Experimental Study of the Vibration Weld Strength of Dissimilar Thermoplastic

Yu Chen¹, Zhuangzhuang He¹ and Xijun Wang²
¹College of Engineering, China Agricultural University, Beijing, China
²Ningbo SPRing Auto Parts Co, Ltd, Ningbo, China
*Corresponding author e-mail: cydesign@cau.edu.cn

Abstract. The strength of vibration weld between dissimilar thermoplastic is a crucial index to evaluate the safety and stability of the structures. It can be classified into normal strength vertical to the surface and shearing strength along the surface according to different failure modes under load. In this paper, a set of tensile experiments were designed and operated to measure the normal strength and the shearing strength. Experiment results show that: 1) the vibration weld strength increases along with the increase of material’s Young module; 2) impact of the vibration direction on the weld strength is not obvious as the same basic and welding plastic material.

1. Introduction
Vibration welding is a highly efficient plastic vibration welding technology [1, 2, 3, 4], and is widely applied in automobile, household electrical appliances, aircraft manufacture and medical sectors. As a crucial indicator in the evaluation of structure safety and stability, the plastic bonding strength and mechanical properties is a focus in the research of vibration welding. Vijay K. Stokes once conducted some experimental study on the welding of some certain plastic materials, and collected the experimental data for the weld strength of different materials under different welding parameters [5, 6]. Recently, Leyu Lin etc. studied the impact of material formulation on weld strength [7, 8]. In China, Hualong Zhou etc. analyzed the impact [9] of material formulation, welding technology and other factors on the vibration weld strength of glass fiber reinforced nylon 6. Xingcheng Yang etc. studied the impact of technical conditions on welding structure and mechanical properties [10, 11].

It could be concluded from the above analysis that the current study on plastic weld strength mainly focuses on material formulation and technical conditions, and mainly adopts tensile experiments. However, in practical engineering the load on weldments is complicated, and the studies on other basic mechanical properties are rare. This paper studied the plastic weld strength using polypropylene (PP) as base material, and thermoplastic polyolefins (TOP) and glass fiber reinforced PP (PPGF) as welding materials. It introduces a plastic vibration welding method, and determines the failure strength of two welding materials through tensile experiment, to provide engineering reference for its application.
2. Specimen processing
This weld strength experiment used 3 materials: PP, TPO and PPGF, with their respective physical properties described in Table 1.

| Materials | Density (g/cm$^3$) | Young’s modulus (MPa) | Poisson’s ratio |
|-----------|--------------------|-----------------------|----------------|
| PP        | 1.08               | 2050                  | 0.40           |
| TPO       | 0.98               | 120                   | 0.40           |
| PPGF      | 1.21               | 5000                  | 0.36           |

This experiment used PP as base material, and PPGF and TPO with rib as welding materials. The experimental purpose was to test the weld strength between PP and PPGF, and PP and TPO. Such strength can be divided into normal strength vertical to the surface and shearing strength along the surface, thus corresponding normal and shearing tensile experiments were designed accordingly.

Vibration welding technology produced flash on the weld face. In order to reduce flash, the cross section of the specimen’s weld rib was designed as Fig. 1, which was 1.8 mm in height, leaving 1 mm residual height after processing; and 1 mm 1.92 in width at the top, leaving 2 mm width after processing. The groove at the top of the rib could effectively reduce the flash produced from the welding process and realize thorough welding between materials. The deformation of weld ribs’ section shape before and after the processing was shown in Fig. 2.

Figure 1. Section sizes of weld ribs.  
Figure 2. Deformation of weld ribs’ section shape due to weld.

The specimen was divided into three types: “+”, “—” and “|”, based on the rib shape. The weld area was 258mm$^2$ for “+”, 132mm$^2$ for “—”, and 130mm$^2$ for “|”.

The processing sketches of traverse specimen and longitudinal specimen were shown in Fig. 3 and Fig. 4. The arrow on the upper clamp indicated the vibration direction of the vibration plate. Before the processing, fixed the base material onto the upper clamp (vibration plate), and placed a certain amount of welding materials PPGF, or TPO weldment on the lower clamp (fixation table) in longitudinal or traverse direction. The same specimen with different vibration direction could be produced for different arrangement direction, as a preparation for further studying the impact of vibration direction on weld strength. Took “—” rib shape specimen for example, the specimen in Fig. 3 was labeled “longitudinal —” due to the longitudinal arrangement of weld rib and vibration plate, and the specimen in Fig. 4 was labeled “traverse —” due to the traverse arrangement of weld rib and vibration plate.
3. Experiment equipment

The equipment used for testing weld strength was EHF-LB20KN-20L fatigue testing machine, with the maximum load of 20 KN, tensile rate of 300 mm/s and data output interval of 0.1 ms.

4. Experiment method

4.1. Shear strength experiment

Conducted tensile experiment on the specimen, with the load direction parallel to the weld face. Fixed the two sides of PP base material onto the clamp with steel plate, and connected the steel plate with the working end of the fatigue testing machine so that when it worked at certain tensile rate, shear stress would be formed on the weld face. Analyzed the data collected in terms of the displacement of the working end and load change with time and generated the shearing strength of the weld face. The device for tangential strength experiment was shown in Fig. 5 and its sketch was shown in Fig. 6.

4.2. Normal strength experiment

In normal strength tensile experiment, the load direction was vertical to the weld face, and the device was slightly different from that for tangential tensile strength experiment. Since plastic material was comparatively soft and its deformation would have significant impact on the experiment result. In order to reduce the deformation of plastic materials, the four points of the weldment were fixed between two layers of steel plates.

The upper steel plate had the same size with the weldment, and the lower steel plate was a square shaped hollow steel plate. The load was applied on the center of the upper steel plate. During the tensile process, normal stress would be formed in the weld face, and the failure strength would be generated by analyzing the experiment data. The device for normal strength experiment was shown in Fig. 7 and its sketch was shown in Fig. 8.
Fig. 7 and Fig. 10 shown the square fixture designed to prevent the significant deformation of the plastic material. The weldment fixation device was shown in Fig. 9 and its sketch was shown in Fig. 10.

5. Experiment result
The working end displacement and load change with time of the fatigue testing machine were recorded automatically, and the load applied to different materials and different specimen were drawn into curve with the highest point of the curve recorded as the failure weld point. The failure strength of the weld face could be generated by dividing maximum load by weld area.

5.1. PP and TOP weld strength experiment results
Fig. 11 shown the tensile load curve of PP and TPO traverse weld specimen in tangential strength experiment; and Fig. 12 shown the tensile load curve of PP and TPO longitudinal weld specimen in normal strength experiment. The x axis represented time (unit: ms) and y axis represented load value (unit: N), the number “1” and “2” represented the two times repetitions on the same specimen.

The maximum load and failure time of weld face could be generated from Fig. 11 and Fig. 12. The failure strength of the weld face could be calculated from the maximum load value in the load curve and the weld area of the specimen.
Figure 11. Tangential tensile load curve of transverse vibration welding between PP and TPO.

Figure 12. Normal tensile load curve of transverse vibration welding between PP and TPO.

The comparison on the failure strength of PP and TPO weld specimen was shown in Fig. 13. The x axis represented different specimen and y axis represented failure strength of different specimen. The load curve and comparison of normal strength experiment for PP and TPO welding could be generated with the same method as shown in Fig. 14.

It could be concluded from Fig. 13 and the comparison results in Fig. 14 that in the tangential strength experiment on TPO and PP welding, the strength difference was significant with “longitudinal+”, “traverse+” and “longitudinal—”, “traverse—”, while not so obvious with “longitudinal|”, “traverse|”; and in the normal strength experiment on PP welding, the strength difference was not as significant among the three specimen “+”, “—” and “|”.

Figure 13. Comparison of tangential strength between transverse and longitudinal vibration welding [TPO].

Figure 14. Comparison of normal strength between transverse and longitudinal vibration welding [TPO].

5.2. PP and PPGF weld strength experiment results
The comparison on tangential strength and normal strength PP and PPGF welding was shown in Fig. 15 and Fig. 16.
Figure 15. Comparison of tangential strength between transverse and longitudinal vibration welding [PPGF].

Figure 16. Comparison of normal strength between transverse and longitudinal vibration welding [PPGF].

It could be concluded from the tensile experiment results of PPGF and PP welding that in the tangential strength and normal strength experiments on the two materials, the failure strength difference was not significant for the same specimen, which meant PPGF and PP weld strength was not related with weld direction.

6. Conclusion

Tensile experiment is conducted with fatigue testing machine to determine the weld strength of different materials. As shown in the load curve, the curve shape is similar between the two weld specimens in the tangential strength experiment, but the break load and time are different, as demonstrated in Fig. 17. It indicates that under tangential load, the weld face of the specimen fails at the same time; while in normal tensile experiment, the load curves of “+” specimens roughly equal the superposition of “—” and “|”, which means in normal tensile experiment, the transverse and longitudinal rib weld faces fail first, as demonstrated in Fig. 18. Therefore, for large scale weld products, under tangential load, the weld faces fail simultaneously; and under normal load, the weld faces fail partially.

In addition, it can be concluded from the strength comparison calculated from experimental results:

(1) When welding different weldments with same base material, the weld strength has significant relationship with Young’s modulus of weldments. And the weld strength increases with the Young’s modulus.

(2) The tangential strength is greater than normal strength for plastic welding. In this experiment, the tangential strength for PPGF and PP, and TPO and PP is 2-4 times greater than the normal strength.
(3) When welding TPO and PP with small Young’s modulus, the weld direction has greater impact on tangential strength, while not so obvious on normal strength.

(4) When welding PPGF and PP with big Young’s modulus, the weld direction has insignificant impact on tangential strength and normal strength.

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