Experiments on interface properties for interpenetrating network composites

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Abstract. The mechanical properties of the interface between matrix and reinforcement of INC material are the key parameters that affect the properties of INC materials. Because of many influential factors, it is difficult to accurately analyze the adhesion strength on the interface. In this paper, the tensile specimens of a single reinforcement were prepared, and the tensile forces of different sizes of reinforcement were obtained by uniaxial tensile test. The tangential adhesion strength of the interface was further calculated. It can provide help for the establishment of the finite element analysis model and the development of new INC materials.

1. Introduction
Interpenetrating network composite (INC) is composed of two phases including reinforced and matrix phases. The two phases produced by metal, ceramics etc. are interconnected, inter-twisted and interpenetrated each other in three dimensions. Due to the continuous network structure, the INC has good mechanical properties and wide application in various engineering fields[1-5]. The properties of the interface properties between the two phases have key effects on cutting properties. They are also the important parameters for establishing the finite element model for cutting process. It is therefore important to master the interface property parameters for improving the cutting properties as well as improving the reliability of the established simulation model. Thus the properties were invested by uniaxial tension experiments. The experiment results could provide reliable basis for development of novel INC materials in future research.

2. Experiment Design
The INC materials are composed of two phases including matrix and reinforcement as shown in Fig.1. The reinforcement is designed to network structure with regular or irregular geometric topology structure. According to the previous researches, physical contact usually occurs at the interface between two phase materials. Moreover, there is less chemical reaction and diffusion at the interface. It can be predicted that the stress state is very complex on the interface under the action of external load. Thus the mechanical property parameters on interface are difficult to precisely be acquired. Considering these properties are key parameters for establishing simulation model, thus it is difficult to analyze the properties in cutting process by FEM without precise the parameters mentioned above. As reported in [6], in INC cutting process, the relative slip occurs in the interface tangential direction on interface. So the reinforcement could be pulled out of the matrix in cutting process. Based on this, the tangential mechanical parameters are key parameters for analyzing INC cutting process. Thus, uniaxial tension experiment was proposed to investigate mechanical properties on interfaces. As shown in Fig.2, the overall shape tension specimen bar is cylindrical. A single reinforcement like a silk is set at the center of the specimen. In order to exert tension force, one end of the reinforcement extent out of the matrix bar which can be easily clamped by machine chuck.
3. Specimen Preparation
According to the actual requirements of the material, the INC matrix is aluminium alloy ZL107 and the reinforcement is stainless steel 0Cr18Ni9. The blank bar is firstly produced by negative pressure infiltration casting process. Considering improving the dimensions precision and surface quality, the specimens are turned to be cylindrical bar with a diameter of 40mm and a length of 35mm. In order to analyze the effect of the reinforcement size on interface mechanical properties, the reinforcement diameters are determined to be 1mm, 1.5mm, 2mm, 2.5mm, 3mm, 4mm, 5mm and 6mm, respectively.

4. Experiment Results and Analysis
When the reinforcement diameter is adopted as 3mm, tension force curve varies with displacement is shown in Fig.5. It is found that, in the initial stage, tensile deformation gradually increases with the increasing tensile load. When the curve reaches the maximum, the fixed bonding state between two phases was destroyed which results in relative sliding on interface. When the load continues to be applied, the tensile force decrease gradually, which indicates that the two phase interface materials are
completely separated from each other during this stage. The tangential interaction force between them can be approximately considered as sliding friction force. Therefore, the maximum tensile force at the early stage of the test curve could be considered as the tangential adhesion force at the two phase interface. Thus, the force value represents the bonding properties of the two phase interface.

According to the above analysis, tensile tests were carried out for other group of specimens. The maximum tensile forces were measured, and the average values marked as $F$ were subsequently calculated for each group of specimens. The relationship between the maximum tangential adhesion force and the reinforcement diameter is obtained as shown in Fig.6. It can be seen that with the increase of the reinforcement diameter, the interfacial adhesion force $F$ between the single reinforcement and the matrix increases gradually. On the other hand, with the increase of the reinforcement diameter, the contact area on the two phase interface also increases, so the maximum tensile force can not represent the actual bonding characteristics of the interface. It is necessary to calculate the interfacial adhesion force per unit area of the reinforcement diameter. The calculation method is shown in equation (1).

$$\tau = \frac{F}{\pi d l}$$

where: $F$  adhesion force on interface  
$\tau$  tangential adhesion force per unit area  
$d$  reinforcement diameter  
$l$  axial length of reinforcement

The relationship between the adhesion force per unit area and the reinforcement diameter is shown in Fig.7. It can be found that the force value decreases with the increase of the reinforcement diameter, then increases gradually, and finally tends to a constant value. This indicates that the interfacial
adhesion properties of INC materials are related to the casting conditions and material properties, but not to the shape and size of the reinforcement. When the reinforcement diameter is small, the reinforcement is rapidly heated up to high temperature, which makes fluidity and wettability better. The interfacial bonding between the two phases is better, and the interfacial adhesion force of the two phases is larger. When the reinforcement diameter continues to increase, the interface area increases more, which causes casting properties drop largely. Moreover, the micro defects at the interface will affect the binding state of the two phases, so the interfacial adhesion force of the unit area will gradually decrease.

![Image](image_url)

**Figure 7.** Relationship between adhesion force per unit area and reinforcement diameter

According to the experiment results, it has higher interfacial bonding strength when the reinforcement diameter is 1mm. At the same time, a smaller diameter can be easily used to weave the reinforcement phase into a reasonable network geometry structure, so as to make the material get better performance. Therefore, the subsequent INC materials are prepared with reinforcement phase with a diameter of 1mm. when the Analysis of cutting INC materials is carried out by using the finite element method, it is necessary to create constraint on the interface between two phases. Thus the results of the interfacial bonding strength obtained by experiment can be regarded as node stress which is the essential parameters for effective establishing INC cutting model.

5. Conclusions
This paper suggests that the interfacial bonding characteristics of INC materials are important factors that affect the cutting characteristics of INC materials. The interfacial bonding strength was measured by uniaxial tension test. According to the experimental results, it is proven that when the reinforcement diameter is 1mm, it has good interfacial bonding properties and is also conducive to material preparation. In addition, the experimental results provide powerful support for the finite element cutting model of the INC material.

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