Ultrasonic Investigation Of Thermoplastic Polymers

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Abstract : Polymers classify in the nonmetallic section of the engineering materials. They form the backbone of today's industries. Polymers combines the most desirable physical and mechanical properties side by side with low production cost if compared with metals. This research aims to investigate the ultrasonic characteristic in two of the most common used polymeric materials in the engineering and industrial applications. The results of the research can pave the way for the next step of assessing the using of the ultrasonic inspection as a quality control tool to detect the manufacturing defect in these materials through determining the optimal frequency spectrum that can be adopted during the inspection. Samples of PMMA and ABS have been cut to cylindrical specimens of different thicknesses. Compression ultrasonic wave probes of different frequencies (1, 2 and 4 MHz) have been used to transmit the ultrasonic waves into the samples.

At the given specimen thicknesses, the results showed that ABS caused in higher acoustic attenuation if compared with acoustic attenuation of PMMA samples in all probes frequencies employed. Furthermore, 4MHz compression wave probe frequency demonstrated the lower maximum echo amplitude in both PMMA and ABS samples comparing with the probes of 1MHz and 2MHz frequencies.

Keywords: Ultrasonic Inspection, Pulse-Echo Technique, Thermoplastic Polymers.

I. INTRODUCTION

Plastics have come on the scene as the result of a continual search for man-made substances that can perform better or can be produced at a lower cost than natural material such as wood, glass, and metal, which require mining, refining, processing, milling, and machining [1]. Nowadays, polymers become the backbone of the new engineering materials, especially nanocomoposites materials. Many of the researches have been done using the ultrasonic technique to study the characteristics of the polymeric structure, and the physical and mechanical properties of polymers [2],[3],[4],[5],[6]. The physical and mechanical properties of polymeric composites materials represented an area of research for many other scientific researches [7],[8],[9],[10],[11], the ultrasonic technique parameters such as attenuation and velocity of the transmitted waves have been used as an estimation tool of these properties. Due to its practical importance, many of the research have been carried out on PMMA as a polymeric material or a matrix material in polymeric composites. Langlois and Jia [3] employed the ultrasonic velocity and amplitude measurements as a monitoring tool of the elastic properties during the pressure sintering of PMMA beads packings. Khidhir and Al-Jarjees [7] used the ultrasonic pulse-echo technique to assess the effect of percent of fillers in polymeric composites. PMMA matrix and calcium silicate and black carbon fillers have been used in this study. Bansod et al. [11] studied the dielectric, optical and thermal properties of PMMA/Fe_2O_3 composite films. The ultrasonic velocity is found to be decreased with increase in Fe_2O_3 wt.%. Yochev et al. [12] developed a new technique adopted hydrophilic polymers for dry-coupling ultrasonic inspection to overcome the problem of using a liquid or gel couplants which sometimes undesirable because it may contaminate or penetrate into the material being tested leading to reduction of mechanical properties or corrosion. In addition, ultrasonic pulse-echo or through transmission measurements are used for a quality control of products in various areas of industry. For example, ultrasound has found numerous applications in characterization of various polymers [13],[14],[15]. Wierzbicki et al. [16] compared application possibilities of non-destructive ultrasonic and thermographic testing methods to detect defects in polymeric materials. The experimental results have demonstrated that application of ultrasonic and thermographic testing are effective methods to visualize and reveal defects in the polymeric materials. In this research work, two of the widely used polymeric materials in the local engineering and industrial applications have been chosen to investigate their ultrasonic response characteristics by using ultrasonic pulse-echo technique in order to explain the effect of type of structure of the adopted polymers on the response of ultrasonic waves in these polymers and to determine the effect of the used frequency, which is a critical factor in the ultrasonic inspection. The research can be regard as a step towards introducing the possibility of using the ultrasonic technique as a quality control tool to detect the manufacturing defects that might be initiated in the products that have been made of these polymeric materials during the production and manufacturing processes.

II. MATERIALS AND METHODS

Materials adopted in this research covered two of the thermoplastic polymers from Turkey, one of them is PMMA (Polymethylmethacrylate); the other is ABS (Acrylonitrile – Butadiene – Styrene). Polymethylmethacrylate is a strong, rigid clear, amorphous polymer. It has excellent resistance to weathering, low water absorption and good electrical resistivity [1]. ABS is a copolymer of the three monomers: Acrylonitrile, Butadiene and Styrene. Specimens of these polymers, which have been produced in Turkey, have been cut by a lathe machine to cylindrical shape of the dimensions shown in Table 1, in order to study the effect of the sound scanning distance on the acoustic attenuation of the ultrasonic waves. These dimensions are chosen to be fitted with the compression waves probes. The ultrasonic test was carried out by using Ultrasonic Krautkrammer Instrument shown in Fig.1 (Krautkrammer type USM2 - made in Germany) and compression wave probes with different frequencies shown in Table 2 to assess the effect of the frequency on the response of the ultrasonic waves. The sensitivity level has been chosen to be 80 % of F.S.H. (Full Screen Height), i.e., the echo received from the backwall of the sample has been brought to four-fifth the screen height and the number of decibels required to bring the echo to this sensitivity level have been recorded as shown in Fig. 2.

Table 1: *Dimensions of the specimens.*

Probe	Frequency
Deutsch type 1402.1	1 MHz
Deutsch type 1403.2	2 MHz
Deutsch type 1404.4	4 MHz

Figure (1): *The ultrasonic inspection device (Type USM2) used in the current research.*

III. RESULTS AND DISCUSSION

The results that have been obtained from the ultrasonic testing are graphically represented in figures (3-5) to demonstrate the effect of the sound scanning distance and the probe frequencies used in this research on the ultrasonic response of the adopted polymers. The results of PMMA samples (Fig.3) indicate that as the sound scanning distance increased, the acoustic attenuation increases too. For the probe frequency, the 1MHz probe frequency resulted in the lower acoustic attenuation (higher maximum echo amplitude); while the 4MHz probe frequency resulted in the higher acoustic attenuation if compared with both 1MHz and 2MHz probe frequencies. This can be attenuation coefficient on the frequency of the transmitted waves. This relationship has been confirmed by He [14] and Umchid [17] who claimed that the attenuation is linearly depends on the frequency of the incident beam. For the results of ABS samples. Obviously, the acoustic attenuation indicates the same behavior of PMMA in related with the sound scanning distance and the probe frequency attributed to the dependence of the ultrasonic effect on the ultrasonic response as Fig. 4 clearly illustrates.

A comparison can be made between the results of PMMA and ABS (Fig.5), as shown ABS caused in higher acoustic attenuation of the ultrasonic waves than PMMA in all of the sound scanning distances and probe frequencies. This can be interpreted by the
lower damping of the ultrasonic waves in PMMA [16], [17], which means lower attenuation of the ultrasonic waves because the attenuation of these waves during its travelling into the medium mainly depends on the absorption and reflection properties of the medium which determine the amount of the reflected energy to the transducer. In polymeric materials ultrasonic attenuation is mainly contributed to viscoelastic relaxation and scattering effect. While ultrasonic longitudinal wave propagates in solid polymeric materials, energy loss will occur as there exist retardation phenomenon between stress and strain. Attenuation due to scattering factors are usually produced because of the presence of the heterogeneity in polymeric materials [13].

In addition, the acoustic attenuation in both PMMA and ABS samples using 4MHz is largely increases with increasing the sound scanning distance. These results are in agree with Raišutis and et al [18] as they claimed that the class of the plastics have been observed to have an attenuation function that increases with frequency. As a result, higher frequency components of the pulse are attenuated more than lower frequency components; which leads to distortion of the shape of the pulse.

IV. CONCLUSIONS

The following points can be concluded from this research work:

1- It is plausible to use the ultrasonic technique in the inspection of the polymeric materials covered in this research.

2- The lower the frequency used the better the ultrasonic response.

3- Increasing the sound scanning distance resulted in increasing the acoustic attenuation of the ultrasonic waves in both PMMA and ABS samples.

4- 1MHz compression wave probe frequency has characterized by the lowest acoustic attenuation comparing with 4MHz probe frequency which indicated the highest acoustic attenuation in PMMA and ABS samples.

5- ABS samples caused in higher acoustic attenuation in the ultrasonic waves comparing with PMMA samples in all frequencies and sound scanning distances adopted in this research.

Table 1: *Dimensions of the specimens*

Polymer type	Specimen diameter (mm)	Thicknesses covered in the research (mm)			
PMMA	47.6 ± 0.05	10	20	30	40
ABS	47.6 ± 0.05	10	20	30	40

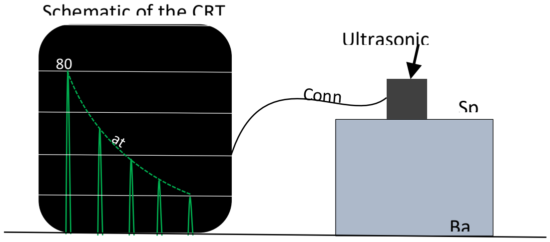

Figure (2): *Schematic representation for*

V. FUTURE WORK

Much research work still needs to be done to support the engineering knowledge in this field of science. Deep analyzing and assessment of the non-destructive techniques is necessary to determine the optimum inspection technique among the ultrasonic techniques. Actually, most of the researches that have been done in this field are chemically-oriented.

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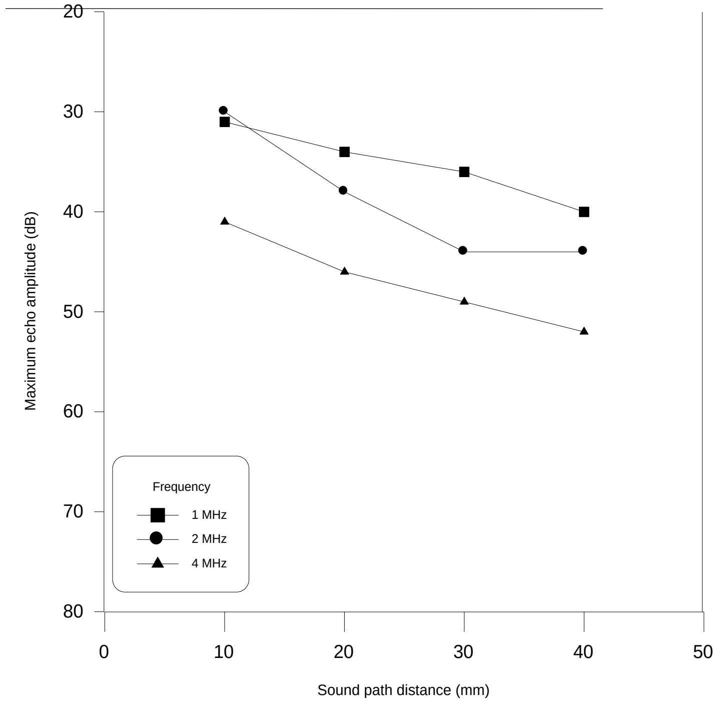

***Figure (3):** The relationship between sound scanning distance and the ultrasonic maximum echo amplitude received from the backwall of PMMA samples using 1, 2 and 4MHz compression*

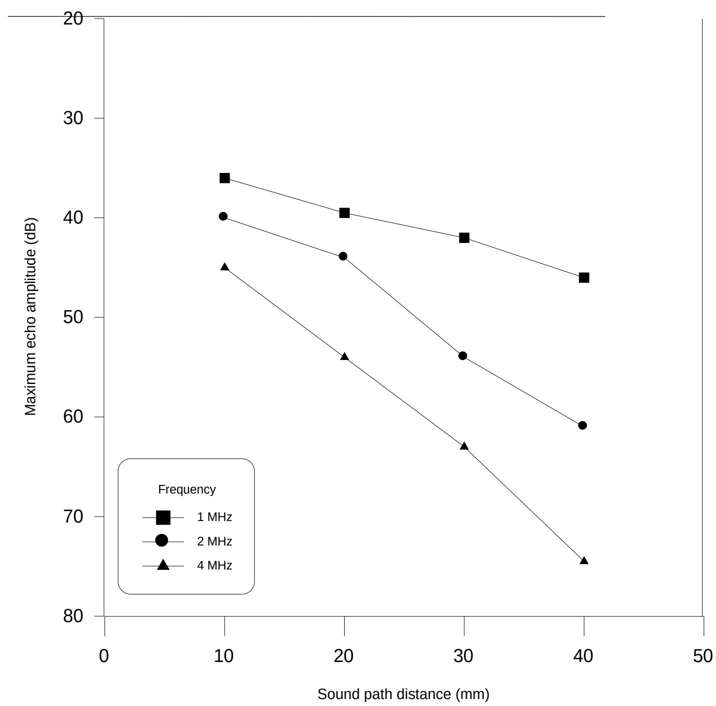

***Figure (4):** The relationship between sound scanning distance and the ultrasonic maximum echo amplitude received from the backwall of ABS samples using 1, 2 and 4MHz compression*

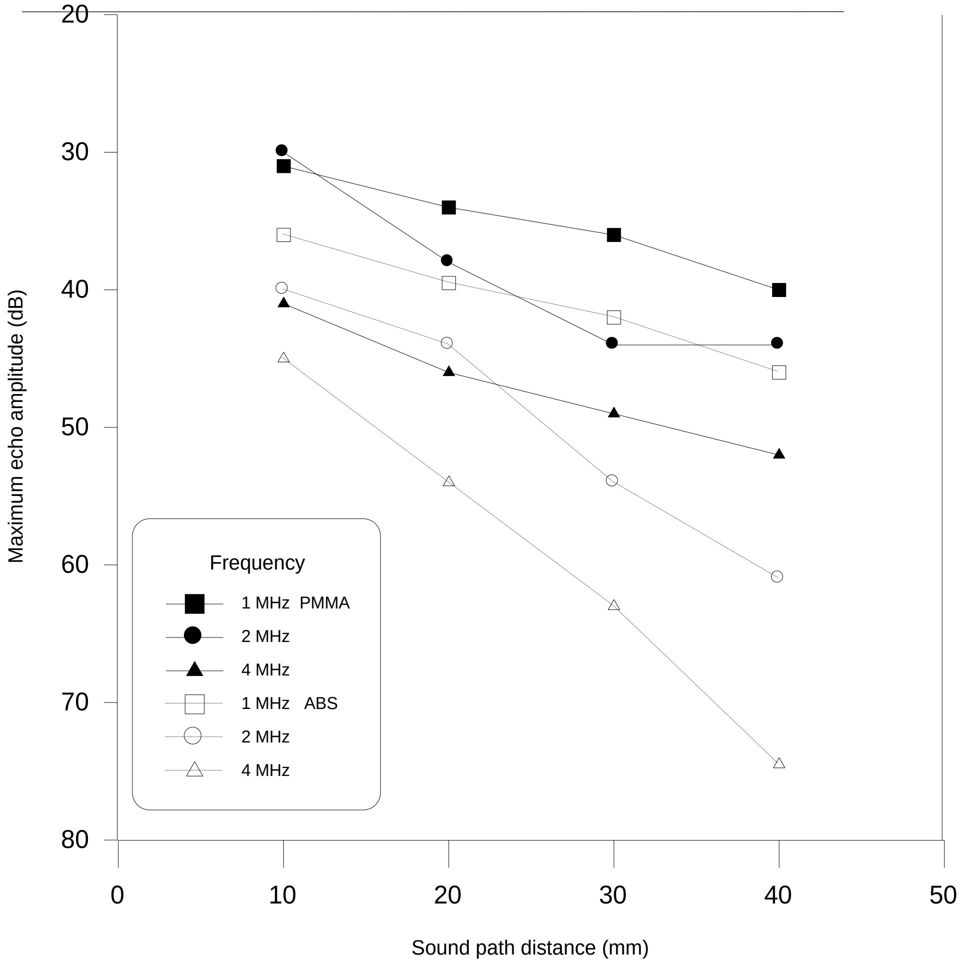

Figure (5): *The relationship between sound scanning distance and the ultrasonic maximum echo amplitude received from the backwall of both PMMA and ABS samples using 1, 2 and 4MHz compression*