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Bearing strength of low-infill 3D-printed composites

Taiga Okamoto[a], Akira Todoroki[b*], Gen Endo[b]

[a] Graduate student at Institute of Science Tokyo, Tokyo, Japan

[b] Department of Mechanical Engineering, Institute of Science Tokyo, Tokyo, Japan

ABSTRACT

This paper deals with the bearing strength of bolted joints. To reduce structural weight, low-infill-rate structures are usually adopted for robot arm structures. Although many researchers have reported the bearing strength of laminated composites, the bearing strength of low-infill-rate 3D-printed structures has not been reported. This paper presents a new bearing strength test method applicable to thick structures. Using the new jigs, the effects of the thickness, twin hole effect, and rotation of the print axis on the plastic yielding strength were experimentally investigated using short carbon fiber/PA-6 composites. As a result, the thickness of the specimens had no effect on the strength, the twin hole reduced the strength by 36%, and the rotation of the print axis increased the strength by 30%.

Keywords: Bearing strength, Infill rate, Short carbon fiber composites, Twin hole effect.

1.Introduction

Haddington Dynamics Co. Ltd. has successfully reduced costs by 58% using a 3D-printed composite robot arm. In the robot arm, the motor torque is transmitted to the arm structure by many bolts arranged around the circumference. Currently, it is necessary to fasten the motor and decelerator using many bolts arranged around the circumference to transfer the motor torque to the arm.

The most practical 3D printer for printing continuous carbon fiber composites is the Markforged Mark Two® printer. For the Mark Two, fiber arrangement is performed using Eiger® Markforged slicing software. Eiger sometimes leaves areas where the fiber paths are not arranged around the bolt holes near the arm's structural edge. Thus, a conservative evaluation requires only short-fiber composite materials around the bolt holes. Additionally, to transfer the motor torque to the arm, the weakest hole must not plastically deform. Furthermore, the robot structure is a thick plate, and to reduce the weight, designers want to reduce the infill rate. Therefore, a thick structure with a low infill rate should be considered for robot arm design. This requires a new bearing strength test method that differs from that of ASTM D5961.

In this study, we proposed a new test method capable of conducting bearing strength tests on thick test specimens and experimentally investigating the effect of specimen thickness on plastic deformation. Additionally, the effect of the relationship between hole position and infill structure was experimentally investigated.

* Corresponding author
Email: todoroki.a.aa@m.titech.ac.jp
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2. New bearing test method and specimens

The newly developed bearing test method is shown in Fig. 1. The specimen configuration is shown in Figs. 2 and 3. PH-1 has a single hole, and the tests were conducted to investigate the effect of specimen thickness using three different specimen thickness: 6, 12, and 18 mm. The infill rate was only 36.6%, and the triangular fill pattern was adopted here. The PH-2 test specimens have two holes, as shown in Fig. 2, to experimentally investigate the effect of the relationship between hole position and infill structure. The PH-2-r45 specimens were printed at an angle of 45° from the print bed axis to investigate the effect of rotation.

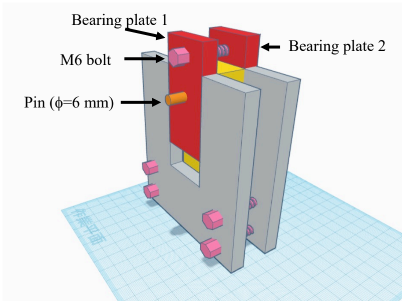

Fig. 1 Setting of the new bearing test jigs.

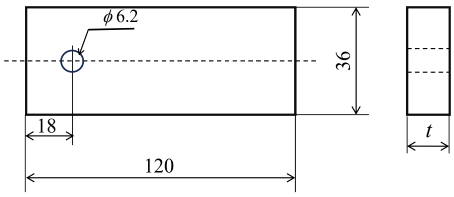

Fig. 2 Specimen configuration of the PH-1 specimen.

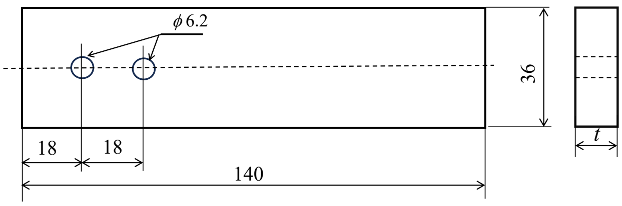

Fig.3 Specimen configuration of the PH-2 specimen type.

3. Experimental results and discussion

The the bearing strength of the PH-1 specimens are listed in Table 1. In Table 1, σ_{BF} is the bearing strength defined from the maximum load and σ_5 means the bearing strength defined from the load at the beginning of yielding using the 5% offset line method (yielding strength). The results show that specimen thickness has no effect on the σ_5 strength.

Table 1 Averaged bearing fracture strength and bearing proof stress of the PH-1.

Thickness [mm]	σ_{BF} [MPa]	STDEV	σ_5 [MPa]	STDEV
6	34.0	1.77	25.4	2.79
12	28.9	2.62	24.6	1.57
18	31.3	2.01	25.6	2.26

As shown in Table 1, there is no effect of specimen thickness; the specimens of PH-2 with a thickness of 6 mm were fabricated. The mean value of σ_5 was 16.2 MPa. σ_5 of PH-2is smaller than that of PH-1 by 36%. The plastic deformation around the two holes indicates that the deformation of the upper hole is smaller than that of the lower hole. The mean value of σ_5 of PH-2-r45 was 21.0 MPa, which is 30% larger than that of PH-2. There was a small difference between the plastic deformation around the two holes of PH-2-r45.

For specimen PH-2, the specimen surface layer is ±45°, and the print path pattern is the same between the upper and lower holes. However, the infill pattern differs. Figure 4 shows the print path patterns of PH-2. The red arrows indicate that the print paths of the infill on the load-bearing side (right side of the hole) differ between the upper (left) hole and the lower (right) hole. This resulted in difference in the plastic deformation around the hole and a decrease in σ_5 compared to the σ_5 of the PH-1.

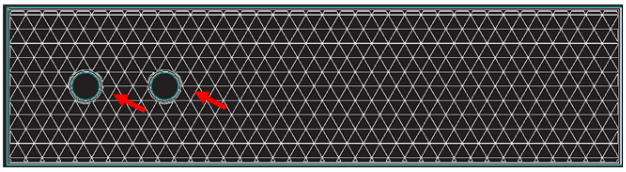

Fig. 4 Print paths of the inner layer of the PH-2 type specimen. Read arrows show the difference of the supporting infill structure between the two pin holes.

For specimen PH-2-r45, the surface layer is 0°/90°. The infill pattern is different from that of PH-2. Figure 5 shows the print path patterns of PH-2-r45. As the surface layer of PH-2-r45 is 0°/90° which has higher stiffness, σ_5 increased with increasing higher yield strength of the surface layers.

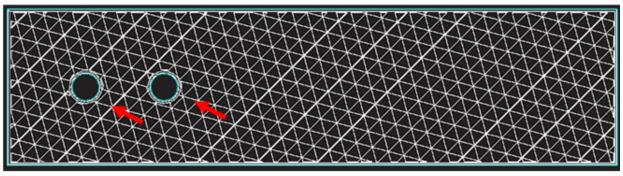

Fig. 5 Print paths of the inner layer of the PH-2-r45 specimen. Read arrows show the difference of the supporting infill structure between the two pin holes.

4. Conclusions

(1) Using a small infill rate of 36.7%, bearing strength tests were performed with newly designed jigs. There is no effect of specimen thickness on the yielding bearing strength of the single-hole specimens.

(2) The yielding bearing strength of the two-hole specimen is 36 % lower than that of the single-hole specimen. This decrease was caused by the different infill path patterns around the two holes.

(3) The 45°-rotated specimens had different surface layers and infill patterns. The specimens exhibited 30% higher yielding bearing strength.

(4) The yield bearing strength changes with 45° rotation, which means that when the bolt holes are arranged around the circumference, such as in motor torque transmission, the yield bearing strength varies depending on the hole position.

References

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