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Effect of fish scale biomimetic structure on composite bonding properties

QinghuaLi,Shuangyue Zhao
School of Mechanical Engineering, Changchun University, Changchun, China
Correspondent: Qinghua Li

ABSTRACT: *In order to solve the problem of composite bonding structure, it is easy to fall off. In this paper, a new bionic scale structure is proposed to study the effect of bionic scale structure on adhesion performance under the same experimental conditions. Firstly, the change of stress and strain under normal adhesion conditions and bionic scale structure are compared and analyzed based on simulation experiment. Secondly, the distribution spacing of bionic scale structure was changed to investigate the effect of bionic scale density on adhesion performance. Finally, the effects of normal structure and biomimetic scale structure on adhesion performance were evaluated from the angle of stress and strain. It was found that the biomimetic scale structure was optimized by 23.5% and 5.3% compared to normal structural stress and strain, and that the viscosity increased by changing the density of the biomimetic scale structure.*

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NOMENCLATURE

Symbol	Description	Unit
P	Maximum force of specimen destruction	MN
S	Adhesive area of sample	m^2

Greek letter

σ_{sh}	Composite and metal bonding strength	MPa

Key words: Bionics; Shear strength; Fish scale structure; Finite element analysis

I. THE INTRODUCTION

Adhesive is widely used in manufacturing processes [1-3]. Studies have shown that gluing is the best way to connect structures that do not need to be disassembled. Adhesive bonding has the characteristics of high bearing capacity, uniform distribution of force, high specific strength and stiffness, and good performance of absorbing energy and reducing vibration and noise. In order to improve the friction performance of bonded structures, the use of composite materials has become very common in recent years. Liu Yu and others designed several bonding specimens with different bonding angles to test the ultimate failure strength, obtained the fracture stress of the adhesive at different angles, and then put forward a method for evaluating the bonding strength of the rail vehicle bonding structure. Dong Liqiang compared the shear adhesion strength and interface morphology of different borax admixture, hydrogel ratio and age of magnesium phosphate cement substrates to obtain the optimal ratio of magnesium phosphate cement substrates for road composites [6]. The compound synchronous ring is obtained by using modified epoxy resin to bond the carbon fiber cloth to the synchronous ring, which improves the thermal and abrasion resistance of the synchronous ring. But with the development of modern tribology and biomimetics, it has not been found that smoother surfaces are more conducive to composite bonding [8-10]. Hou Xianglong and others investigated the mechanical behavior of shell-pearl layers and their structure-optimized composites with "brick wall" configurations. [11] The team of Yu Shuhong of the Chinese University of Science and Technology has discovered a procedural method for assembling nanofibers, and successfully created a novel lightweight, high-strength, non-continuous Bligan-like nanocomposites with "brick wall" configurations.

It is found that the application of microstructure to composite bonding is rare and there is a lack of targeted research to prove the effect of microstructure on adhesion, stress and strain. Therefore, three bionic scale structures with different spacing are designed in this paper. The effects of bionic scale structures on stress and strain are studied by finite element simulation, and the optimal spacing structure is optimized. Adhesive tensile test was carried out between the preferred bionic scale structure and pit structure.

II. COMPOUND ADHESIVE FINITE ELEMENT ANALYSIS

1.1 Modelling

In order to determine the adhesion strength of composite adhesions, a four-plate method (GB / T 12830-91) for determination of the adhesion strength of vulcanized rubber to metal was used in this paper [13]. The four-plate bonding model, shown in Figure 1, consists of four iron plates interlaced with epoxy resin and Kevlar fabric. The shear force is measured using a stretch tester by applying tension at both ends until the bond is separated.

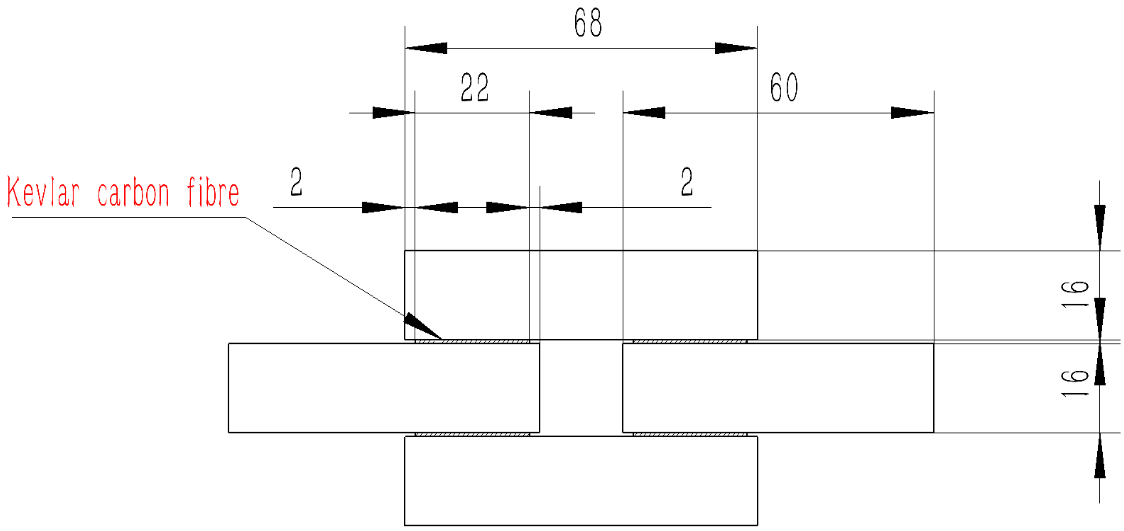


Fig. 1 Four-plate method for tension measurement

Since the four plates are integrated with the carbon fiber cloth after bonding, all their boundary conditions are set to be combined. The grid partition is shown in Figure 2, and the bond layer between epoxy resin and Kevlar fiber after curing is modeled as a whole for the purpose of finite element analysis due to the lower external force of the grid density set at 5 mm, as shown in Figure 3. The density of the strong grids between the fabric and the crater is set at 1mm, the structure shown in Figure 4 can be hidden by the middle plate, and the use of tetrahedral grids is more conducive to delineating complex fish-scale structures [14-16].

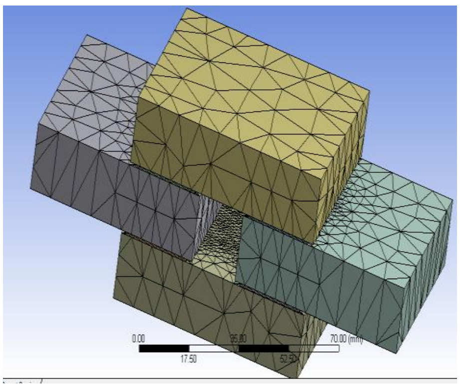


Fig. 2 Overall Meshing by Four-PlateMethod

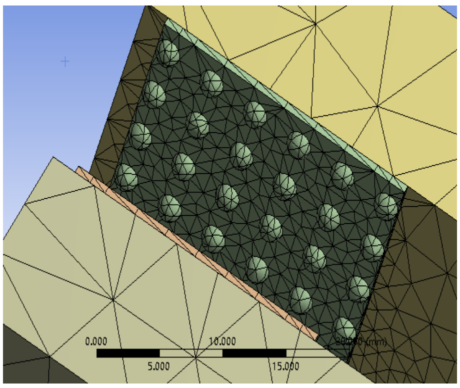


Fig. 3 Fiber Bonds

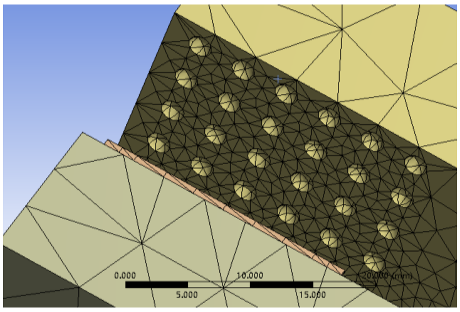


Fig. 4 Meshing of Pits

In order to ensure that other factors do not influence the results of the analysis, the grid division of the fish scale structure is consistent with that of the pit bonding grid. At the same time, in order to observe the strain at the joint, the strain at the joint can be seen directly by hiding the upper plate (all the strain diagrams in this paper are hidden upper plate).

1.2 Pit adhesion simulation

In this paper, a spherical pit with a diameter of 1mm is designed and its array is arranged on the surface of the metal plate. The stress and strain are obtained by finite element analysis, as shown in figures 5 and 6. Since the spherical structure is the first to bear the pressure during tension, the stress is concentrated in the spherical structure. When a tension of 50 N is applied at both ends, the stress value in the pit adhesion is 2.4567 e5Pa and the strain value is 5.7626 e -5 mm.

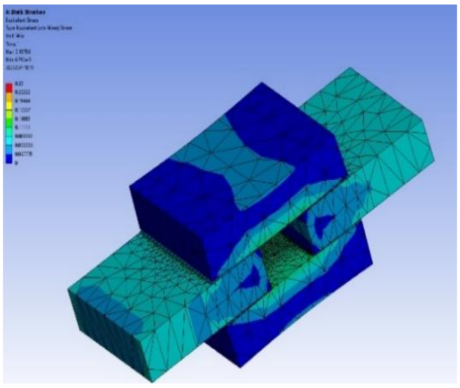


Fig. 5 Pit adhesion Stress diagram

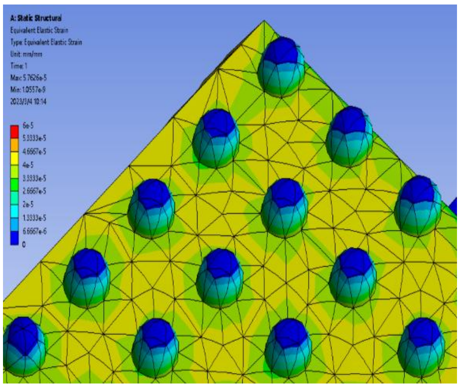


Fig. 6 Pit adhesion Strain diagram

1.3 Fish Scaly Structure Adhesion Simulation

Fish scales have high strength and toughness [17]. Modeling mimics the structure of fish scales to create the structure shown in Figure 7 [18-19]. The stress and strain cloud is obtained by finite element analysis with the same parameters as the concave adhesion setting as shown in Fig. 8 and Fig. 9. The stress values of fish scales are 2.0959 e5Pa and 5.6069 e -5 mm from figures 8 and 9. Compared with the pit structure, stress decreased by 14.7% and strain decreased by 2.7%. Because the shape of the scale structure is arched and can withstand greater shear force when applied to the tensile force, the adhesion of the scale structure is better than that of the pit structure.

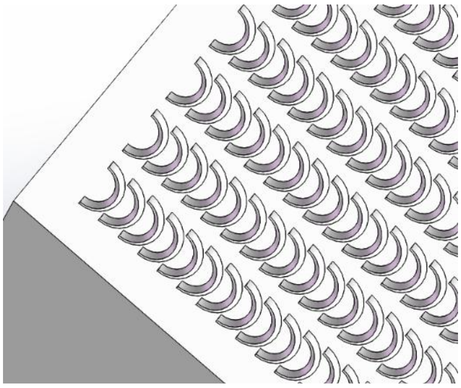


Fig. 7 Fish scale biomimetic structure

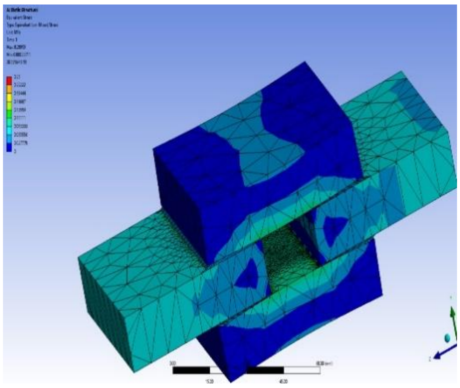


Fig. 8 Scalyadhesion Stress diagram

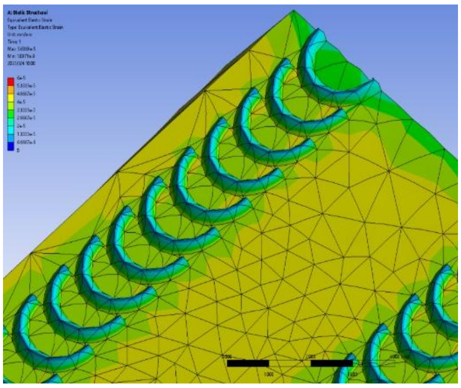
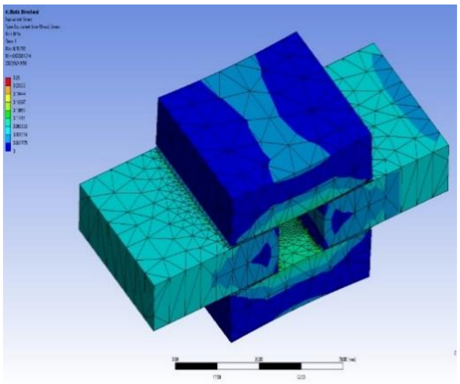


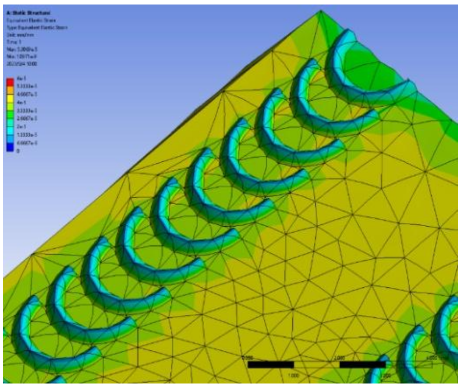
Fig. 9 Scalyadhesion Strain diagram

1.4 Simulation of Scaly Structure Adhesion at Different Spaces

In order to optimize the scale structure further, three types of scales with different spacing, 3mm, 5mm and 7mm, were set up in this paper. They were modeled by finite element analysis, and the stress strain clouds shown in Figure 12 were obtained by applying the same strain.

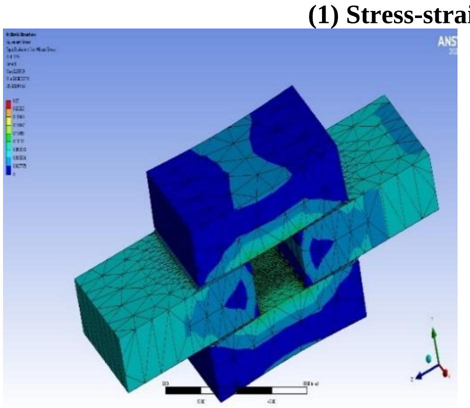


(a)Stress diagram

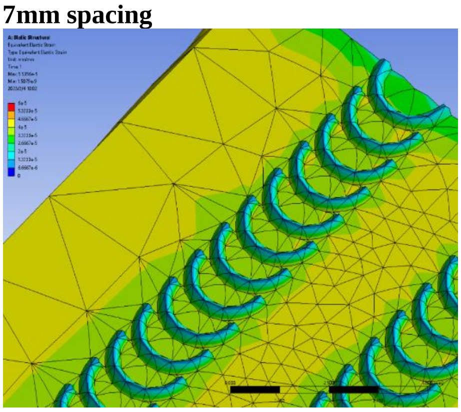


(b) Strain diagram

(1) Stress-strain clouds with 7mm spacing

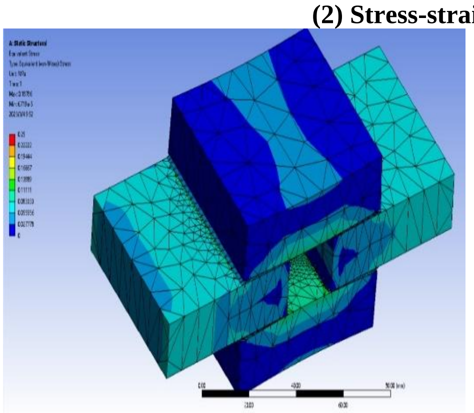


(a)Stress diagram

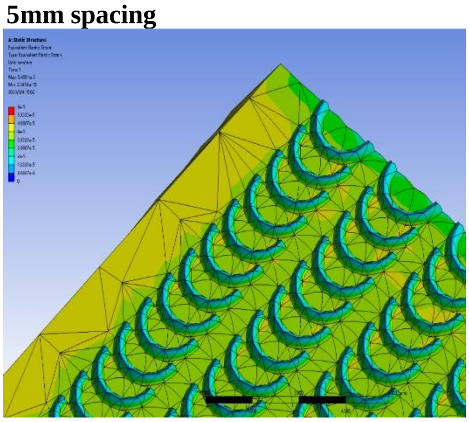


(b) Strain diagram

(2) Stress-strain clouds with 5mm spacing



(a)Stress diagram



(b) Strain diagram

(3) Stress-strain clouds with 3mm spacing

Fig. 10 Stress-strain clouds of three species of scales adhesion

Ascan be seen from Figure 10, the stress-strain distribution is concentrated in the fish scale structure. Compared to the 7mm scale structure, the stress of the 5mm scale structure is reduced by 5.7%, the strain is reduced by 1.3%, and the stress of the 3mm scale structure is reduced by 10.4% and the strain is reduced by 2.7%. This is because as the spacing between the scales decreases, the number of fish scales increases, further increasing the area of adhesion between the glue and the structure. Carbon fibre cloth comes into close contact with the metal surface, making the bond stronger. Therefore, the smaller the spacing between the scales, the smaller the stress strain.

III. BIONIC FISH SCALE STRUCTURE BONDING EXPERIMENT

2.1 Materials & Equipment

Materials and equipment used in this paper include 18 CrMnTiH plates (consistent with the materials in the synchronous ring), Kevlar fabric, non-inertial (electronic) stretch testers, ovens, electronic scales, ultra-depth of field microscopes, and 1mm inverted angle knives.

2.2 Preparation of fish scale and pit structures

The surface of the 18CrMnTiH plate is smoothed with a grinder to remove the burrs on the surface, and then a 45-degree inverted angle knife is used to process the fish scale structure in the engraving mill. Due to the number of structures processed, 798 structures need to be processed on one side of the largest plate. High-speed engraving millers are selected for both efficiency and quality to ensure their quality and to avoid the vibration of the machine at low speeds. At the same time through the lubricating oil will be timely chip out to ensure the processing quality. The finished object is shown in Figure 11.

Fig. 11 Fish Scale Structure

The concave structure uses a spherical milling cutter to create a semi-spherical concave on the surface as shown in Figure 12.

Fig. 12 Pit Structure

2.3 Adhesive tensile test

In this paper, epoxy resin is used as the main adhesive for bonding. The epoxy resin needs to be heated and melted before bonding for easy application. However, epoxy resin is more viscous, and the two groups of structures are bonded according to the standard of the four-plate method by adding catalyst.

In this paper, the shear force is measured using a tensile tester. The glued specimen is mounted on the tensile tester as shown in Figure 13, then positioned so that the specimen is relaxed and the tensile velocity is set at 20 mm / min for tensile testing [20].

Fig. 13 Test Equipment Diagram

The maximum load of the scale structure is $32.19 \times 10^{-3} MN$ The maximum load on the pit structure is $30.26 \times 10^{-3} MN$
The strength of both is calculated according to the following formula.
$\sigma_{sh} = \frac{P}{S}(1)$
According to the formula, the adhesion strength of the fish scale structure was 19.77 MPa and that of the pit structure was 18.59 MPa. It can be explained that the strength of the scale structure is higher than that of the pit, which is consistent with the simulation.
2.4 Stretching test of scales at different intervals
Adhesive and tensile experiments were carried out on three types of scales, and the maximum load of 3mm scales was $38.45 \times 10^{-3} MN$, the maximum load of 5mm scales was $35.78 \times 10^{-3} MN$, the maximum load of 7mm scales was $32.19 \times 10^{-3} MN$, According to formula (1), the adhesion strength of fish scales was 23.62 MPa, 21.98 MPa and 19.77 MPa, respectively.
Compared with the three results, the 3mm scale structure has the best effect. The smaller the scale spacing, the better.

IV. CONCLUSION

In this paper, the effects of fish scale structure on compound adhesion performance are studied by means of finite element simulation and tensile test. The optimization of bionic scale structure is evaluated from the angle of stress and strain, and the following conclusions are obtained:
1. In both simulation and tensile tests, it is found that the fishscale structure can optimize the adhesion performance of the composite, and the stress and strain values decrease, increasing the adhesion of the material.
2. By changing the distribution density of fish scale structure, it was found that with increasing density of fish scale structure, the stress and strain were decreasing gradually, and the 3mm scale structure was better than the other two kinds of spacing.
3. By constructing bionic fish scale structure, we can optimize the difficulty of adhesion and easy shedding of composites, which provides theoretical basis for the adhesion of composites.

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