Joint Efficiency of Ultrasonic Welding of CFRTP for Structural Applications

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Abstract

To apply CFRTP (carbon fiber reinforced thermoplastics) to various industrial fields as a material for structural members, it is necessary to establish affordable jointing methods. Mechanical fastening such as bolt connection and rivet connection, adhesive bonding and welding are well known as jointing methods for structural members. In this research, we focused on ultrasonic welding method using thermal plasticity of CFRTP itself since its affordable equipment and welding speed may be suitable for mass production automobile. Concretely, several types of CF/PP (carbon fiber reinforced polypropylene) were used, and both single lap joint and cross joint specimens were prepared by using ultrasonic welding. Then the effects of surface preparation, ultrasonic conditions, etc. on the joint efficiency were investigated.

1 Introduction

1.1 Background

Among all types of CFRP (carbon fiber reinforced plastics), the most common matrix resin is thermosetting resin such as epoxy. CFRTS (CFRP with thermosetting resin matrix) shows several superior performances like heatproof and high specific strength, leading to a considerable potential of weight-lightening. As a result, CFRTS has been applied to special industrial fields such as aircraft, F1 and space usage [1]. However, long time and expensive equipments are necessary for CFRTS's molding, which causes high processing cost, then CFRTS's application field has been limited.

On the other hand, CFRTP (carbon fiber reinforced thermoplastics) is expected to realize low-cost and high-cycle molding, along with improvement of process ability, repair ability and recyclability. Hence, though there remain some technical difficulties in such as weaker interfacial adhesiveness between CF and thermoplastics, and impregnation of thermoplastics into CF-bundle, CFRTP has a possibility to lighten the weight of mass production automobile drastically.

Especially, the largest difference between CFRTP and CFRTS is the molding method. Because CFRTS is a brittleness material, CFRTS is molded as possible to avoid making holes and joint parts. Therefore, manufacturing facilities of CFRTS are large-scale and expensive such as autoclave, which is major reason of the limited application field of CFRTS [2]. However, CFRTP can be easily deformed and jointed by heat, then press molding and welding joint like metals can be used for their manufacturing.

Then, to apply CFRTP to various industrial fields as structural material, it is necessary to establish affordable jointing methods. Mechanical fastening, such as bolt connection, rivet connection, adhesive bonding and welding are well known as jointing methods for structural members [3]. In this research, we focused on welding joint by using the thermal plasticity of CFRTP itself to apply to automotive structural members [4]. Carbon fiber reinforced polypropylene is used to clarify its' basic characteristics of joint efficiency by using both single lap joint specimen and cross joint specimen.

2 Consideration about testing condition

2.1 Welding time

Welding time is one of the most important parameters for ultrasonic welding. We need to take a certain level of welding time to let resin on joint surface melt. The purpose of this consideration is to clarify the most suitable welding time for the material we used.

We made test pieces of 15×100×2 mm for UD (unidirectional) material, provided by MITSUBISHI RAYON CO., LTD. and TOYOBO CO., LTD. Then we jointed by ultrasonic welding under the condition of 25 mm of lap length and 0.3-2.0 sec of welding time. The frequency of ultrasonic wave is 20 kHz.

We calculated average shear strength by the equation below:

$$\bar{\tau} = \frac{F}{LB} \tag{1}$$

where $\bar{\tau}$ is average shear strength, F is maximum load, L is lap length and B is breadth of test piece respectively.

Figure 1 shows the joint areas after shear tests. Figure 2 shows the relationship between welding time and average shear strength. When we jointed under the condition of 1.3 sec and more, smoke reeked up from joint surface. We found that 1.0-1.2 sec is the suitable condition for this material.

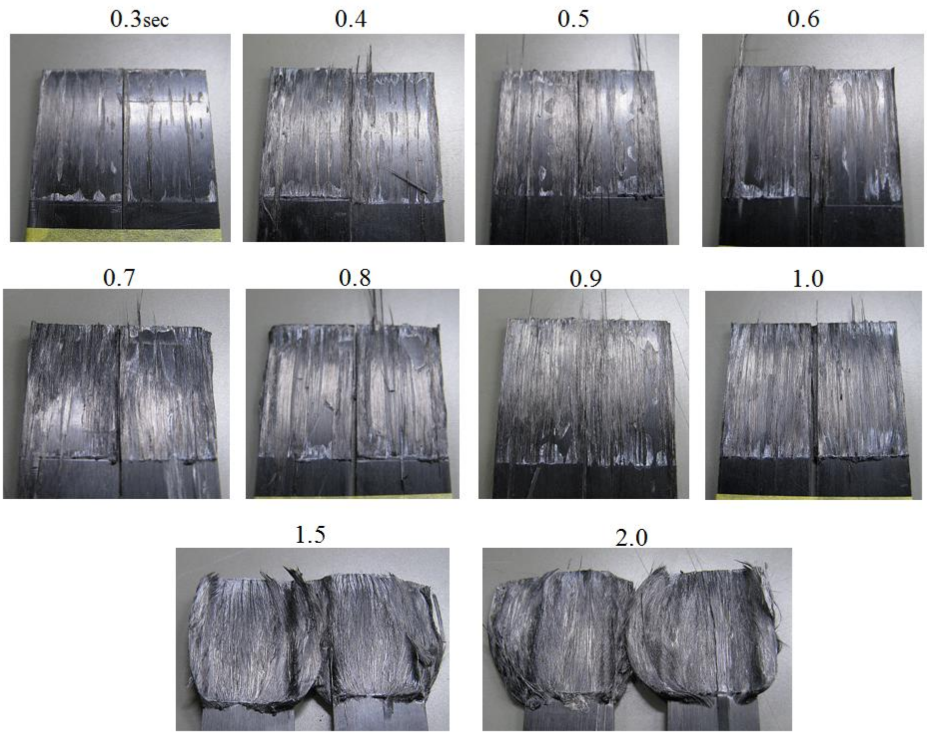

Figure 1. Joint areas after shear tests.

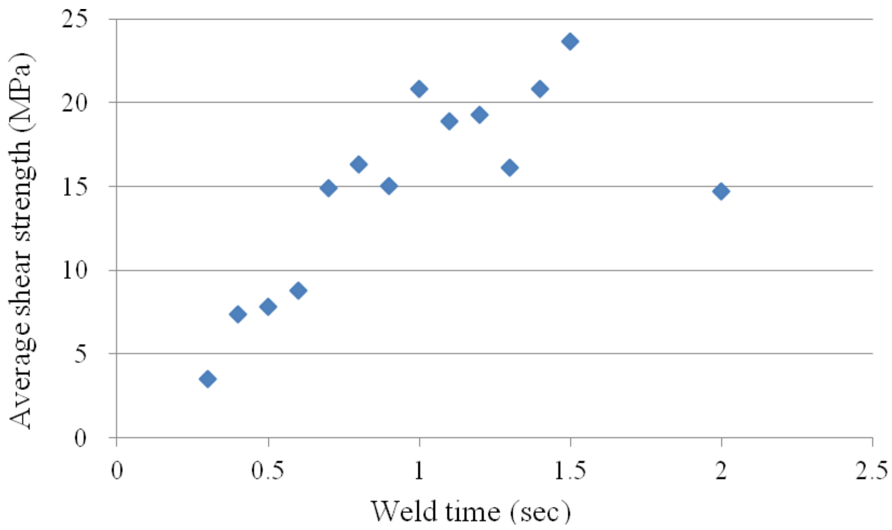

Figure 2. Relationship between weld time and average shear stress of single lap joint.

3 Joint strength by surface welding

3.1 Single lap joint

We made test pieces of 15×100×2 mm for UD material and 25×100×2 mm for CTT (chopped carbon fiber tape reinforced thermoplastics) material. These materials were provided by MITSUBISHI RAYON CO., LTD. and TOYOBO CO., LTD.

Then we jointed by ultrasonic welding under the condition of 25 mm of lap length and 1.0 sec of weld time. We also welded small pieces of CTT material to the edge of test pieces to avoid moment generation during tensile test, shown in Figure 3. We calculated average shear strength by equation (1).

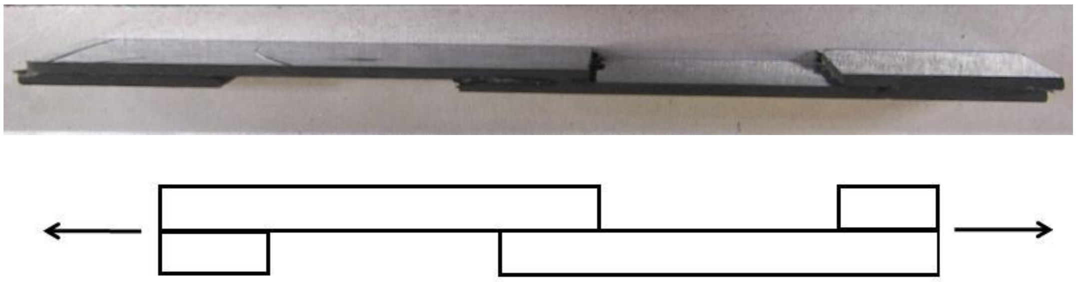

Figure 3. Specimen of shear test and the load direction.

Figure 4 shows the results of tensile test. Average shear strength of UD and CTT specimens are 21 and 17 MPa respectively, which are almost the same as hot press molded specimen's lap shear strength. We think that the difference between UD and CTT specimens comes from asperity of joint surfaces shown in Figure 5.

Figure 6 shows the result of observation by X-ray computed tomography. Unlike hot press, we found that fiber on joint surface got curved. We have trouble applying this method to painstaking applications such as airplane because quality of joint surface might be changed.

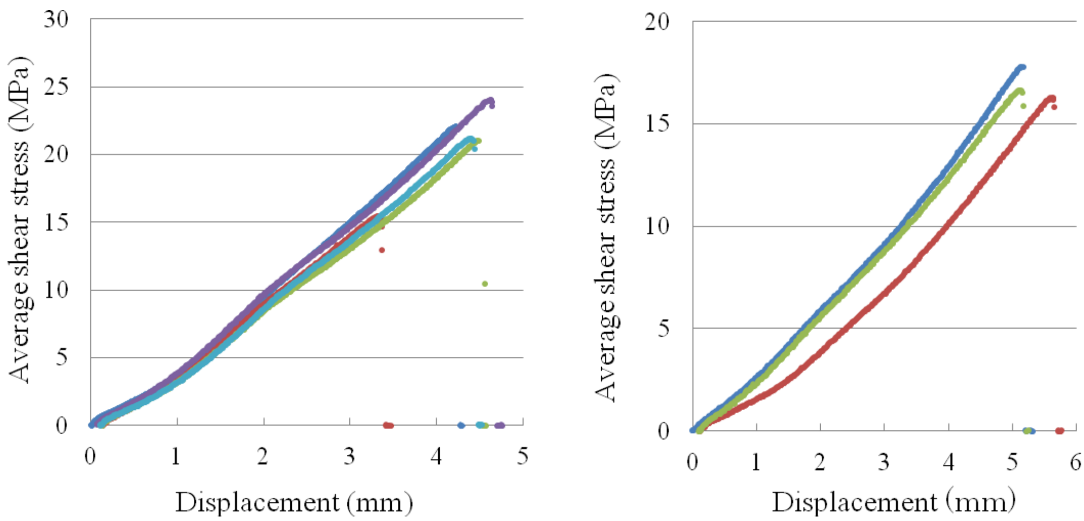

Figure 4. Relationship between displacement and average shear stress of single lap joint (left: UD, right: CTT).

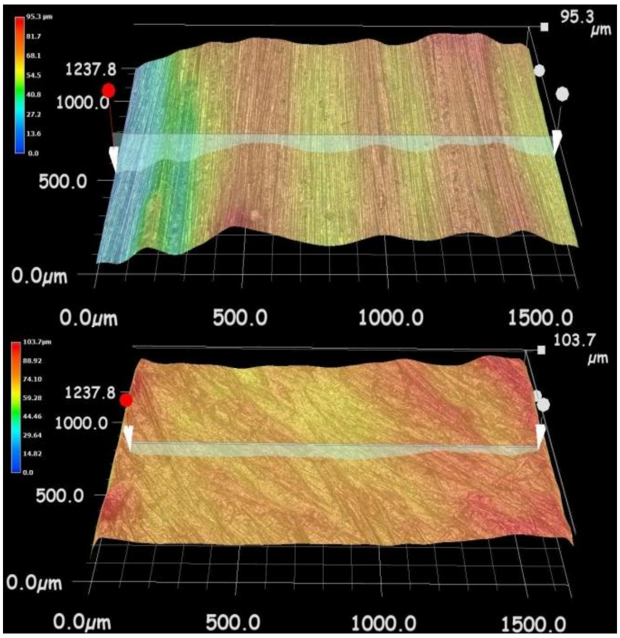

Figure 5. Joint surface (upper: UD, lower: CTT).

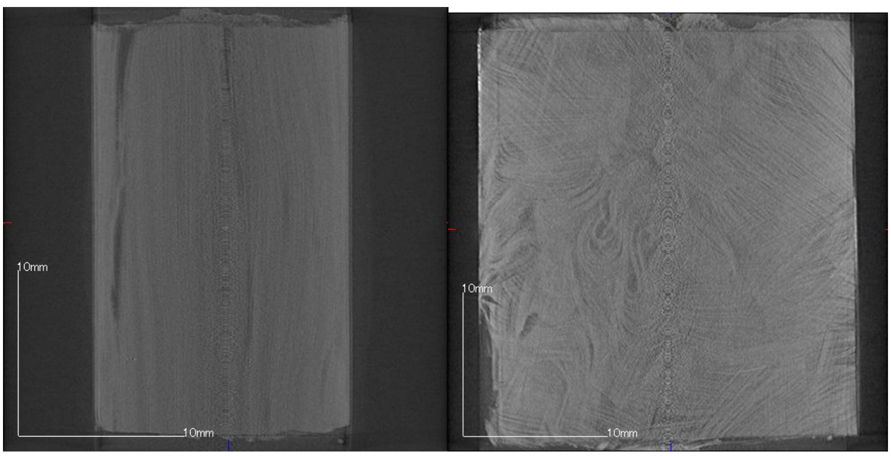

Figure 6. Joint surface observed by X-ray computed tomography (left: UD, right: CTT).

3.2 Cross joint

We orthogonally jointed the test pieces of the same size of single lap joint specimen by ultrasonic welding under the condition of 1.0 sec of weld time. Figure 7 shows a specimen of CTT material and the load direction. We found that we could not join the entire joint surface, so we just show the relationship between displacement and load in Figure 8. We think that the variation in the maximum load comes from that of welded area, shown in Figure 9.

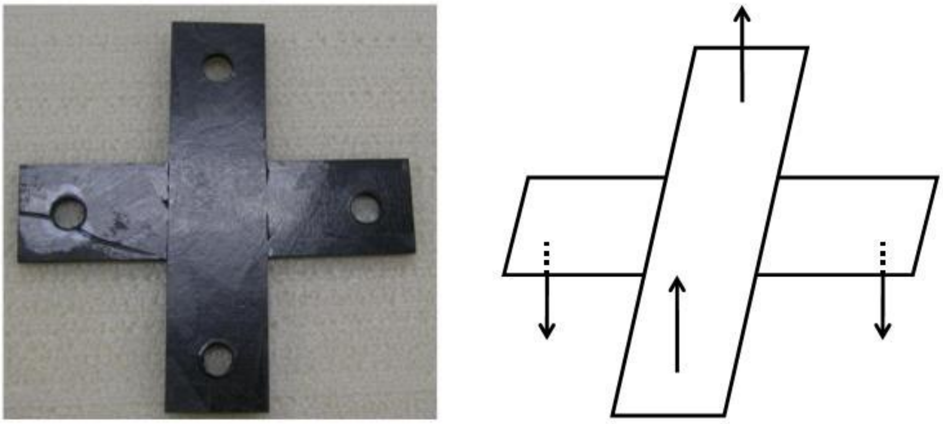

Figure 7. Specimen of peel test and the load direction.

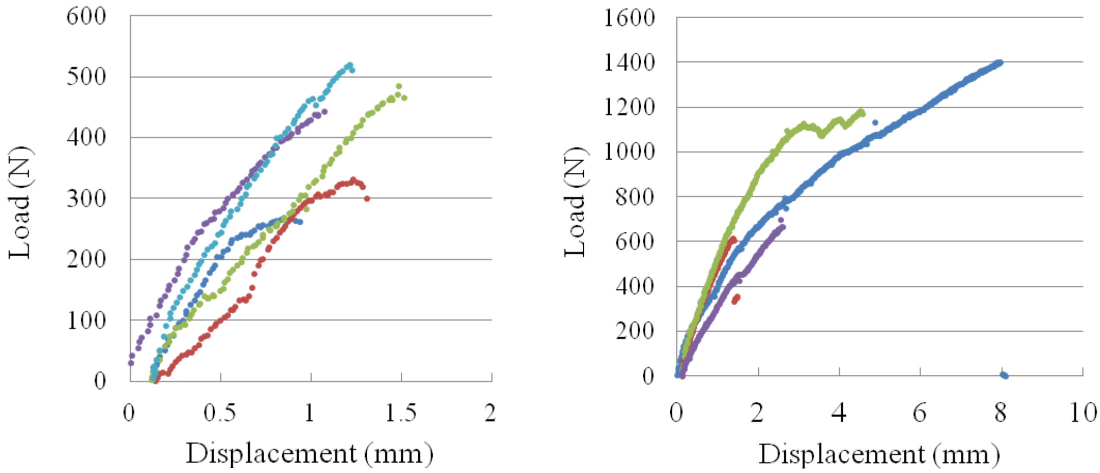

Figure 8. Relationship between displacement and load of cross joint (left: UD, right: CTT).

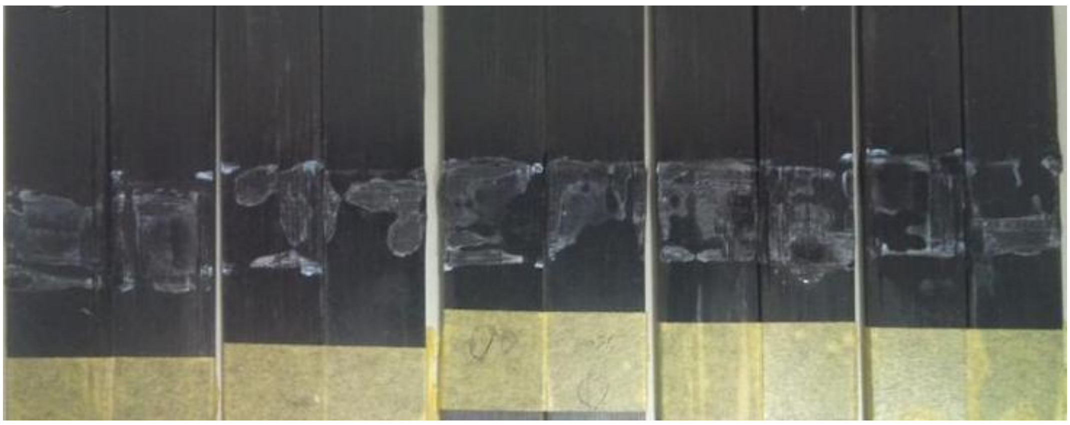

Figure 9. Joint areas after peel tests.

3.3 Discussion

We think that ultrasonic welding is an effective jointing method for single lap joint because almost the entire joint surfaces are welded with only one second and average shear strength is almost as same as hot pressed one's. However, for cross joint, we still need to use our ingenuity because we could not join the entire surface. We think that energy director, which is used in ultrasonic welding for thermoplastics, is one of the approaches for solution.

4 Joint strength by spot welding

4.1 Single lap joint

We jointed the test pieces of the same size of surface joint specimen by ultrasonic spot welding. We decided weld time as below: for CTT material, 1.5 sec and 2.5 sec for φ2 mm, and 2.5 sec and 3.0 sec for φ3 mm; for UD material, 2.5 sec.

Figures 10 and 11 show the results of tensile test and Figures 12 and 13 show the joint surfaces. Effective welded area was calculated by excluding the hole area of the ultrasonic hone.

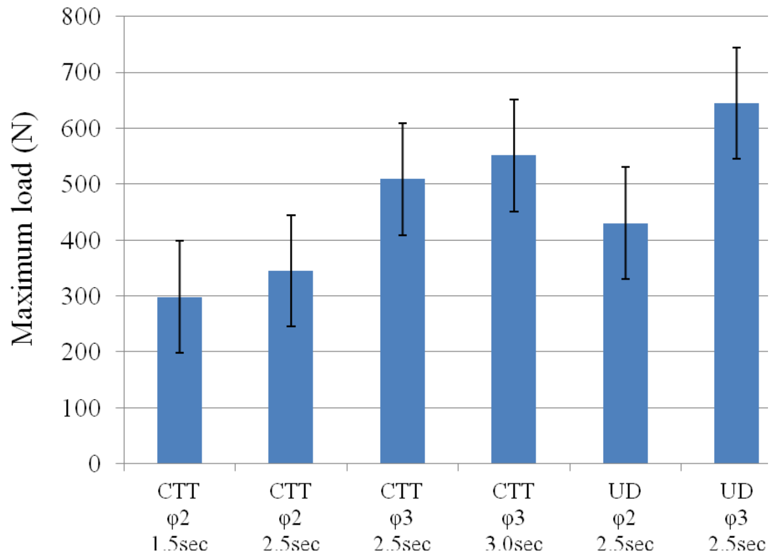

Figure 10. Maximum load of specimens of single lap joint by spot welding.

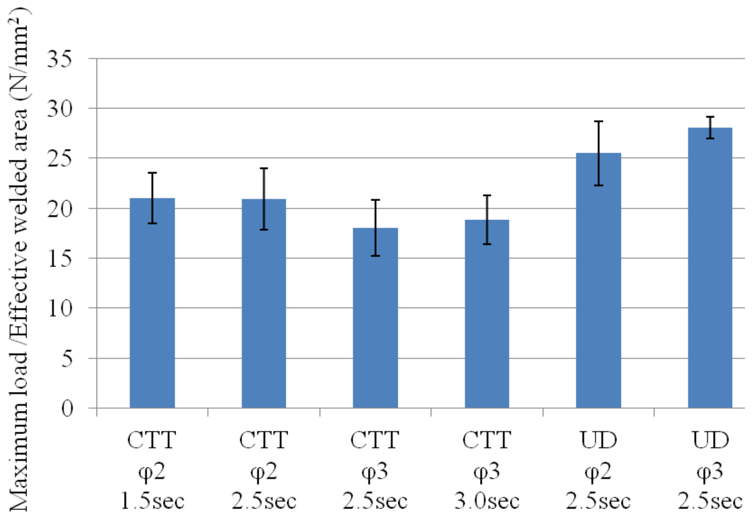

Figure 11. Comparison of shear strength among the conditions of spot welding.

Figure 12. Joint part of single lap specimens by spot welding (UD): (left) oscillation time of 2.5 sec with horn diameter of 2 mm; (right) oscillation time of 2.5 sec with horn diameter of 3 mm.

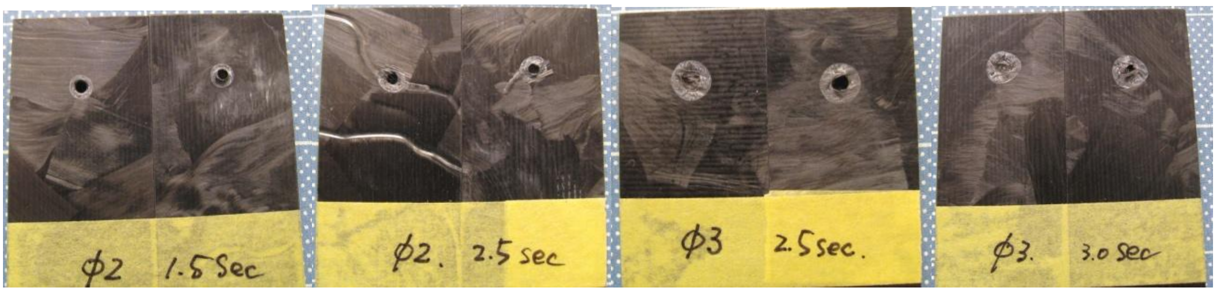

Figure 13. Joint part of single lap specimens by spot welding (CTT).

We found that the maximum load tends to be higher when we make diameter of hone larger. Comparing with diameter of hone, weld time makes smaller influence to maximum load and shear strength. From these results, we could argue that it is more important to consider diameter of hone than weld time when we design with spot welding.

Welded area of UD specimen is shaped like an ellipse. On the other hand, welded area of CTT specimen has a circular shape. It is because heat conductivity of carbon fiber is much higher than that of polypropylene.

4.2 Cross joint

We orthogonally jointed the test pieces of same size of surface joint specimen by ultrasonic welding. Weld time is 1.5 sec for φ2 mm and 2.5 sec for φ3 mm for CTT material, and 2.5 sec for φ2 mm and φ3 mm for UD material.

Figures 14 and 15 show the results of tensile test. The definition of effective welded area is the same as single lap joint specimen.

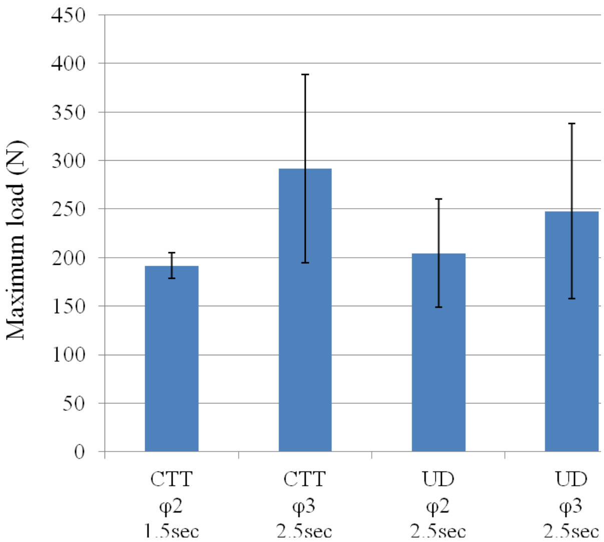

Figure 14. Maximum load of specimens of cross joint by spot welding.

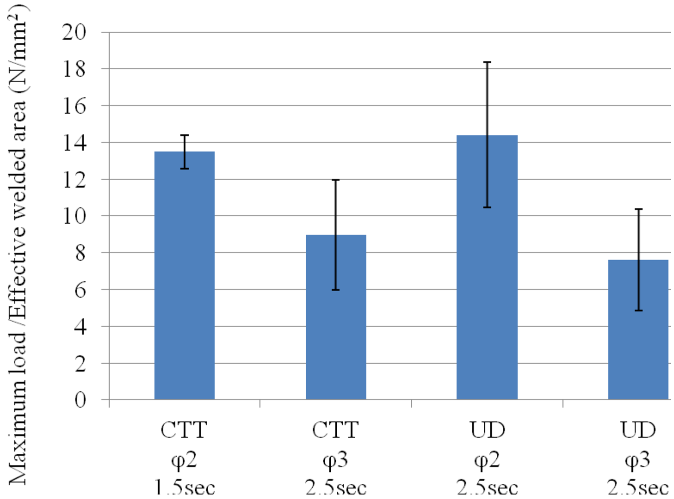

Figure 15. Comparison of peel strength among the conditions of spot welding.

4.3 Discussion

When we made diameter of hone larger, welded area and maximum load became larger accordingly. Then the maximum load of jointed specimen is more influenced by the diameter of hone than welding time.

Joint strength of spot welding specimen is almost the same as surface welding specimen. However, the hone's hole makes effective welded area smaller and stress concentration might occur for larger load. Therefore, we need to consider the size and the shape of the ultrasonic hone.

5 Conclusions

In this research, we thought that it is necessary to establish affordable jointing methods to apply CFRTP to various industrial fields as structural members, hence we focused on ultrasonic welding which uses the characteristics of thermoplastics effectively and considered influencing factor on shear strength and peel strength. As a result, we found that this method is effective because joint efficiency is as good as hot press jointing. Also, modifying joint surfaces such as energy director would avoid the variation in welded area and joint strength. Investigating of the influence of the surface processing and other conditions are mentioned as future works.

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References

[1] Mel M. Schwartz. *Composite Materials, Vol. II: Processing, Fabrication, and Applications*. Prentice Hall, New Jersey (1997).
[2] *Report on applying CFRTP to the industrial field*, The Japan Machinery Federation and R&D Institute of Metals and Composites for Future Industries, (2008).
[3] Kunihiko Sato. *General statement of engineering with welding and jointing*, Rikogakusha, Tokyo (1990).
[4] M. J. van Wijngaarden. *Robotic Induction Welding of Carbon Fiber Reinforced Thermoplastics* in “Proceeding of *the first CETEX conference*, Hannover, Germany, (2006).