Stress Wave attenuation in SiC\textsubscript{3D}/Al Composite

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Abstract. SiC\textsubscript{3D}/Al composite is a kind of special composite with interpenetrating network microstructure. The attenuation properties of stress wave propagation along the SiC\textsubscript{3D}/Al composite are studied by a Split Hopkinson Pressure Bar system & FEM simulations, and the attenuation mechanism is discussed in this paper. Results show that the attenuation rate of the stress wave in the composite is up to 1.73MPa \cdot mm\textsuperscript{-1}. The reduction of the amplitude of waves is caused by that plenty of interfaces between SiC and Al within the composite acting with stress waves. When the incident plane wave reaches the SiC\textsubscript{3D}/Al interface, reflection wave and transmission wave propagates in different directions along the irregular interface between SiC phase and aluminium phase due to the impedance mismatch of them, which leads to the divergence of stress wave. At the same time, some stress micro-focuses occurs in the aluminium phase for the complex wave superimposition, and some plastic deformation may take place within such micro-regions, which results in the consumption of stress wave energy. In conclusion, the stress wave attenuation is derived from divergence and consumption of stress wave.

1. Introduction

SiC\textsubscript{3D}/Al composite is a kind of special composite with interpenetrating network microstructure. For well integration of the properties of SiC and aluminum, it has better impact resistance performance in comparison with high hardness SiC and good plasticity of aluminum, exhibiting very attracting application potential in the field of high-speed brake pads.

The better impact resistance performance of SiC\textsubscript{3D}/Al composite depends closely on the stress wave attenuation in the composite under impact load [1, 2]. Previous studies have shown that mechanical properties of material and its microscopic structure affect the stress wave propagation in it, and the divergence of stress wave or absorption of stress wave energy will occur when stress wave spreads through the material. There are a large number of experiments about stress wave propagation in the rock and results demonstrate that stress wave attenuates when it spreads through the rock [3–5]. Nail et al [6] found that when the planar longitudinal stress wave encounters an interface between the grain and the grain boundary, reflection and transmission of the incident stress wave take place because of the impedance mismatch at the interface, clearly this leads to attenuation of stress wave.
intensity. And Lagoudas et al [7] found that NiTi SMA can transform or absorb the stress wave energy in the form of phase transformation and/or detwinning.

There are a great many interfaces between SiC and Al in the microstructure of SiC$_{3D}$/Al composite, but up to now research about the stress wave propagation in such material is relative rare. In this paper, interaction between the stress wave propagation and microstructure of SiC$_{3D}$/Al composite was studied, and the mechanism of stress wave attenuation was discussed, which laid a solid foundation for the further application of SiC$_{3D}$/Al composite on impact resistance.

2. Experiment and Results
Stress wave propagation is studied by Split Hopkinson Pressure Bar system, and the data is recorded by the strain gauges [3~9]. The diameter of the SHPB system is 14.5mm and the experimental apparatus is shown in Fig. 1. In order to avoid superposition of the incident pulse and the reflected wave at the interface between specimen and the transmission bar, the distance from the last strain gauge to the transmission rod should be enough for stress wave reflection. And because the length of incident pulse is about twice of the striker bar length, for reducing the total length of the sample, 37mm short striker bar is used in the experiment and three short composite bars with 70 mm are connected one by one along the axis of wave conducted bar, and the final length of specimen is 210mm. Three strain gauges were placed at the position of 20 mm, 50 mm and 80mm from the impact end of the specimen respectively, and strains was real-time monitored at different positions during the wave propagation. The intensity of incident wave is low enough in order to make the specimen deformed in elastic stage during the testing.

Fig. 1. The apparatus of testing the stress wave propagation

The curves of strain signals at different locations along SiC$_{3D}$/Al composite are shown in Fig. 2. The stress wave amplitudes in SiC$_{3D}$/Al composite decreased gradually with the position of strain gauges away from the impact point. And the attenuation rate of the stress wave in the composite is up to 1.73MPa • mm$^{-1}$, which is twice than the rate of the stress wave attenuation in the SiC$_p$/Al composite, it's only 0.81MPa • mm$^{-1}$ [10]. The area of the curves enclosed is the momentum, and the attenuation rate of the momentum in SiC$_{3D}$/Al composite is 0.02MPa • ms • mm$^{-1}$.

Fig. 2. Strain-time curves in SiC$_{3D}$/Al composite at different location
3. Numerical studies and Results

The physical experiments about stress wave propagation show that the stress wave attenuates when it passes the SiC$_{3D}$/Al composite. Obviously this phenomenon relates to the microstructure of the composite greatly. However, the interaction between the stress wave and complex micro interfaces has not been formulated clearly. So in this section, the numerical simulation, based on microstructure technology, is used to study the stress wave propagation to discuss the mechanism of stress wave attenuation in the SiC$_{3D}$/Al composite.

Fig. 3 is the diagrammatic sketch of the model and loading pulse. To avoid the influence of reflection wave at the end of the model, the total solving time is set as 0.02$\mu$s, where $T=L/C$, $L$ is length of the model, $C$ is the wave velocity of SiC$_{3D}$/Al composite.

![Diagram of Finite Element Model and Loading Method](image)

Fig. 3. Finite element model and the loading method

Plastic-Kinematic model was used for Aluminium phase of the SiC$_{3D}$/Al composites and Material properties used in the model are shown in Table 1.

| Density (kg/m$^3$) | Modulus of elasticity (GPa) | Poisson’s ratio | Yield strength (MPa) | Bulk modulus (MPa) | Hardening coefficient |
|-------------------|-----------------------------|-----------------|----------------------|-------------------|----------------------|
| $2.7 \times 10^3$ | 70                          | 0.36            | 70                   | 700               | 1                    |

And JH2 model was used for the SiC$_{3D}$ Ceramic phase. Material properties for SiC$_{3D}$ Ceramic phase are shown in Table 2.

| A     | B     | C     | N     | M     | Beta | HEL (GPa) | HEL Pressure (GPa) |
|-------|-------|-------|-------|-------|-------|-----------|-------------------|
| 0.96  | 0.35  | 0     | 0.65  | 1.0   | 1.0   | 14.567    | 5.9               |
| D1    | D2    | K1 (GPa) | K2 (GPa) | K3 (GPa) | Tensile Strength (GPa) | Normalized Fracture Strength |
| 0.48  | 0.48  | 204.785 | 0     | 0     | 0.37  | 0.8       |

Three elements were picked out along the loading direction corresponding to the positions of the strain gauges in experiment. The numbers of the elements are 12210, 12244 and 12289 respectively and there are aluminium phase between them as shown in Fig. 4.
Effective stress of three selected elements is shown in Fig. 5. It can be seen that, with the same Fringe Levels, effective stress of the first element is higher than the second and third element which corresponding to the middle and lower levels in Fringe Levels respectively. It means that the stress wave attenuated gradually from the first element to third one. At the same time, stress-time curves in the three elements are shown in Fig.6, as can be seen that the amplitudes of stress wave decreased significantly too.

![Diagram](image-url)
The reason for the stress wave attenuation in SiC\textsubscript{3D}/Al composite is that, for the impedance mismatch between SiC phase and aluminum phase, stress wave reflects and transmits in different directions along the irregular interface, which leads to the divergence of stress wave. As shown in Fig. 7(a), with the same Fringe Levels, effective stress on the front edge of stress wave pulse is higher than the other parts and when the stress wave propagates through the interface effective stress decreased gradually. It means that the stress wave intensity reduced when the stress wave passed through the interfaces of SiC and Al.

When stress wave propagates in SiC\textsubscript{3D}/Al composite, some stress concentration regions can be found in the aluminum phase which resulted from the complex wave superimposition. And some plastic deformation was seen within such regions, which resulted in more consumption of stress wave energy and enhanced the stress wave attenuation rate. To be clear, effective stress of aluminium phase under the Fringe Levels in which the maximum stress is about 70MPa was shown in Fig. 8. It can be seen that stress of aluminium phase has reached yield strength in the red regions. But such area is too small, which is less than one percent of the overall aluminum phase, so the plastic deformation just consumed some stress wave energy, not be enough for macroscopic damage in SiC\textsubscript{3D}/Al composite.

In summary, when stress wave passes through SiC\textsubscript{3D}/Al composite and encounters an internal interface, for the impedance mismatch between SiC phase and aluminum phase, reflection and transmission of the stress wave take place along the irregular interface in different directions, which leads to the divergence of stress wave. At the same time, plastic deformation can be found in some aluminum phase, part of the stress wave energy was absorbed during this process. So the farther the stress wave propagates, the lower the stress wave amplitude is.
4. Conclusions

From above discussion we can draw the conclusion that stress wave attenuation in SiC$_{3D}$/Al comes from the divergence and consumption of stress wave by the irregular internal micro-SiC$_{3D}$/Al interfaces and slight plastic deformation of aluminium phase within the stress concentration region.

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