BASIC STUDY ON JOINT STRENGTH OF WELDING FOR CARBON FIBER REINFORCED THERMOPLASTIC

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1 Introduction

In recent years, several measures for the better global environment have been taken in a variety of different fields. In transportation sector, it has been necessary to install extremely light material into vehicle body structure for massive energy consumption saving[1].

From this viewpoint, carbon fiber reinforced plastics (CFRP) have been widely used as high performance structural materials for aerospace and leisure applications because of its high specific strength and high specific stiffness. However, it still remains problems, high cost and low productivity, and its scope has remained small in the entire industry.

Therefore, to advance society toward greater environmental protection, ultra-light materials such as CFRP is required to be widely applied in the automobiles, which is the majority of the energy consumption in transportation sector.

2 Objective and Overview

In current manufacturing process of automobile, the joining has been one of the key technologies because of its purpose to reduce the number of parts of vehicle body structure for lightening vehicle weight and make it easy to fabricate the vehicle body for improving speed of production.

With respect to carbon fiber reinforced thermosetting (CFRTS), which has been mainly used for primary structure of airplane, adhesive bonding is useful as a utility joining method because it has some advantages over mechanically fastened joints [2]. But, generally understood, the joint strength with using adhesive bonding depends directly on adhesive cement itself. So, however strong the base materials are, the joint strength is not higher than adhesive cement.

When it comes to applying carbon fiber reinforced thermoplastics (CFRTP) to vehicle body material, welding joint of CFRTP is considered one of the promising joining methods. As shown in Fig.1, its new joining method is different from some conventional adhesive joints, and it is capable of joining two parts made from CFRTP just by heating up them and putting pressure upon each other without bonding or fastening like conventional welding metals[3].

In addition, the availability of welding joint in CFRTP leads to a solution to prevent the joining area from stress concentration, so that the body structure achieves high strength and high stiffness.

To apply the welding technology for the CFRTP vehicle body structure, the authors examined fundamental mechanical properties of base material of CFRTP and its welding joint by basic tensile tests.

We focus on CFRTP, which are composed of carbon fiber(CF, light fiber) and polypropylene(PP, cheap and general resin). And shown in Fig.2, we evaluated two types of reinforced plastics, uni-directional(UD) and random chopped plate (Random). UD is the base material to evaluate characteristic of composite, and Random is developed for more practical use.

UD is made from prepreg tape(thickness is 0.1 mm and width is 10 mm), and we made its test piece by ourself. Random is also made from the tape(chop length is 40 mm), and these fiber bundle are ramdomly oriented. Its test piece is made by the expert, Toyobo, because the advanced technique is needed in the making process.

3 Tensile test of base materials

3.1 Making process of base material

As previously stated, UD test pieces are made from the prepreg tape as shown in Fig.3. First of all, the prepreg tapes are cut in the same length and stacked in the mold. Next the tapes in the mold are heated up to 200 ℃ by hot plate and cooled down to 100 ℃ under constant pressure, 2.45 MPa, then the laminate plate is completed.

The thickness of the test piece can be controlled by the number of the stacked tape, and to make test piece of 2 mm in thickness, the amount of tape to stack is 22 layers.

In this way, UD test pieces are made and cut out to 200 mm in length, 20 mm in width, 2 mm in thickness. And Random test pieces are also cut out to the same size from the random chopped plate made by Toyobo.

The number of test piece is each five.

3.2 Result of the tensile test

To obtain the characterization of the base material, the tensile test was done with load examination machine. The result was shown in Table 1.

As to the destruction style, shown in Fig.4, five test pieces of UD are all broken along fiber direction and no fiber destruction occurred. It seems that main reason of this destruction style is the undulation of fiber, which occur at the molding process. The fibers are not straight and continuous at the edge of test pieces because the fiber and melting resin flew into the space between the upper mold and the lower one and thus generated burr was excised.

Then, about Random, test pieces are all broken where the chopped CF tape is arranged in the direction of the width of the specimen, shown in Fig.4.

Next, I discuss strength. About UD, the tensile strength of CF is 4.9 GPa and the volume fraction of fiber is 42 %. As a result of calculation with these data, the theory tensile strength is about 2060 MPa and actual strength is 1331 MPa, about 65 % of the theory value.

On the other hand, the strength of Random is 283 MPa, which is about 85 % of quasi-isotropic material's theory strength. As a feature point, the coefficient of variation of Random test pieces is 34 %. The reason of this uncertainty of data is the above-discussed direction of the chopped tape. From this result, it seems that the material characterization of the Random is greatly influenced by the array of the chopped tape where we cut out from the random sheet.

In this study, we use these values as a reference value of the tensile strength of UD and Random.

4 Tensile test of Welding joint

4.1 Factors acting on joint strength

As shown in Fig.5, we think three factors, which act on joint strength. They are presence of load offset, presence of stress concentration and presence of fiber intertwining.

The load offset is generated when there is the gap between the action points of two tensile loads. The load offset cause the eccentric moment and the peel stress work at the joint part.

The stress concentration is generation of excessive stress on the part where the cross-sectional shape of material changes rapidly[4]. It can be reduced, for example, by processing the edge of material in the taper.

The fiber intertwining is a phenomenon that occurs where the fiber has come in contact mutually in respect. When the fiber overlaps on the joint surface, it is thought that there is the fiber intertwining and this phenomenon rises a joint strength of CFRTP.

4.2 Evaluated joint geometry

For fundamental examination of joint geometry, we evaluate single lap joint and scarf joint. Each of joint geometry is shown in Fig.6.

The single lap joint is the simplest joining structure and basic in the evaluation of joint performance. In this joint, the fiber intertwining can be expected, but the load offset and the stress concentration will generate.

On the other hand, the scarf joint is the structure that improves the fault of the single lap joint, the load offset and the stress concentration

In this study, width of test piece is 20 mm, thickness is 2 mm and lap length is 15 mm.

4.3 Process of welding

In this study, the welding method is heat plate welding as shown in Fig. 6. This is the method that operation of device is simple and welding is easy. In addition, it has high applicability for the welding of the single lap and the scarf joint.
The welding is done with the base material which is molded according to the above-mentioned process. As for the single lap joint, the test pieces are cut out to the size fitting for the mold. And for the scarf lap joint, the edge of the test pieces are processed in the taper.
Thus, we prepare two base material for welding, and put them in the mold, heat with a hot plate, cool down under constant pressure, then, they are welded. In this process, the temperature and pressure are the same conditions as the UD material molding.
Fig.7 is the radiograph of joint area, which is seen from board width angle. From the figure, it is found that both of joint surfaces are smoothly connected with no delamination or bubble.

4.4 Tensile test for welding joint

We evaluated the performance of the welding joint by the tension test. From the result of the test, the joint strength is derived by the following equation (1) where S_{joint} means joint strength [N/mm], P means maximum load [N] and b means width of specimens[mm].

$$S_{joint} = P/ b \qquad (1)$$

4.5 Tensile test result

The test result is shown in Fig.8 and Fig.9. As to single-lap joint, joint strength of each materials are 240 N/mm(UD) and 293 N/mm(Random). And of scarf joint, they are 322 N/mm(UD) and 238 N/mm(Random).
Moreover, the appearance after each test piece are destroyed are shown in Fig.10 and Fig.11. UD test pieces are all destroyed at the joint surface, but Random are at the base material itself. So we couldn’t measure joint strength of Random materials.

4.6 Discussion about welding joint

First of all, I describe about the Random material.
Both joint strength of Random was higher than that of base material. This is because Random specimens are not destroyed at a joint surface, but at base material, and the accurate joint strength can’t be measured.
Moreover, in the tensile test of Random base material, there is a large uncertainty of strength, and we can’t measure the accurate strength of the base material. It is one factor of this inversion phenomenon.
When two joint geometries are compared, as to Random, the single lap joint, with the geometry that causes load offset and the stress concentration, showed higher strength than scarf joint. I think that it is because, in scarf joint, the fibers of the joint surface were shortened by the taper processing and strength fell.
Next, about UD, strength of scarf joint, 23 % compared with base material strength, is higher than that of single lap joint, 17 %. From the data, the effect of scarf joint to reduce load offset and stress concentration can be confirmed. However, on the joint surface of scarf joint, the fibers are not overlapped but compared. Therefore, joint surface is composed of resin without any fiber intertwining.
On the other hand, about single lap joint, there thought to be fiber intertwining. The factor I think so is the following two points. One is the undulation of the fiber in joint surface shown in Fig.7 and the other is a mark that the fiber is peeled off in joint surface after tensile test shown in Fig.10.

5 New proposal

As previously stated, scarf joint can reduce the load offset and the stress concentration but there is no fiber intertwining. Oppositely, in the single lap joint, fiber intertwining can be confirmed but there are the load offset and the stress concentration.
I think that stepped lap joint can develop the strong points of each joint and its utility is large. The geometry of stepped lap joint is shown in Fig.12. This joint can reduce the load offset and the stress concentration. Moreover, fibers overlap mutually in the interlayer and the fiber intertwining can be expected.

6 Conclusion

In this study, we evaluated the relation between the joint geometry and the strength of welding joint for CFRTP. We evaluated two materials, UD and

Random. The obtained conclusion is shown below.

- We molded UD base material from the prepreg tape by means of hot plate.
- In the tensile test of UD base material, all specimens were broken along fiber direction and no fiber destruction occurred.
- In the tensile test of Random base material, all specimens were broken where the chopped CF tape was arranged in the direction of the width of the specimen and the uncertainty of data was large.

- We did welding with hot plate and evaluated the joint performance with tensile test.
- In the tensile test of UD joint, all specimens were destroyed along the joint surface and the joint strength of scarf joint was higher than single lap joint. It is because scarf joint reduces the load offset and the stress concentration.
- About UD joint, fiber intertwining occurred in single lap joint, but in scarf joint, joint surface was composed of resin without any fiber intertwining.
- In the tensile test of Random joint, all specimens were broken at base material and we couldn't measure the joint strength.

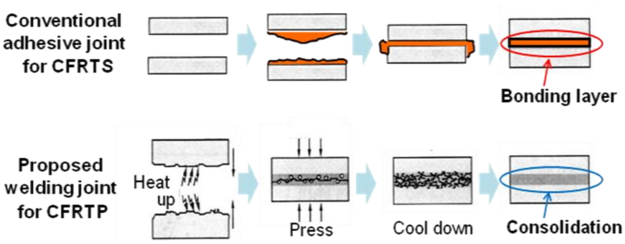


Fig.1 Comparison between joining methods

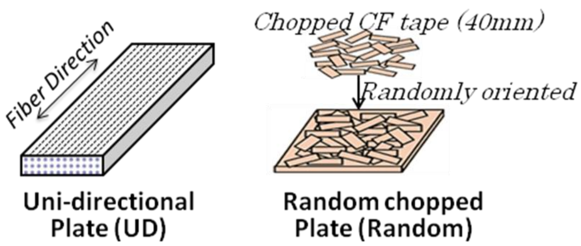


Fig.2 Two types of fiber reinforced form

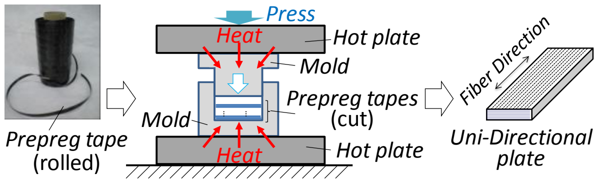


Fig.3 Process of laminate molding for UD test pieces

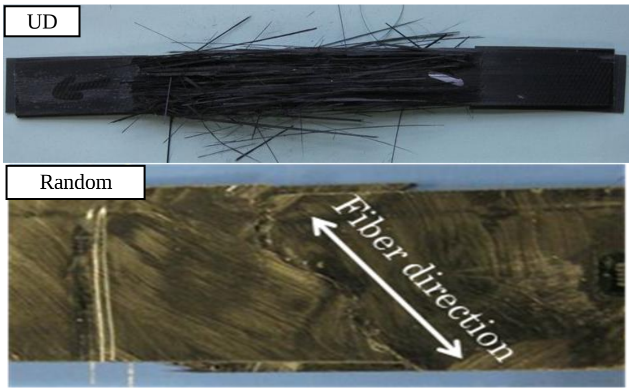


Fig.4 Appearance of destruction

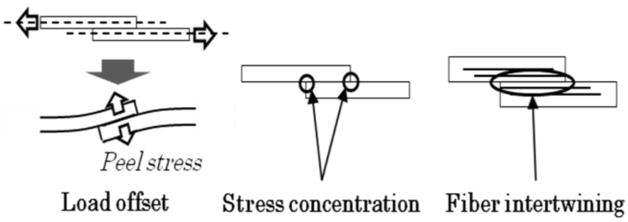


Fig.5 Factors acting on joint strength

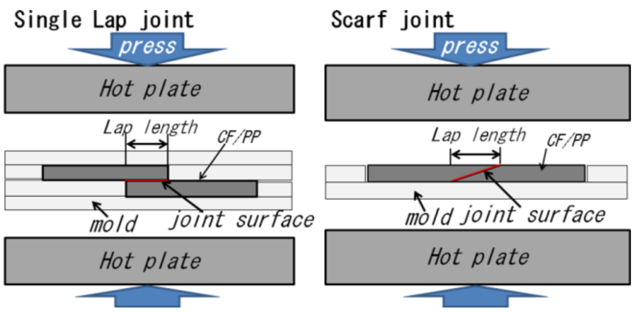


Fig.6 Joint geometries and measures;
(Left) Single lap joint (Right) Scarf joint

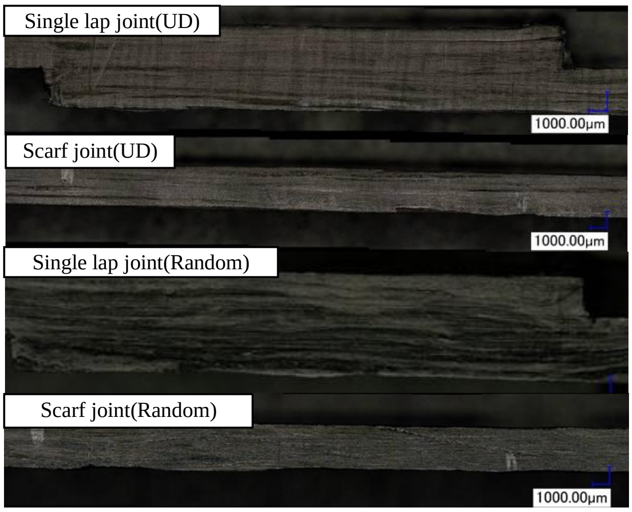


Fig.7 Radiograph of junction

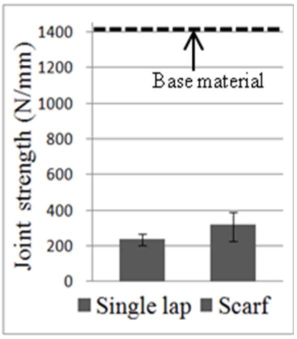


Fig.8 tensile test result of UD

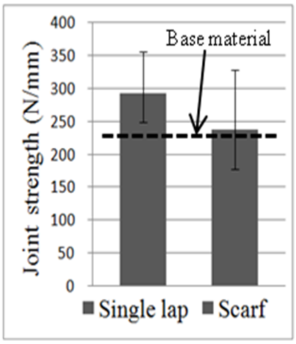
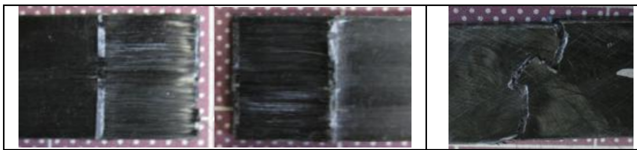


Fig.9 tensile test result of Random



UD	Random

Fig.10 Destruction of single lap specimens

UD	Random

Fig.11 Destruction of scarf specimens

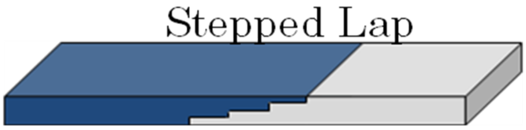


Fig.12 Image of stepped lap joint

Table1 tensile test results of base materials

	Tensile strength [MPa]	Modulus [GPa]
UD	1331.4	97.5
Random	283.1	30.4

Acknowledgement

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