Agora of Additive Manufacturing (2024) paper24005

JAMS

Agora of Additive Manufacturing

journal homepage: http://additive-manufacturing.or.jp/

Proposal of 3D Printed Parts Joining Method for Larger Size

Noirsato KANAI[a], Gen ENDO[b*]

[a] School of Engineering, Institute of Science Tokyo, Tokyo, Japan

[b] School of Engineering, Institute of Science Tokyo, Tokyo, Japan

ABSTRACT

In recent years, it has been expected that conventional parts used in industrial robots can be replaced with 3D printed materials to reduce weight and improve performance. However, producing large parts in one piece using a 3D printer takes work. This is due to the problem of thermal shrinkage and the fact that the size of the part depends on the bed size of the 3D printer. Therefore, it would be highly versatile if small parts could be joined easily and without losing strength to form large parts. We proposed a new joining method by mating and bonding square pyramidal concavo-convex parts and evaluated its strength by three-point bending tests. As a result, a strength of about 140% was obtained compared to Z-X bulk materials of the same size. Comparisons were also made with different shapes and materials to demonstrate the effectiveness of the proposed joining method.

Keywords: 3D Printing, Additive Manufacturing, Potassium Titanate Fiber Reinforced Material, Joining

1. Introduction

3D printing technology facilitates the production of complex shapes that are difficult to achieve with traditional machining processes, leading to its increasing application across various fields. In industrial robotics, 3D printed materials are anticipated to contribute to lightweight designs by replacing conventional parts. However, the fabrication of large parts in a single piece faces challenges, such as the size limitations of 3D printers and dimensional inaccuracies due to thermal shrinkage. This study aims to address these issues by proposing a novel joining method that enables the assembly of large parts by dividing them into smaller parts for later connection, thus expanding the scope of feasible applications. While existing joining methods, such as Friction Stir Welding (FSW) and conventional screw fastening, are available, they present challenges related to equipment costs and joining condition settings. This research seeks to overcome these limitations by developing a joining technique with higher strength and broader applicability.

2. Proposed joining method

In this paper, the build direction of the specimens shown in Fig. 1 is referred to as the X-Y direction, while the build direction shown in Fig. 2 is referred to as the Z-X direction.

* Corresponding author
Email: endo.g.aa@m.titech.ac.jp
Received 19 June 2024; Revised 2 October 2024; Accepted 21 October 2024
Available online 1 November 2024

The proposed joining method involves fitting parts with square-pyramidal concavo-convex shapes and bonding them with an adhesive. Fig. 3 represents the convex part, while Fig. 4 denotes the concave part. The dimensions are as follows: width of 20 mm, height of 20 mm, distance from the end of the protrusion to its base of 16 mm, with a base dimension of 18 mm × 18 mm, and a protrusion length of 48 mm with an apex angle of 8.0°. The convex part is fabricated in two parts along the X-Y direction, bonded with adhesive, and then fitted and adhered to the concave part such that the joining interface is perpendicular to the build plate. The concave part has a length of 64 mm and is fabricated along the Z-X direction. After joining, the combined dimensions of the convex and concave parts result in a 20 mm × 20 mm × 80 mm structure (Fig. 5). This shape is specifically designed to ensure that the bonding interface remains as perpendicular as possible to bending loads, thereby facilitating uniform adhesive application. The square-pyramidal geometry is also expected to enhance strength against moments (torsion) around the long axis. This configuration enables stable strength performance even under loads applied from different directions.

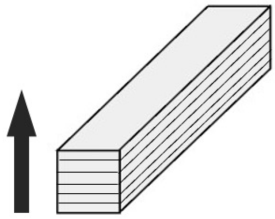

Fig. 1 Build direction (X-Y)

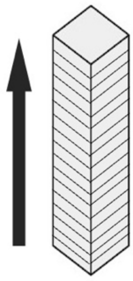

Fig. 2 Build direction (Z-X)

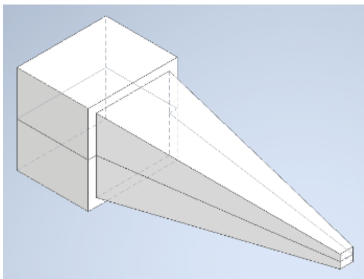

Fig. 3 Convex part

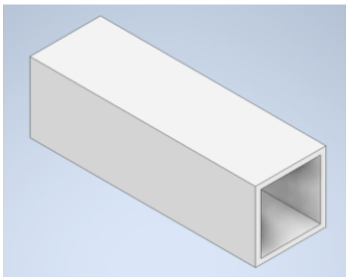

Fig. 4 Concave part

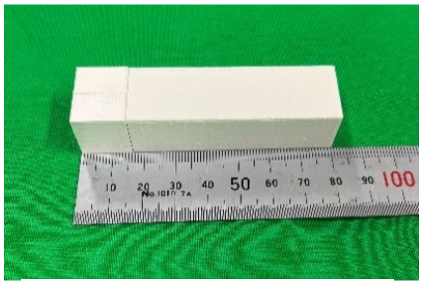

Fig. 5 After joining

3. Test methods and results

The material used in this study was potassium titanate fiber-reinforced nylon filament (POTICON filament, NTL34M[1], manufactured by Ltd. Otsuka Chemical Co.). The testing method employed was a three-point bending test using an Autograph universal testing machine (Shimadzu Corporation, model AGX-20kNVD). In this study, three different experiments were conducted to evaluate the effectiveness of the proposed joining method. These experiments included

1. a comparison of joining methods with varying geometries,
2. a comparison of different materials and
3. an evaluation using low-fill-rate, larger printed objects.

In each experiment, bending strength and bending modulus were assessed.

The first experiment involved a comparison between the proposed joining method and alternative methods (screw fastening, conical shape, and square-pyramidal shape). With the proposed joining method, results showed a bending strength of 139% and a bending modulus of 74.4% relative to the reference specimen (100% infill specimen fabricated in the Z-X direction). The results are shown in Fig. 6, 7, and Table 1.

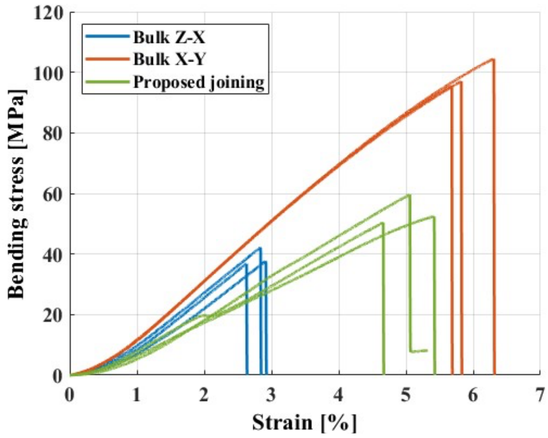

Fig. 6 Results of three-point bending test (Proposed joining)

Table 1 Summary of results (Comparison of shapes)

Shape	Bending strength [MPa]	Bending modulus [GPa]
Bulk (Z-X)	38.9	1.60
Bulk (X-Y)	99.0	1.95
Proposed joining	54.1	1.19
Screw (ϕ18)	39.1	1.14
Screw (ϕ10)	26.0	0.973
Cone	48.7	1.27
Pyramid	52.0	1.35

These results confirmed that the proposed joining method demonstrated the highest bending strength, indicating that the joint's geometry significantly contributes to its strength.

Next, tests were conducted using different materials to verify the proposed joining method's effectiveness with other materials (Z-ULTRAT[2] and Onyx[3]). Z-ULTRAT is a high-performance ABS-based 3D printing material known for its durability, temperature resistance, and interlayer solid adhesion, making it ideal for functional prototypes and industrial applications. Onyx is a high-strength 3D printing material that combines nylon with chopped carbon fibers, resulting in enhanced stiffness, durability, and heat resistance, making it suitable for producing functional prototypes and industrial-grade components.

The results are shown in Fig. 8, 9. Specimens of each material were fabricated to the same dimensions, and three-point bending tests were performed using the proposed joining method. Z-ULTRAT, an ABS-based material, showed a bending strength of 83.5% relative to the reference specimen (Z-X). This result is likely due to the characteristics of the adhesive used and the high ductility of Z-ULTRAT itself. Onyx displayed a trend similar to that of POTICON, with a bending strength reaching 107% of the reference specimen, confirming that the proposed joining method also applies to other materials.

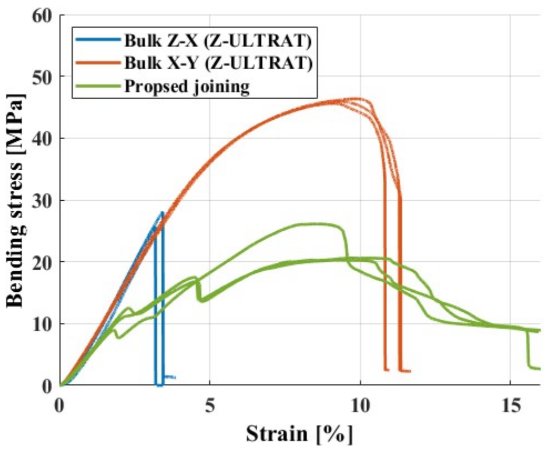

Fig. 8 Results of three-point bending test (Z-ULTRAT)

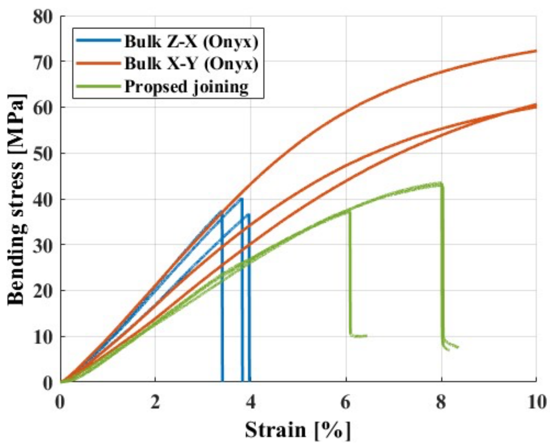

Fig. 9 Results of three-point bending test (Onyx)

From these results, it was determined that while the proposed joining method exhibits high bonding strength independent of the material, variations in material properties affect the outcomes. Therefore, appropriate adhesive selection and condition adjustments are necessary.

Finally, to verify the effectiveness of the proposed joining method under more practical conditions, tests were conducted using specimens fabricated at a low infill rate (37%) with dimensions of 20 mm × 20 mm × 160 mm. For specimens using the proposed joining method, only the joint area was set to 100% infill, while the remaining sections were fabricated with a 37% infill rate (Fig. 10, 11). In specimens utilizing the proposed joining method, a bending strength of 42.3 MPa and a specific strength of 21.7 kNm/kg were achieved, indicating an improvement in strength due to the 100% infill at the joint area. Notably, although increasing the infill rate at the joint area resulted in a slight increase in overall mass, the corresponding enhancement in strength more than compensated for this increase.

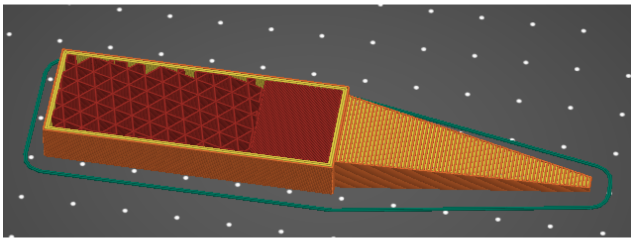
Fig. 10 Inner structure (Convex part)

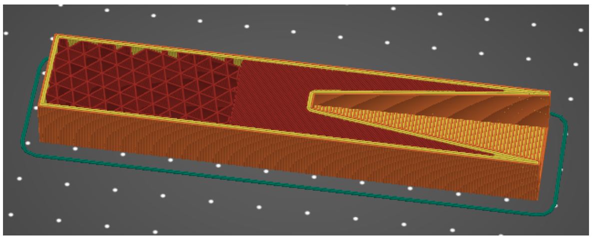
Fig. 11 Inner structure (Concave part)

Table 2 Summary of results (practical conditions)

	Mass [kg]	Bending strength [MPa]	Specific strength [kN · m/kg]
A. Specimen	0.0422	36.7	27.8
B. Proposed joining	0.0625	42.3	21.7

These results determined that while the proposed joining results demonstrate that even at low infill rates, adjusting the infill rate specifically at the joint area can reduce weight while maintaining sufficient strength. This approach effectively balances weight reduction and strength retention in large parts, such as robotic arms.

4. Conclusions

(1) A new joining method using mating and bonding square-pyramidal parts was developed to upscale 3D-printed parts.
(2) Among various joint geometries tested (including screw fastening, conical, and square-pyramidal shapes), the proposed method demonstrated the highest bending strength, achieving 139% of the bulk Z-X specimen's strength.
(3) The proposed method was tested with different materials, showing similar behavior with some, but further testing with a broader range of materials is necessary for comprehensive evaluation.
(4) Practical testing with larger specimens and reduced infill rates confirmed that optimal infill settings can achieve both lightweight properties and sufficient strength.

References

[1] Ltd. Otsuka Chemical Co., POTICON TISMO Reinforced Compound., https://www.otsukac.co.jp/ products/chemical/poticon/, Accessd: November 28, 2023.
[2] TECHNICAL DATA SHEET, chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://cf.zortrax.com/wp-content/uploads/2018/06/Z-ULTRAT_Technical_Data_Sheet_eng-1.pdf, Accessed: April 8, 2024.
[3] Markforged MATERIAL DATASHEET, chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://web-objects.markforged.com/craft/materials/CompositesV5.2.pdf, Accessed: April 8, 2024.