.

Couplants	Carbon steel (Amp %)	Aluminium (Amp %)
Honey	80	81
Glycerine	76	77
Motor oil SAE 20	75	60
Sunflower oil	73	52
Baby oil	71	44
Ultrasound gel	66	40
Grease	58	36
Vaseline	52	33

(b)

In figures 2(b) and 3(b), honey and glycerine are used as couplants on the aluminium specimen. As seen in the figures, when using honey as a couplant, the amplitude of the first back wall is higher than the one obtained when using glycerine as a couplant. The amplitudes of the first back wall echoes are 81% and 77% for honey and glycerine respectively. It is evident from these results that the amplitude of the first back wall echo increases with increasing acoustic impedance of the couplant.

Table 3: Results from aluminium specimen

Couplant	Amplitude (%)
Honey	81
Glycerine	77

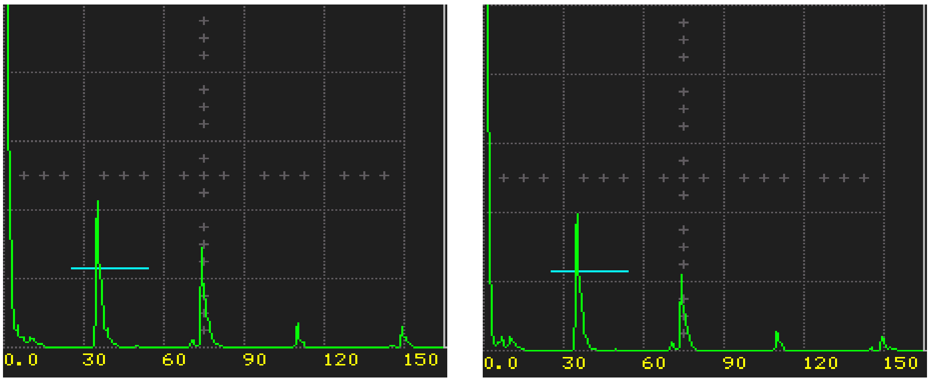
Considering honey, motor oil SAE 20 and ultrasound gel couplants, motor oil SAE 20 is less viscous than honey because of the liquid state it is in. Composition of ultrasound gel may be varied by the amount of water added and this affects their viscosity. In essence, ultrasound gel has the highest viscosity when compared with honey and motor oil SAE 20. Viscosity of couplants is an important factor to consider when vertical and rough surfaces are to be inspected. With respect to acoustic impedance, honey has the highest, followed by motor oil SAE 20. Ultrasound gel is assumed to have the least acoustic impedance.

From the above results, the highest amplitudes of first back wall echoes were obtained when honey, glycerine and motor oil SAE 20 as couplants regardless of the specimen material, were used. Honey has high acoustic impedance, followed by glycerine. Vaseline has the least acoustic impedance of all the couplants used in this study. It is therefore evident that the amplitudes of first back wall echoes increase with increasing acoustic impedances of couplants. It is also observed from the above results that a material with low acoustic impedance, in our case, aluminium, results in first back wall echoes of high amplitude, hence the reduction of the gain in the experiments.

It can be said that the most average couplant from the experiments is ultrasound gel and it is commonly used when performing ultrasonic tests. Though honey provides the best results, it is expensive and becomes sticky if left on the surface of a material for a long period.

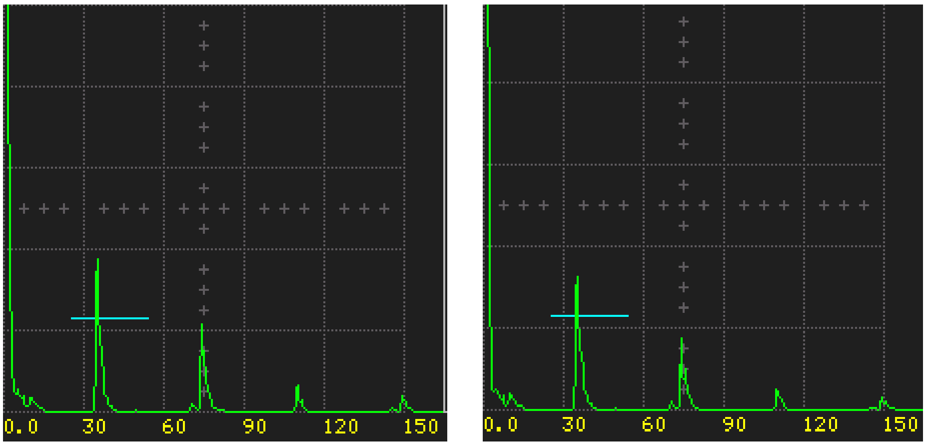
3.2.2 Part II

All the couplants were also used on specimens with defects. The amplitudes of the defect echoes were noted and the results from only two couplants are shown in the figures below.



(a) (b)

Figure 10. Defect echoes from (a) aluminium (43%) and (b) carbon steel (40%) with honey used as couplant



(a) (b)

Figure 11. Back wall echoes from (a) aluminium (38%) and (b) carbon steel (33%) with glycerine used as couplant

After calculating the transmission coefficients of all couplants, results show that honey, followed by glycerine has the highest transmission coefficients. From these results, it can then be deduced that couplants with high transmission coefficients should be used for defect detection in materials as the signals obtained from the defects are sharp and distinct.

Conclusions

Our study shows that couplants are a requirement for all contact ultrasonic tests to be successful. Amplitudes of back wall echoes are observed and their results are noted in order to investigate the effects couplants have on the materials under test. Comparison between steel and aluminium has shown that aluminium has low acoustic impedance, thus resulting in back wall echoes of high amplitudes. This study also shows that couplants with high acoustic impedance and high transmission coefficients are most effective for detection of defects. It is also known that attenuation contributes to the loss in amplitude of back wall echoes but couplants have a major effect. According to this study, honey is the most suitable couplant to be used as better results are obtained during defect detection.

Reference

1. Young H. Kim, Sung-Jin Song, Sung-Sik Lee, Jeong-Ki Lee, Soon-Shin Hong, A study on the couplant effects in contact ultrasonic testing, 10th APCNDT Brisbanne, 2001
2. NDT Data Fusion, Xavier Emanuel Gros, 1997, pp: 63
3. Chi-hau-chen, Ultrasonic and advanced methods for non-destructive testing and material characterization, 2007, pp: 665
4. C. Li & E. Nordlund, Effects of couplants on acoustic transmission, Rock Mech. Rock Engng.(1993)26(1), pp:63-69
5. A. Kumar, N. Gupta, R. Gupta & Y. Kumar, Effect of coupling conditions on ultrasonic echo parameters, J. Pure Appl. Ultrason. 27(2005) pp: 70-79
6. A. Vincent, Influence of wear plate and coupling layer thickness on ultrasonic velocity measurement, 1987, Ultrasonic, 25, pp:237-243
7. Ashok Kumar, Correction factor due to couplant in ultrasonic thickness measurement, Insight (UK) 38 (1996) pp: 336-337
8. J. C Drury, Ultrasonic Flaw detection for technicians, 3rd edition, pp 23