FREQUENCY FEATURES OF 3D BASALT FIBER WOVEN COMPOSITES UNDER COMPRESSION AT HIGH STRAIN RATES

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1. Introduction

Three-dimensional (3D) orthogonal woven composites (3DOWC) have high strength, high ratio of modulus to weight and high impact damage resistance owing to the existence of Z system yarns. The aim of studying compression behaviors of 3DOWC in frequency domain is to indicate the failure mechanisms which are hidden in time domain. Gu [1-4] has investigated the impact damage behavior of 3D textile composites in frequency domain, including the 3D braided composite, 3D angle-interlock woven composite, multilayer multi-axial warp knitted composite and co-woven-knitted fabric composite. This study focused on the compression behavior of the 3DOWC under quasi-static and high strain rates. The fast Fourier transform (FFT) method was employed to analyze the compression behavior of the 3DOWC and its energy absorption at various strain rates in frequency domain. It is expected that such analyses could be used to design the structure of 3DOWC. The typical samples cut along the weft direction under the compressive loading conditions were presented in this paper for the introduction.

2. Experimental

2.1 Material

The basalt filament tows without twists were employed to weave the 3D orthogonal woven fabric shown in Fig.1. The basalt filament tows were manufactured by Hengdian Group Shanghai Russia & Gold Basalt Fiber Co., Ltd. Vinyl ester resin (Type RF-1001, manufactured by Shanghai Sino Composite Co., Ltd), the viscosity of which is 0.45 Pas at room temperature, was used to manufacture the woven composite. Butanone and acrylic cobalt were used as the curing agent and catalyst, respectively. The proportion of resin, curing agent, and catalyst was 100:1:0.5 by weight. The unsaturated polyester resin was injected into the 3D orthogonal woven fabric performs with vacuum-assisted resin transfer molding (VARTM) technique to manufacture the 3DOWC. The fiber volume fraction is about 40%. The thickness of the 3DOWC plate is 5.0mm. The composite plates were cut into composite coupons along the warp and weft directions of the woven fabric, respectively. The in-plane size of composite coupons for compressive tests is 9.0×9.0mm. The photograph of 3DOWC coupon is shown in Fig.2.

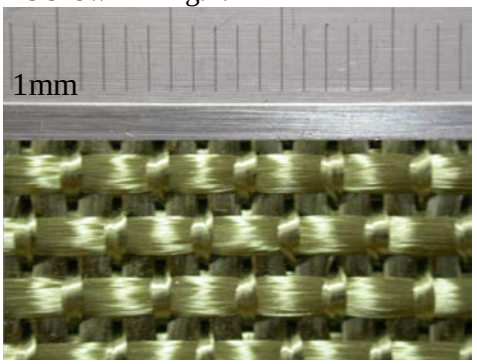

Fig. 1.Photograph of 3D orthogonal basalt woven fabric surface

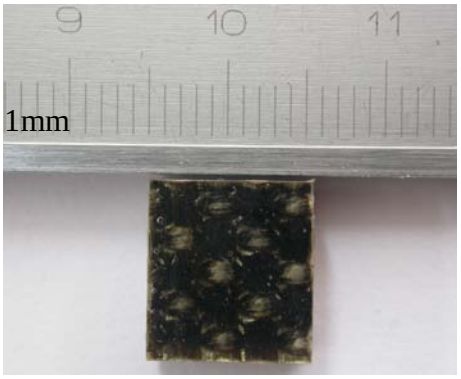

Fig. 2.Photograph of 3D orthogonal basalt woven composite coupon

2.2 Compression impact tests

The mechanical behaviors of 3D basalt fiber woven composite materials under various strain rates have been studied [5]. The in-plane and out-plane compressive properties of 3DOWC under quasi-static and high strain rates (from $800s^{-1}$ to $3500s^{-1}$) have been tested on a MTS 810.23 tester and split Hopkinson pressure bar (SHPB shown in fig.3), respectively. The average properties of 3DOWC along weft direction under compressive load are shown in table 1.

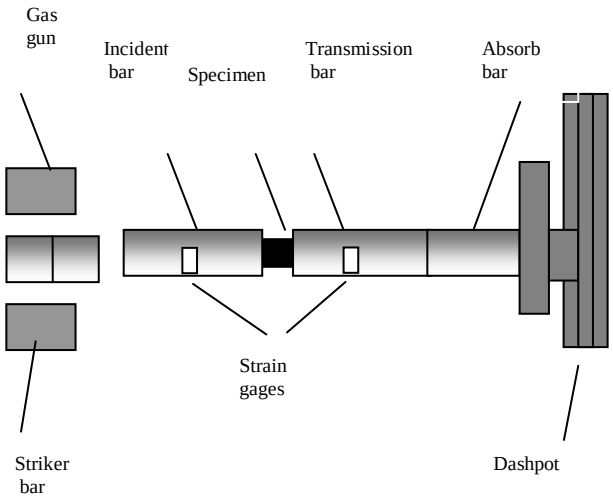

Fig.3.Schematic of split Hopkinson pressure bar

Table1. The properties of 3DOWC along weft direction under compressive load

samples	Rate (/s)	Stress (MPa)	Strain (%)	Modulus (GPa)
W1	0.001	196.2282	4.2	6.17362
W2	800	229.9078	3.6679	8.9199
W3	1500	253.0632	3.3873	11.7415
W4	2100	270.9955	3.0637	14.3366

2.3 Damage morphologies

Both the damage and compression deformation of the composite coupons could be found at high strain rate compression. Fig.3 shows the post-mortem photographs of the compressed composite coupons along weft direction under compressive loading. It is obviously that the damage of the 3DWOC is rate-sensitive. Only compression deformation of the composite could be found in quasi-static compression tests; while both composite damage and compression deformation could be found at high strain rate compression tests. Especially at strain rate of 2100s-1, the composite coupons were compressed into debris. There are failures of reinforcing phase, matrix cracking, fiber failure, etc. And for the damaged coupons, the shear failure could be found. Although there are Z-binder yarns which exist along the through-thickness direction, they will be failure at high rate of compression loading. In quasi-static compression tests, no breaking of these yarns has been found.

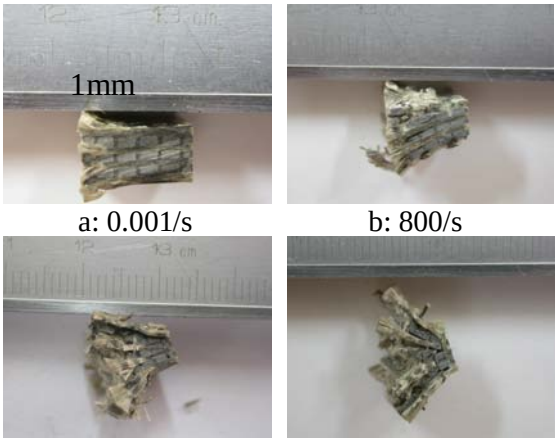

Fig. 3. Post-mortems of 3DOWC coupons after in-plane weft direction compression at various strain rates

3. FFT analyses for the compression behaviors

During compression tests, the stress-time history could be recorded, the stress vs. strain curves could also be calculated as Fig.4 shown. The stress history in time domain can be transformed into frequency domain to find the damage features. Origin 8.0 was employed to analyze the FFT transform.

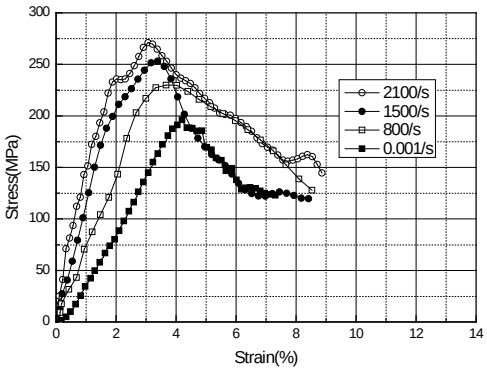

Fig. 4. Stress-strain curves of 3DOWC at various strain rates along weft direction compression

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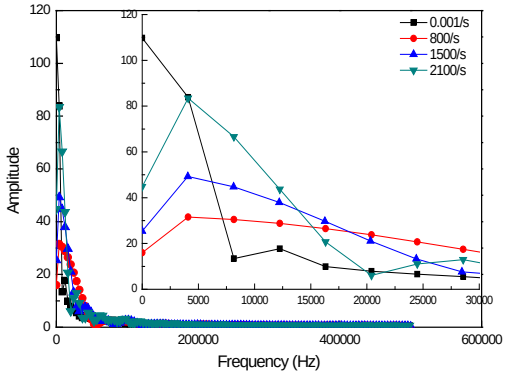
The amplitude, phase and power spectrum under different strain rates along weft direction are illustrated in Figs. 5-7. These amplitude spectrums show that the amplitude distribution concentrates in a narrow frequency region closed to zero under quasi-static condition. The amplitude distribution concentrates in a wide frequency region about 0~100 kHz under high strain rates. The amplitude increases to the maximum value at low frequency and then decreases rapidly. The maximum value of amplitude increases along with the increase of strain rate under the dynamic compression loading.

The phase spectrums show different tendency between the static compression loading and the dynamic compression loading. The phase of the sample under the static compression loading increases as the increase of frequency, while the phase of the sample under the static compression loading decreases. At the higher strain rate the composite specimen reflected a lower phase.

These power spectrums have the similar features as the amplitude spectrums. The energy power of the 3DOWC at quasi-static state is located at lower frequency region closed to zero, and under high strain rates, the energy power distribution is mainly concentrate at the region of 0 ~ 100 kHz, and the maximum value of energy power can be increased when the strain rates increase. The power spectrums of composite specimens under higher strain rates decrease more quickly than those under lower strain rates.



4.

Fig. 5. Amplitude spectrum of 3DOWC under weft direction compression.

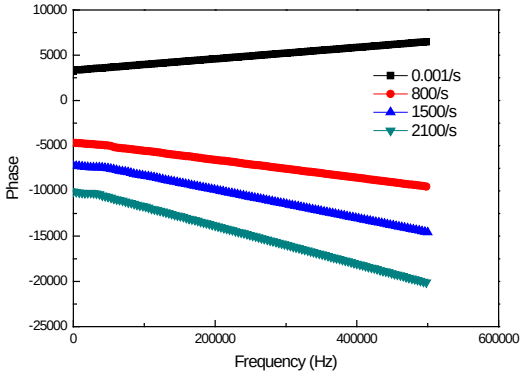


Fig. 6. Phase spectrum of 3DOWC under weft direction compression.

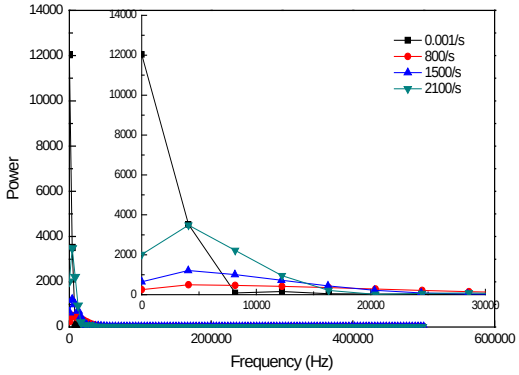


Fig. 7. Power spectrum of 3DOWC under weft direction compression.

The frequency analysis replies the compression fracture behavior of 3DOWC. From the damage

morphologies and frequency analysis, it can be found that the main failure modes are fibers failure at the quasi-static state, and the amplitude and power are locate at a low frequency region closed to zero, which indicates that the main failure mode is fibers failure at a low frequency region closed to zero. Under high strain rates, the failure modes along weft direction are fibers failure and shear damage of matrix, while the amplitude and power are maximize at about 4 kHz. These indicate that each failure mode can correspond to a certain frequency range.

5. Conclusions

Based on the previous researches, the compression features of the 3DOWC along weft direction under various strain rates compression were compared and analyzed in the frequency domain by the fast Fourier transform (FFT) method. There are different frequency features among different directions. The results show that the compression behavior, amplitude spectrums and phase spectrums of the 3DOWC spectrums are strain rates dependent. The 3DOWC can also absorb higher energy in a specific frequency range. The analyses may be beneficial to the application of the 3DOWC in the impact loading design.

6. References

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