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Research on Ultrasonic Velocity Imaging of Metal Matrix Composites with TIRP Method

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Abstract

In order to evaluate the uniform of SiCp reinforced aluminum metal-matrix composites (MMC) fabricated by powder metallurgy, the ultrasonic velocity imaging was carried out with the method of thickness independent reflector plate (TIRP). Ultrasonic velocity in MMC can be used to calculate the stiffness constants and Yang's modulus, which are influenced by the volume percentage of SiCp. The TIRP method based on pulse-echo mode was developed to measure very small changes in thickness and velocity with a flat and rigid reflector plate behind specimen. Firstly, purpose of ultrasonic velocity imaging of MMC and basic principle of TIRP were introduced. Secondly, an ultrasonic scan system employed to apply TIRP method was described. Thirdly, the experiments' results of ultrasonic velocity imaging of MMC specimen obtained with TIRP and back surface echo (BSE) respectively were compared and discussed. It is showed that the images generated by TIRP have more details than those by BSE. Finally, the factors affecting accuracy and precision in the implementation were considered which may be used to advance the experiment.

Key Words: ultrasonic velocity imaging, aluminum metal-matrix composites, thickness independent reflector plate (TIRP)

1. Introduction

Silicon carbide particulate (SiCp) reinforced aluminum metal-matrix composites are promising new engineering materials for aeronautics and astronautics because of their high specific stiffness and specific strength, and service temperature capability much higher than that of polymer matrix composites. The manufacturing process of powder metallurgy (P/M) makes SiCp/Al become a kind of commercially viable material for structural applications.

The properties of SiCp/Al are greatly influenced by the fabricating process, and inhomogeneity of SiCp is a common fault. The material homogeneity can be judged by the volume percentage of SiCp in different locations measured from traditional metallograph[1]. This approach of testing which need destroying the samples in order to prepare the metallographic specimen is limited to inspecting small area because of its complicated operation. Thus, the SiCp distribution in the whole sample is hard to know with metallography. Ultrasonic testing is a potential method to evaluate the uniform of SiCp with nondestructive means[2]. The ultrasonic waves propagate faster in the SiCp reinforced than in the Al matrix. When SiCp content increases, the stiffness and hence the elastic modulus of the MMC increases. Therefore, ultrasonic waves travel faster in the SiCp/Al than in those without reinforcement, and the propagation velocity increases with raising amount of SiCp content. With this relationship between the volume percentage of SiCp and ultrasonic propagation rate, the colors' range and distribution in the image of ultrasonic velocity can be used to evaluate homogeneity of samples. *The thickness independent reflector plate* (TIRP) was developed to achieve high accuracy and precision velocity imaging. TIRP measures velocity using several (usually three or four) time-of-flight (TOF) data and the speed of sound in water with the aid of a reflector under the specimen. The thickness is unnecessary in the velocity imaging with TIRP method[3].

2. The principle of TIRP

In the experimental setup, a flat and rigid reflector plate is placed behind the specimen perpendicular to incidence direction of ultrasound as shown in Figure 1. The TOF between probe and reflector without sample is T_w', where c is the speed of sound in water, the distance L from probe to reflector is

$$L = \frac{c \times T_w'}{2} \qquad (1)$$

After the sample is put in, the thickness d of sample can be given by

$$d = v\tau \qquad (2)$$

Where v is the velocity of ultrasound propagating in the sample, τ is half of the TOF of two back surface echoes.

In the same time, the TOF of the echo returning from the reflector plate changes to

$$T_w = \frac{2(L-d)}{c} + \frac{2d}{v} \qquad (3)$$

The sound velocity in sample can be deducted from Eqs. (1) to (3) and written as

$$V = c\left(\frac{\Delta t}{2\tau} + 1\right) \qquad (4)$$

Where Δt is T_w' minus T_w, represents the difference of TOF between measurements when the sample is in the acoustic path and that when the sample is not in the path.

It is known from the principle of TIRP that the velocity in the sample is related to the speed of sound in water, the flight time change between probe and reflector with and without the sample and the TOF of ultrasonic in the sample, but has nothing to do with the thickness of the sample.

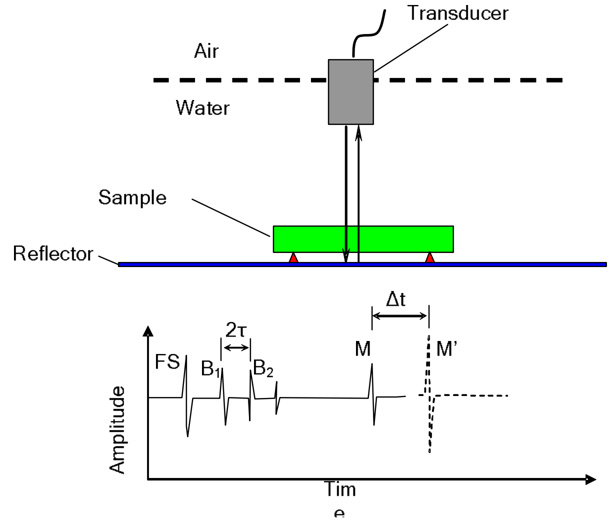


Figure 1 TIRP measurement configuration and typical received echoes

(FS—Front surface of sample；B1—The first back surface of sample；B2—The second back surface of sample；M—The front surface of plate reflector with sample in the acoustic path; M' —The front surface of plate reflector without sample in the path.)

3. The velocity imaging based on TIRP

The ultrasonic velocity image of sample can be generated by calculating point by point follow the principle of TIRP, just like C scan imaging. The ultrasonic scan system is shown in Figure 2 which is composed of PANAMETRICS computer controlled pulser/receiver, industrial computer, high-resolution PCI digitizer with 130MS/s sampling rate, motion control card, longitudinal wave transducer and reflector. The flat and rigid plate reflector with three adjustable legs is made from the titanium. The reflecting surface can be adjusted by changing the height of each leg in order to make the surface parallel to the scan plane.

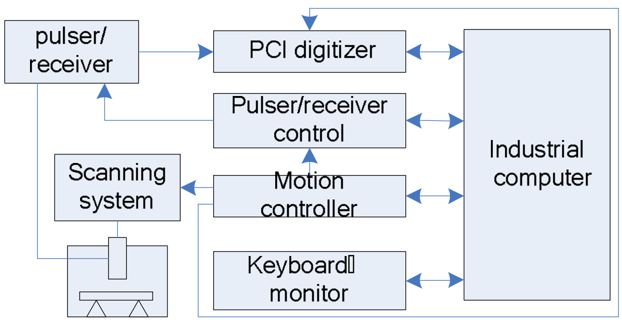


Figure 2 Structure of ultrasonic scan system

Before the sample is placed on the reflector, T_w' should be known in order to calculate the velocity by TIRP. It is assumed that T_w' is equivalent at every point in the reflecting surface when the surface parallel to the scan plane in a kind of usual means. This method is easy to be operated and scans fast, but it will bring about errors because of the bend of screw driving the probe in the scan system, the roughness of reflector and other factors, and the error rate is affected by system design, scan mode, facilities position and etc.

In order to improve accuracy and remove the errors caused by mechanical structure, a double-scan method based on TIRP is developed. The first scan gets the travel time between transducer and reflector before the sample is placed, and the second scan gets the several TOF data which are already described previously after the sample is put in. Finally, the velocity image is generated by calculating the speed of ultrasound in sample at every point with two sets of scan data. The method is inefficient because it needs scan twice, whereas it has more accuracy and precision because T_w' at every scan point is measured instead of considered as a fixed constant. The distance change from probe to reflector, the roughness of reflector and other factors are avoided or depressed by double-scan; therefore the velocity image with more details can be acquired and it is more suitable for evaluating homogeneity of SiCp/Al.

The operation of TIRP method improved by double-scan has three steps:

Firstly, the reflecting surface is adjusted to parallel to the scan plane, and a destination area, where is rigid and flat, is selected to perform the experiment;

Secondly, the destination area is scanned in order to acquire the T_w' at every point before putting in the sample;

Finally, the sample is placed on the top of reflector. The destination area is scanned again from the same original point as the last time. The current data and T_w' get from last scan are used for calculating the velocity of ultrasound in the sample and generating the image.

4. Experimental results and analysis

The samples of SiCp/Al with different volume percentage (from 10% to 30%), as shown in Figure 3, were fabricated by control the content of SiCp, and were shaped to same dimensions.

Figure 3 Samples of SiCp/Al with different SiCp content

(From left to right, the volume percentages of SiCp content are 10%、15%、20%、25%、30%)

Single-scan and double-scan method based on TIRP are applied to achieve velocity imaging for five samples along extrusion direction. The temperature of water was 18 degrees centigrade. The speed c in water can be obtained by[4]

$$c=1402.9+4.835T-0.047016T2+0.00012725T3 \quad (5)$$

Therefore the velocity of ultrasound in water was 1475.44m/s.

The T_w' at original point was used for calculating velocity at each point in the single-scan method. Figure 4 gives imaging results, which shows the velocity changes from 6700m/s to 7200m/s when SiCp content is increased. The color becomes lighter from left to right in the images when the velocity increases and the stiffness of material rises. All samples are inhomogeneous slightly, and the sample with 30% volume percentage SiCp content is more seriously which can be judged from the difference of colors in each velocity image.

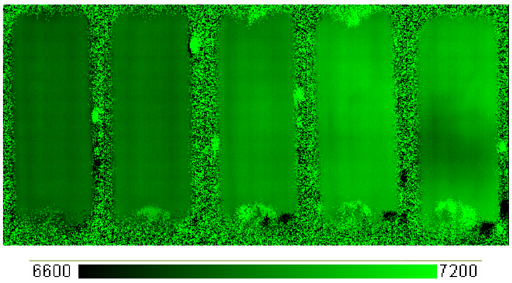
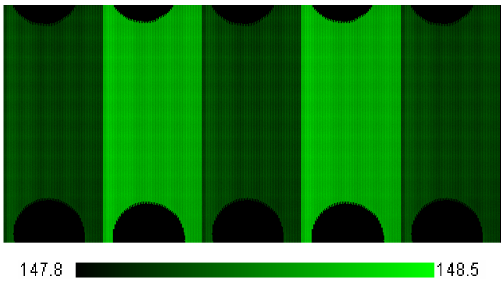


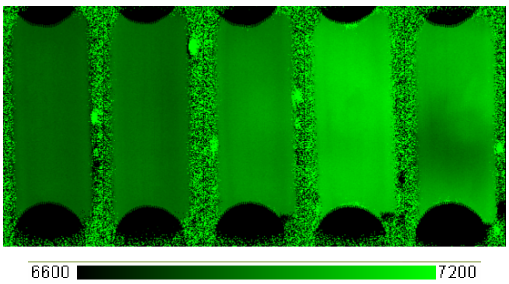
Figure 4 Velocity imaging result generated by using single-scan

(From left to right, the volume percentages of SiCp content are respectively 10%、15%、20%、25%、30%)

The T_w' of each point can be measured in the first scan in double-scan method. The image generated by data of T_w' shows the distance variedness between probe and reflecting surface as shown in Figure 5 (a). There are grid pattern in the images, and the range of T_w' is between 147.8μs and 148.5μs. Figure 5 (b) gives the result of the second scan. The trend of colors changing is as same as Figure 4, whereas the colors are more uniform because of using actual data of T_w'.



(a)



(b)

Figure 5 Velocity images of double-scan method based on TIRP. (a) Images of time-of-flight between probe and reflector (T_w'), (b) The imaging result of double-scan method.

(From left to right, the volume percentages of SiCp content are respectively 10%、15%、20%、25%、30%)

In order to compare the results of different methods, the scan data of the sample with 15% volume percentage of SiCp content are reprocessed and used to generate the images with a zoomed in color map so as to examined obviously. Figure 6 (a) shows the velocity image calculated by back surface echo (BSE) and a fixed thickness value of the sample. It has less detail, accuracy and precision because of effect of thickness change of the sample. The reason of slight color difference cannot be judged only from the image because the thickness of the sample and the velocity of ultrasound in the sample can both affect the result.

The grid pattern appears in the result image of single-scan as shown in Figure 6 (b) because of distance change between the transducer and reflector. The image of Figure 6 (c), which is created by the data of T_w', is similar to the texture in Figure 6 (b). Thus it can be seen that T_w' affects more to accuracy and precision in the velocity imaging by TIRP method. Compared with BSE and single-scan, the result of double-scan method has more details as shown in Figure 6 (d). The grid pattern disappears from the image because of using actual data of T_w'. The result can display the relationship between ultrasonic velocity and SiCp content clearly without the effects of other factors, such as thickness change and roughness of the sample surface.

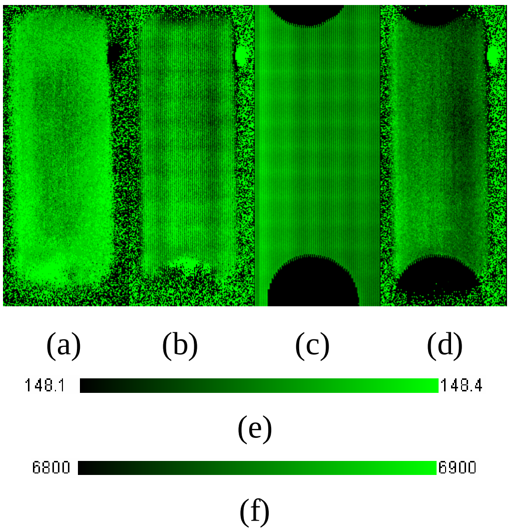


Figure 5 Velocity imaging results by BSE、single-scan and double-scan method. (a) Velocity image generated by BSE, (b) Velocity image generated by single-scan, (c) Image of data of T_w', (d) Velocity image generated by double-scan, (e) Palette of (c), (f) Palette of (a), (b) and (d).

5. The error analysis for velocity imaging by TIRP method

In the experiment, speed of ultrasonic in water is affected by its purity and temperature. The purity is guaranteed by using pure water. The temperature is measured in order to amend the velocity.

There are at least three factors including gate setting, peak detector setting and noise, which can influence time delay from the first to the second back surface echo[5]. The different echo signals may cluster in a small range because of the effects of thickness and position of the sample. If gate settings including gate length and position are not proper, the correct echo peak may be difficult to find out from these very closer signals. Seven kinds of peak detector, such as “negative”, “positive” or “absolute”, can be used to calculate result of electronic gate in the ultrasonic scanning systems. The different result can be calculated out with different type of peak detector especially when pulses are distorted or phase changes. The noise and other non-ideal factors can make the echo peak bias the original position and consequently the time delay of the echo peak is incorrect.

There are much more factors can influence the time difference (Δt) of two TOF for peak M and M' in Figure 1. In single scan method, the parallelism of scan surface and reflector, the roughness of reflecting surface and straightness of screw all can affect measure result. In double scan method, the effects of many factors are removed by scanning twice, but the repeat allocation accuracy of scanning system is demanded because the original points of two scans must coincide.

Several methods can be used to solve the before-mentioned problems and improve accuracy and precision of TIRP. The accurate speed of ultrasound in water can be calculated from water temperature by using high-accuracy temperature sensor. The distortion of moving track of transducer can be reduced by using pair of slide rail instead of cantilever. The roughness of reflector can be depressed by improving precision of manufacture. The gate and detector settings may be selected by the shape of signals, signal noise ratio and etc.

6. Conclusion

The non-destructive testing for SiCp reinforced aluminum metal-matrix composites becomes more necessary when this new engineering material is applied in the field of aeronautics and astronautics widely. The homogeneity of samples can be evaluated by velocity imaging based on TIRP. It is very suitable to inspect products in the research or production because of its non-destructive, easy operating and thickness independent. The experiment results show that the velocity image generated by double scan method has more accuracy and precision than that acquired by BSE or single method, thus double scan is more suitable for homogeneity testing of SiCp/Al.

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