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The Test for Withstanding Fracture Capacity of Worm Gear Made of Antifriction Composite Material of Polymer Matrix Under Static Loads

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Abstract: Worm gear is usually made of bronze, which is a precious and nonferrous metal. In order to substitute for the bronze, a new kind of antifriction composite material of polymer-matrix, ZW-1 material has been successfully developed. Compared with worm gear made of bronze, worm gear made of ZW-1 material has made worm gear transmission possess many advantageous properties. In order to bring the excellent properties of worm gear transmission of ZW-1 material into play and substitute for bronze, the test for anti-fracture capacity of worm gear made of ZW-1 material under static load has been made. A simple test-bed is designed. The test has been carried out under static load. The test of worm gear with ZW-1 and nylon materials, different teeth numbers、tooth width and tooth forms is made. The test findings show that in the test conditions the invalidation of ZW-1 worm gear is radial fracture in gear rim. Applying stress transmission theory and micrographic analysis, fracture mechanism of ZW-1 material is found out, namely degumming on the interface between fiber and polymer. Anti-fracture capacity of worm gear of ZW-1 material is twenty three times as much as that of bronze worm gear(Q/ZB125-73).Archimedes worm gear has the same anti-fracture capacity as arc tooth worm gear of ZW-1 material. Macrographic analysis shows that load concentration and contact stress concentration of bolt hole caused by bending bolt are significant factors which affect invalidation of worm gear. The test result shows an important fact that overlapping coefficient of worm gear transmission of ZW-1 material worm gear is much higher than that of calculating in theory, for small modulo of elasticity has a good effect upon the worm gear transmission of ZW-1 worm gear.

Keywords: Worm gear transmission; Composite material of polymer matrix; ZW-1 material

1 Introduction

Worm gear transmission has been widely used in engineering because of its compact structure, smooth running and non-noise and big transmission ratio, etc. The rim of worm gear is usually made of bronze, which is a precious and nonferrous metal. The economic loss caused by the consumption of bronze is very tremendous. Therefore, it is an inevitable trend to develop new kinds of substitute materials for bronze. At present, the research on the worm gear material mainly centres on the development of zinc-aluminium alloys all over the world[1][2][3]. Zinc-aluminium alloys possess good casting, friction and wear properties as well as mechanical properties.However, above 100℃, some properties of alloys are decline, for example, low strength, easy creepage and big coefficient of thermal expansion. An overview of the development of the fibre reinforced composite material of polymer matrix shows that composite material of polymer matrix has many characteristics, such as high strength ratio and stiffness ratio, good heat stability, resistance to impact, corrosion resistance, wearability and so on[4].Therefore, it is a very important method to form composite material by applying reinforcing, stuffing and modifying to engineering plastic in order to obtain high performance composite material used for worm gear. On the basis of tribology[5], Changxiang Qi[6] successfully developed a new kind of composite material of polymer matrix (called ZW-1 material) used for worm gear and patented the invention of novel material in China. The further study on it shows that worm gear transmission of ZW-1materil possesses more advantageous properties such as small coefficient of friction, easy and reliable lubrication, good wearability, high

transmission efficiency and low temperature of heat balance and so on. Especially, it has two characteristic properties, namely its transmission efficiency has nothing to do with the types of lubricating oil and tooth geometry of worm gear[7]. Based on achievements mentioned above in scientific research in order to study further the capacity of the ZW-1 worm gear, we find out the form of its invalidation, dig out the potential capability of it, improve it and put it into practice.

2 Summary of ZW-1 Worm Gear

Developing ZW-1 material is based on the tribology. The ingredients of ZW-1 materials, proportion of the ingredients and manufacturing process are selected reasonably in order to make it possess good comprehensive friction properties, mechanical property and physical property etc. Soviet Union scientist[8] puts forward that, in the condition of dry and boundary friction, the mechanism of friction and wear about metal, polymer and composite material can be well explained by molecular and mechanical theory and that destructive property of adhesive points formed on the friction surface is very important to mechanism of friction and wear. In order to bring about external friction, he made a gradient rule of shearing strength. Interaction and destructive process on the surface of two objects must be confined to the thin layer and the shearing strength of the thin layer must be smaller than that of matrix. By shearing strength gradient rule, the softer layer needs to be formed in the matrix.

According to the characteristics and properties of polymer matrix, solid lubricant and reinforced fibre, and requirements of developing the antifriction composite material with best comprehensive property, the nylon 6(PA6) was chosen as matrix, graphite and MoS2 were chosen as solid lubricant and fibre glass and carbon fibre as reinforced fibre. By cross-testing, the best ingredient ratio was fibre-glass 35%, graphite 2%, MoS2 2%. The composite material with the proportion possesses the best property of tribology, called ZW-1 material (Table 1).

Table 1 Raw Material Used for ZW-1 Material

Raw material	Size	Raw material	Size
MoS_2	2~5μm	Carbon fibre	0.003 mm
Graphite	40~60μm	Glass fibre	10~13μm
PA6	φ3×3mm	-	-

The manufacture process of ZW-1 worm gear mainly includes the preparation of raw materials, design and process of die, injection and shaping of worm gear blank and machining. The grain material is made by blending powder material, plasticating and making grain. The worm gear blank shaped by injection needs to be machined, therefore, the size of moulding core is more than the design size of worm gear. Before worm gear blank is injected and shaped, nylon should dry sufficiently because of hydrophilic factors in large molecules, for example, polyamide plastic, which absorbs moisture easily. ZW-1 worm gear is machined in the same way of the bronze worm gear. Heat treatment of worm gear blank must be made before fine machining in order to eliminate internal stress and avoid material instability.

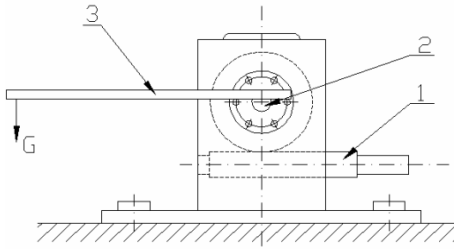
3 Test For ZW-1 Worm Gear

The test is an essential study based on the achievements in scientific research mentioned above in order to study further the maximum capacity of the ZW-1 worm gear, find out its invalidation, explore the potential capability of it, improve it and make it apply early in engineering.

From the overview of the research on worm gear transmission made of bronze, the research mainly focuses on the contact of teeth surface, the friction, wear and temperature rising. The study on bending strength of the teeth root has been seldom carried out. The bronze material has better mechanical and bending property than that of ZW-1 material. ZW-1 worm gear has low bending strength compared with the bronze worm gear transmission. Therefore it is very important to study withstanding fracture capacity of ZW-1 worm gear under static load.

3.1 Test-bed and requirements

Because bending test of the teeth root is seldom made, at present there is not any test-bed which might be used. A simple test-bed is designed. We change a worm gear reduction into experimental device (Fig.1). According to the self-locking of worm gear transmission, by acting on the worm gear axle under static loads, bending test of the worm gear can be carried out.



1-Worm shaft 2-Worm Gear 3-Level

Fig.1 Experimental device Diagram

The test was made in WH-1 Archimedes worm gear reduction. Its central distance is 80mm. There are three kinds of experimental worm gears: Archimedes ZW-1 worm gear with tooth width b=42,22,20mm, arc ZW-1 worm gear with width b=36,25,20mm arc nylon worm gear with width b=36,25,20mm (Fig.2).

Under testing, meshing position of worm and gear on axial section should be installed symmetrically, load being added steadily and without any impact force.

Fig.2 Experimental Worm Gear

3.2 Experimental Results

Loads are added steadily step by step until worm gear is broken, and then torque acting on the worm gear axle is calculated. Torque diagrams of invalidation of them are shown as follows (Fig.3~Fig.5):

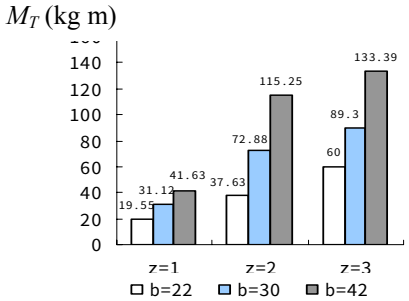


Fig.3 Torque Diagram of Invalidation of Archimedes Tooth ZW-1 Worm Gear

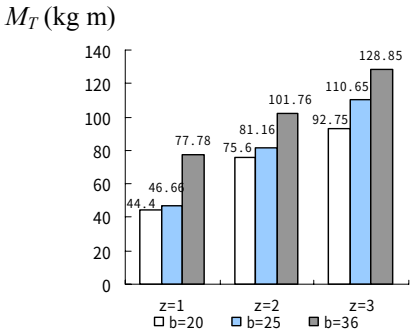


Fig.4 Torque Diagram of Invalidation of Arc Tooth ZW-1 Worm Gear

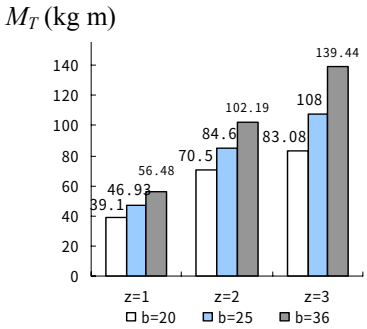


Fig.5 Torque Diagram of Invalidation of Arc Tooth Nylon Worm Gear

4 Experimental Result Analysis

4.1 The Maximum Capacity of ZW-1 Worm Gear

Figure3~Figure5 show the static load bearing torque of worm gear of ZW-1 and Nylon materials with different teeth numbers (z) and different tooth widths(b). The static load bearing torque of three teeth mesh of Archimedes ZW-1 worm gear is 133.39kgm, twenty three times as much as that of the Archimedes bronze worm gear(Q/ZB125-73, M_e=5.7kgm), and that of Arc tooth ZW-1 worm gear is 128.85kgm, seven times as much as that of the arc bronze worm gear(Q/ZB125-73 ,M_e=16.9kgm). This shows that ZW-1 worm gear has high anti-fracture capacity. The invalidate torque of Arc nylon worm gear is 139.44kgm, but its invalidation is plastic deformation of gear rim Archemides worm gear has the same anti-fracture capacity as arc tooth worm gear of ZW-1 material.

4.2 Invalidation of ZW-1 Worm gear

Figure6～Figure8 illustrate the invalidation of three teeth mesh of Archimedes, Arc ZW-1 worm gear and Arc Nylon worm gear.

For the ZW-1 material, worm gears show radial fracture of gear rim[Fig.6~7], and the invalidation of nylon worm gear, plastic deformation of the gear rim[Figure8]. The invalidation of ZW-1 worm gear is different from that of bronze worm gear. This shows that the strength of teeth root of worm gear is larger than that of gear rim when mesh teeth numbers of worm gear are three. But, theoretical calculation gives that overlapping coefficient is 2.12. The reason why teeth mesh numbers are about three is that the elasticity modulo of ZW-1 material (E=4940MPa) is lower, 4.8 per cent of that of bronze (E=103GPa). Being loaded, ZW-1 material has large elastic deformation, which has an increasing effect on overlapping coefficients. Therefore, small elasticity

modulo can have a good effect on worm gear transmission.

Apart from gear rim fracture, there are bolt fracture and the whole structure deformation. The position of fracture takes place at the tooth root of the first mesh tooth of gear[Fig.6~7], for this position bears the biggest loads. The destructive bolt is the one of the nearest fracture section[Fig.6]. At the same time, theconcentration of contact stress of bolt holes caused by the bolts is also significant factors affecting strength of worm gear. In order to develop the capacity of ZW-1 worm gear, the whole structure strength should be investigated further.

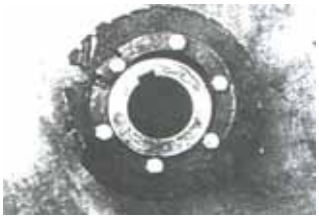


Fig.6 Invalidation of Three Teeth Archimedes ZW-1Worm Gear (b=42)

Fig.7 Invalidation of Three Teeth Arc ZW-1Worm Gear (b=36)

Fig.8 Invalidation of Three Teeth Arc Nylon Worm Gear (b=36)

4.3 Fracture Mechanism Analysis

Figure9 is a photograph of fracture section of ZW-1 worm gear taken by an electron microscope. From the photograph, we know that many holes are left after fibre being pulled out. That means that fracture mechanism of worm gear is degum on the interface between fibre and matrix. Degum is the main invalidate form of ZW-1 worm gear. According to the Rosen's shear-lag method[9] for analyzing stress transference of short fibre composite material, when fibre stress reach the maximum value, namely the fibre strength X_f, the fibre critical length l_{cr} is:

$$l_{cr}=\frac{dXf}{2\tau s} \qquad (1)$$

It is an important property of short fibre reinforced composite material because stress borne by fibre in the critical length is smaller than X_f. If the fibre length is much longer than the fibre critical length, the property of composite material will approach the property of continuous fibre reinforced composite material. ZW-1 material concerned, glass-fibre X_f is equal to1100MPa，diameter 10～13μm, glass fibre length l 2.5~3mm, matrix nylon 6(PA6) and nylon τ_s 67MPa, so critical length is:

$$l_{cr}=\frac{dXf}{2\tau s}=\frac{11\times 1100}{2\times 67}=90\mu m < l=2.5\sim 3mm$$

Obviously, the critical length calculated by theory is smaller than the actual length of glass fibre. The stress borne by glass fibre would reach the most of the stress X_f. But fibre mostly is degummed. Stress borne by fibre glass can not reach X_f. Therefore, the strengthening function on the composite material of polymer matrix by glass fibre dose not bring into play sufficiently. By means of the micrographic analysis, the reason why the fibre could not reach X_f is the low adhesive strength on the surface between fibre and matrix. Therefore the adhesive strength has a great effect on the strength of the short fibre reinforced composite material.

Fig.9 Micrographic Photograph of the Fracture Section of ZW-1 Worm Gear

5 Conclusions

Based on the experimental results and the fracture mechanism analysis of ZW-1 worm gear, conclusions are obtained as follows:

a. The invalidation of ZW-1 worm gear in the test condition is the radical fracture of the gear rim.

b. Worm gear with ZW-1 material has sufficient withstanding fracture capacity under static load. The load bearing capacity of Archimedes ZW-1 worm gear is twenty three times as much as that of the bronze worm gear (Q/ZB125-73). Archimedes worm gear has the same anti-fracture capacity as arc tooth worm gear. Therefore, ZW-1 material is a kind of good substitute material for bronze used for worm gear.

c. By the fracture mechanism analysis of worm gear, the reason why the reinforced effect on ZW-1 material by fibre glass is not sufficient enough is that

adhesive strength of adhesion agent is low. Therefore, in order to bring fibre glass reinforced effect on the ZW-1 material into play sufficiently and improve the strength of ZW-1 material, the strength of adhesion agent should be increased.

d. The strength of ZW-1 worm gear is influenced by the comprehensive factors, such as the ingredient proportion of materials, structure and manufacture of worm gear, etc. The strength of teeth of ZW-1 worm gear cannot be considered as only reliability target of worm gear strength. The strength of the whole structure of ZW-1 worm gear should be investigated in order that ZW-1 material worm gear can be applied early in engineering.

e. With low elasticity modulo of ZW-1 material, numbers of mesh teeth are about three, therefore, small elasticity modulo has a good effect on worm gear transmission.

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