

# Z-TRANSFORM ANALYSIS OF CO-WOVEN-KNITTED (CWK) COMPOSITE UNDER TENSION AT HIGH STRAIN RATE

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## 1 General Introduction

The dynamic strength such as compression and tensile impact under various strain rates are understood more difficult than under static and quasi-static, because the microstructures of textile structural composites are heterogeneous and the stress wave velocities in the matrix and tows are more different under high strain rates [1]. Analysis the dynamic mechanical properties, it is known for us, in frequency domain can help to obtain more detail information which shed at time domain. Gu and Chang [2] used the fast Fourier transition method to discuss the energy absorption features of 3-D braided rectangular composite under various strain rates compressive loading in frequency domain. Sun et al. [3] also studied the dynamic compressive behaviors of 3-D angle-inter lock woven composite via Fourier transform and wavelet packet analysis, and results showed that impact energy concentrated on the low-frequency region. However, all of the frequency analysis is focused on the compression behaviors of composite, and the frequency study on tensile impact of composite is still beyond our attention. Anymore, the frequency analysis method likes Z-transform in a discrete system has been discussed, but the Z-transform in tensile impact, a important frequency analysis area, has not been found in any reference.

In present study, the co-woven-knitted (CWK) composite has been treated as a discrete system. Under these conditions, a discrete system transfer function can be established to link the input (strain-time history) and output (stress-time history). Hence, the tensile impact behaviors of CWK composite under various strain rates in the frequency domain

can be characterized. Furthermore, the Z-transform method was used in discrete system to analysis the amplitude, phase response and system stability at the same time. The research can help us understand the strain rate sensitivity and tensile impact behavior of textile structural composites in the frequency domain via Z-transform methods.

## 2 Experimental and results

### 2.1 CWK composite material

The CWK composite was fabricated with an epoxy resin through VARTM process. A mix of Bisphenol A epoxy (Type 618 made by Shanghai Resin Factory of China, tensile modulus: 1.97 GPa, tensile strength: 68.10 MPa) and agent Tri-methyl-hexamethylene-diameter (Type 593 made by Shanghai Resin Factory of China) in a volume proportion of 3:1 was firstly injected into the CWKF by a vacuum-aided resin transfer molding (VARTM) system, and then consolidated at 110°C for 60 minutes. The void content of the composite was less than 1% and the fiber volume fraction was approximately 40%.



Figure 1. CWK reinforced composite coupon for tensile test

## 2.2 experimental results

The tensile impact test of CWK composite were operated under five various strain rates. The stress-strain curves under various conditions are illustrated in figure 2. It can be seen that the stress-strain curves are strain rate sensitive, the stress increases linearly at begins and then decreases gradually after stress reaches a maximum value.

## 3 Frequency analysis and system stability

According with reference [1], the transfer function and frequency response discrete system can be calculated. At the same time, the stability of the system also can be known due to the pole-zero distribution of each composite system.

For the CWK composite at various strain rates as a discrete system, the amplitude and phase responses in the frequency domain are shown in figure 2.

For the CWK composite at various strain rates as a discrete system, the amplitude and phase responses in the frequency domain are shown in figure 3 and 4. Figure 3 shows the amplitude response, which shows that the response is dependent of strain rates. While there is a peak in a low frequency for higher strain rates, which indicated that the composite can absorb more energy in lower frequency. There is a much obvious maximum value when strain rate is 2586/s along  $0^\circ$  direction. However, the amplitude responses at quasi-static state is fixed and have no any obvious change, which mean that the CWK composite has much lower energy absorption ability at quasi-static than higher strain rates.

For the phase responses at various strain rates along different directions, the responses are also interesting. Such as shown figure 4, which indicate that there is no any obvious phase response at various strain rates but 1840/s, the phase response at  $\omega=1840/s$  decrease largely in much lower frequency and keep stability, then increase obviously in a higher frequency, while the phase responses at other strain rates are concentrated on zero and have no obvious changes.

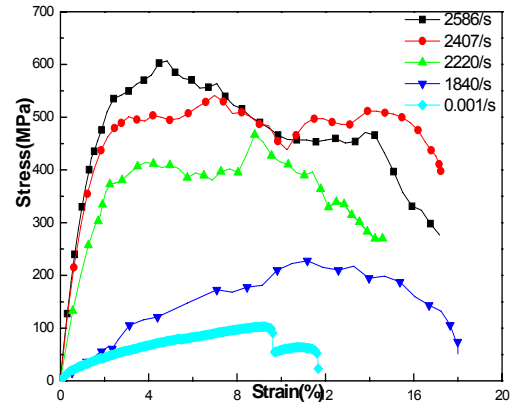


Figure 2. Stress-strain curves of CWK composites at various strain rates

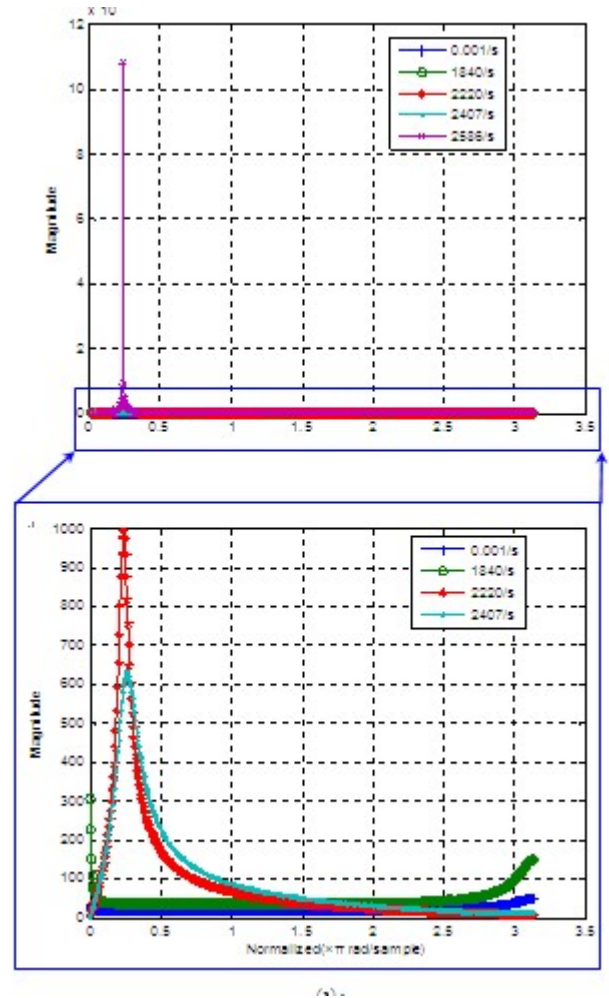


Figure 3. Amplitude responses of CWK composite at various strain rates in discrete system

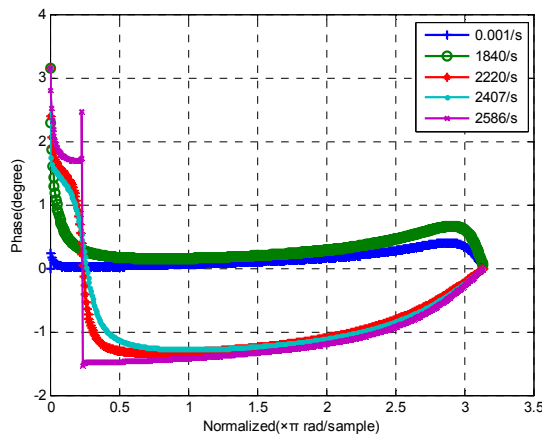


Figure 4. Phase responses of CWK composite at various strain rates in discrete system

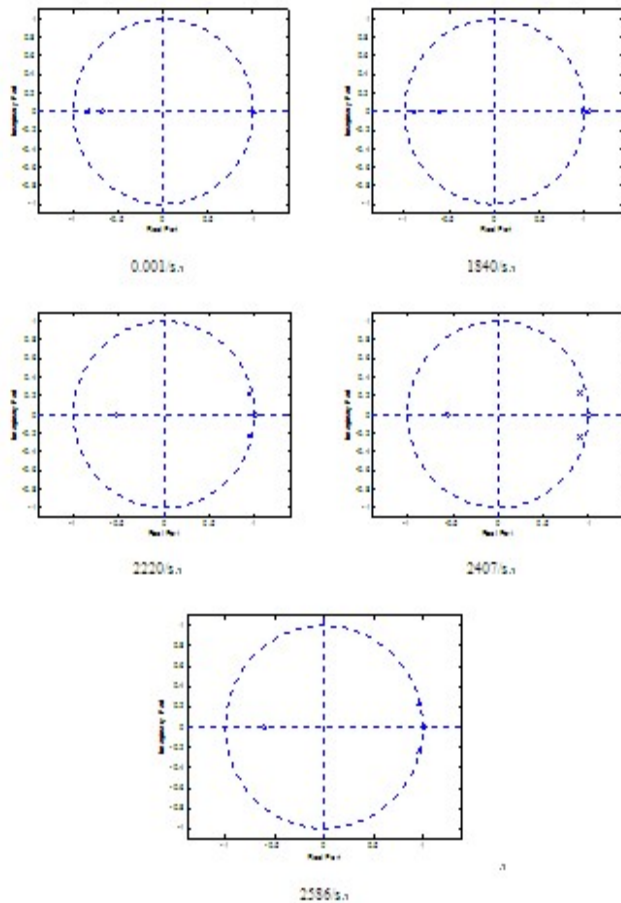


Figure 5. Pole distributions of the discrete system at various strains in discrete system

The pole-zero plots along different directions in continuous system is shown as figure 5. As the

define of stability of continuous system, the system is stability when all poles place the left of the Y-axis, and the system is unstability when one pole is distributed in the right. It can be seen that all plots are not placed in left completely, which means the system is unstability at various strain rates. The pole-zero plots in the discrete system is used to define the stability of system transfer function. This results show that almost all pole plots are placed the unit circle, or near inside. As the define of stability of system transfer function, the system is boundary of stability, while the system is stability during a suitable strain rates.

#### 4 Conclusions

The work analyzed the tensile behavior of CWK reinforced composite at high strain rates in both time domains and frequency domains. The strain-time history and stress-time history were represented the input and output for the system of CWK composite, especially, the CWK composites were treated as a discrete-time system to make a better research.

The results show that, by taking the composite as a discrete system, their various equations and transfer functions can be obtained. For the discrete system, are placed inside of the unit circle, which indicates the system is stable. The comparing systems show that the CWK composite treated as discrete system is reasonable.

#### 5 References

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