THE EFFECT OF SYMMETRIC WRINKLED INTERFACE ON TENSILE STRENGTH OF COMPOSITE SINGLE-LAP JOINT.

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ABSTRACT

The composite material has been widely applied in different engineering fields like automobiles, naval architectures, aerospace, and wind power due to its lightweight and strength in recent years. Many researchers have investigated the means for enhancing the strength of the bonded joint of composite material. One of the topics is changing the surface geometry (e.g. wavy, taper, fillet) of the composite to improve the tensile strength and decreasing stress concentration of the bonded area. In this research, a method capable of improving the tensile strength of the adhesively bonded single-lap joint is introduced. The enhanced material was embedded into the glass fiber in the Seemann Composite Resin Infused Molding Process (SCRIMP) and formed a symmetry wrinkled surface composite material. The composite single-lap joint specimens were fabricated by following the ASTM D5868 01 standard and subjected to the tensile test to compare the strength of the conventional single-lap joint and the improved wrinkled surfaced single-lap joint. The test results have suggested that the wrinkled interface formed by the embedded material could successfully improve the strength. By embedding different materials, the improved rate would vary from 30% to 40%. Moreover, this research, which the common composite material fabrication process, SCRIMP, is applied to make wrinkled surface without a special mold is easier to promote to the industry.

1 INTRODUCTION

With the highly demand of composite material from different engineering fields like automobile, naval architecture, wind turbine industries. Due to the lightweight and the strong strength, the composite material has gradually replaced the metal material. The connection methods for the separate materials are various with different functions. The traditional joining technique, brazing, welding, and screwing are suitable for metal but not for fiber reinforce plastic (FRP) material, because of stress concentration. With the development of the chemistry industry, adhesive bonding is an alternative joining method to connect materials with different geometry and properties. The adhesive bonding method can reduce the stress concentration and transfer the loading more efficient than the conventional mechanical joining method. Additionally, the adhesive bonding method can endure the fatigue loading better and remain the continuity of the material. However, it has the disadvantages like it can't be disassembled easily and it might be the weakest part of the structure.

Since 20th century, many researchers had been developing the technique to improve the strength of the adhesively bonded lap joint. The single-lap joint was a simple type of adhesively bonded joint, and often seen in this type of study. There were several means to enhance the strength of the single-lap joint. The adhesive fillet is one of the technique to improve the performance of the single-lap joints. The adhesive fillet can reduce the stress concentration on the boundary of the overlap. Changing the geometry of the single-lap joint is an alternative method to enhance the joint strength. In 2001, Zeng and Sun[1] proposed the wavy type single-lap joint, and this type could improve the joint strength 1.5 times than the conventional flat surface single-lap joint. In 2007, Da Silva, Lucas and Adams[2] applied the finite element analysis to investigate the effect of the spew fillet, the taper on the single-lap joint. From their result, the peel stress would decrease while the joint with fillet and taper was under the pure tensile loading. With the effect of thermal stress, the peel stress would increase on the contrary. Fessel also used the FEA to optimize the wavy joint with parameter analysis and discussed the stress distribution of the reverse-bent joint. The reverse-bent was an analytical model which proposed in 1958, and the factor k was used to adjust the eccentricity. The reverse-bent was used to reduce the peel stress of the single-lap joint. In their experiment, Fessel concluded that when the eccentricity = 0, the joint could reach the best strength.[3] In 2011, Campilho studied about the reverse-bent joint with FEA and also concluded that the reverse-bent joint could reduce the peel stress of the single-lap joint. However, from Campilho's results, when the eccentricity = -1, it could reach the best strength.[4] In 2012, Ashrafi et. al.[5] developed a sinusoidal interface of the composite single-lap joint. From the experimental results, the non-flat interface could enhance the strength about 40%. In addition, the numerical result showed that the sinusoidal type specimen could reduce the peel stress on the boundary of the overlap, and the stress was ineffective to the central part of the specimen. Kishore et.al.[6] did an experimental study of the flat-joggle-flat single-lap joint. In their design, the flat-joggle-flat joint was aimed to eliminated the eccentricity of the single-lap joint, and its strength from the experiment could enhance 90% than the conventional joint. In 2013, Temiz et. al.[7] also did an experimental study with the adherend curvature-induced geometry to increase the joint strength. In 2014, Haghpanah et. al.[8] developed the interlocking teeth shape interface of the single-lap joint. From their research, this type of interface could not successfully improve the joint strength. However, parameter analysis was under studied and the improvement was proposed in the future work in their conclusion. Among the literature review, the main reason caused failure of the single-lap joint was the interfacial peel stress within the adhesive. Hence, to reduce the peel stress on the boundary of the overlap is one of the goals in our research.

In this research, we investigated the effect of the symmetry wrinkled interface on the tensile strength of the composite single-lap joint. The enhanced material was embedded into the glass fiber in the Seemann Composite Resin Infused Molding Process (SCRIMP) and formed a wrinkled surface composite material. The composite material was cut into pieces' specimen by referring the geometry of the ASTM D5868 standard.[9] After preparing the specimens, they were subjected to the tensile test by MTS810. The load and the displacement would be measure and recorded by the computer. The details of the method will be described in the **Section 2**. The experimental results suggested that the wrinkled interface formed by the embedded materials could successfully improve the single-lap joint strength. By embedding different materials, the improvement rate could vary from 30% to 40%. The details of the results will be showed in **Section 3**. Moreover, this research, which the common composite material fabrication process, SCRIMP, is applied to make wrinkled surface without a special mold is easier to promote to the industry.

2 METHOD

2.1 Seemamn Composite Resin Infused Molding Process (SCRIMP)

The Seemamn Composite Resin Infused Molding Process (SCRIMP) was applied to fabricate the composite in this research. The SCRIMP is a patent [10]of the Seemamn co. which combine the black net with the process of traditional Vacuum Assisted Resin Transfer Molding (VARTM) to decrease the infusion time. The necessary materials and equipment were listed in the Table 1. Fig.1 is the picture before infusing the resin during the SCRIMP process.

To make the wrinkled surface composite material, the linear material would be embedded under the top fabric during the SCRIMP process. The wrinkled surface would be formed under the vacuum condition. Then the composite material with wrinkled surface would be manufacture after infusing the resin and the hot curing process. The horizontal black line in Fig.2 represented the wrinkled surface of the composite material.

Table 1 Necessary materials and equipment

Materials and the equipment	
Glass fiber fabrics	Wax
Resin	Oven
Resin hardener	Vacuum pump
Molding plate	Autoclave
Black net	Composite cutter

Figure 1 Seemamn Composite Resin Infused Molding Process

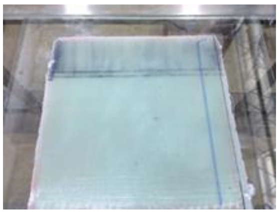

Figure 2 The wrinkle surface of the composite material

2.2 Preparation of Wrinkled Interface Single-Lap Joint

In order to make the wrinkled interface, the geometry of ASTM D5868-01 was referred to assemble the specimen. The specimen would be symmetrically assembled with another corresponding specimen. In this research, the wrinkled interface specimens were named SW (Symmetrical Wrinkled). The schematic of the SW specimen is depicted in Fig.3. The real entity of SW specimen is shown in Fig.4

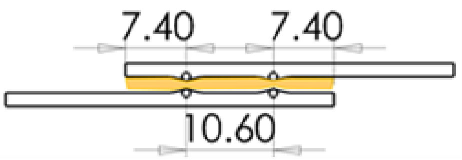

Figure 3 Schematic of the SW specimen

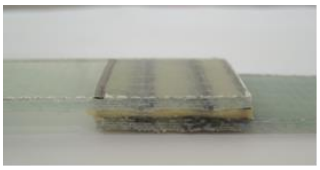

Figure 4 SW Specimen

2.3 Preparation of the Conventional Single-Lap Joint

In order to increase the credibility of this research, the conventional single-lap joint would also be fabricated from the same composite material plate. With this consideration, we can ensure the property of the composite material is equivalent. The conventional single-lap joint was named FI (Flat Interface) in this research. Fig.5 and Fig.6 are the information of FI specimen.

Figure 5 Schematic of FI specimen

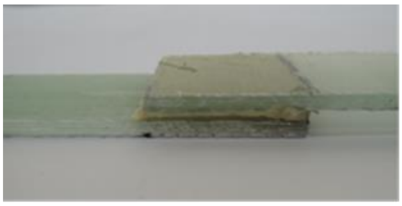

Figure 6 FI specimen

2.4 Single-Lap Joint Shear Test

There were two groups to be tested for the single-lap shear test. There were both type of the interface in each group. The difference between Group 1 and Group 2 was the embedded material. Table 2 is the information of the test groups. All specimens would be subjected into the tensile test by the MTS810 as shown in Fig.7.

Table 2 Information of the test groups

Group	Type of interface	Embedded material	Quantity
1	FI	N/A	5
	SW	Nylon	5
2	FI	N/A	5
	SW	Iron	5

Figure 7 Tensile shear test

3 RESULTS

3.1 Group 1

After finishing the tensile shear test, the load and displacement would be measured by the computer. The failure type of each specimen was classified by the ASTM D5573-99[11] standard. There were 6 failure types for composite single-lap joint as shown in Fig.8. The results of Group 1 are depicted in Table 3-4 and Fig.9-10. The average maximum load of the FI specimen was 3.6506 kN. The average maximum load of the SW-Nylon specimen was 4.7311 kN.

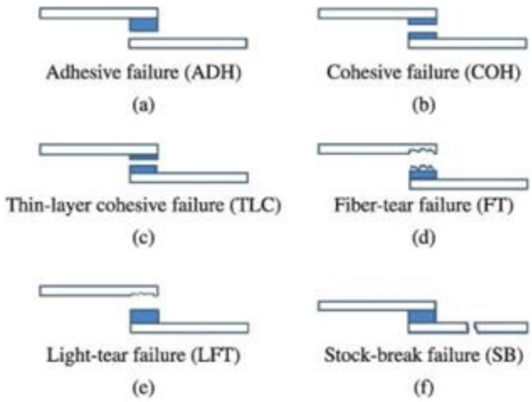

Figure 8 Failure type of ASTM D5573

Table 3 Results of FI Specimen in Group 1

FI	Maximum Load(kN)	Failure Type
01	3.7139	LFT
02	4.4625	FT
03	3.7749	FT
04	3.2845	FT
05	3.0170	FT
Average	3.6506	X

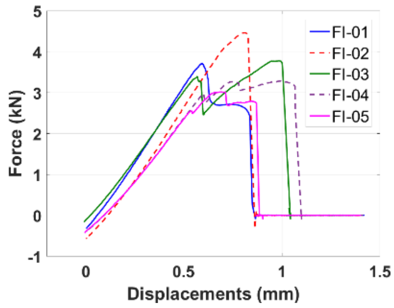

Figure 9 Diagram of FI specimen in Group 1

Table 4 Results of SW-Nylon in Group 1

SW-Nylon	Maximum Load (kN)	Failure Type
01	5.3561	FT
02	4.3479	FT
03	4.8952	LFT
04	4.6267	LFT
05	4.4294	FT
Average	4.7311	X

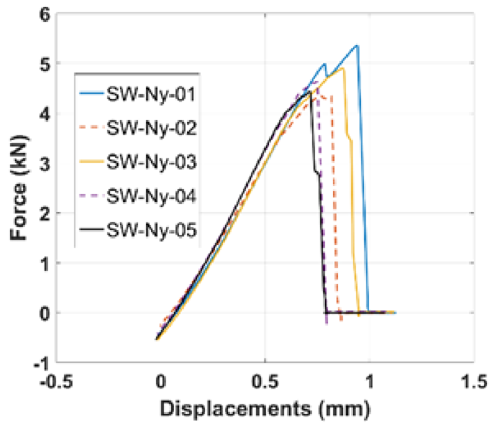

Figure 10 Diagram of SW-Nylon specimen in Group 1

3.2 Group 2

The results of Group 2 are depicted in Table 5-6 and Fig.11-12. The average maximum load of FI specimen was 3.9958kN. The average maximum load of SW-Iron specimen was 5.6400 kN. The specimen FI-02 and FI-05 showed weaker strength due to the ADH failure type.

Table 5 Results of FI specimen in Group 2

FI	Maximum Load(kN)	Failure Type
01	4.7631	FT
02	3.8301	ADH
03	4.0323	LFT
04	4.1031	LFT
05	3.2503	ADH
Average	3.9958	X

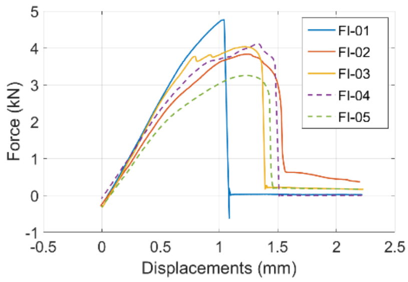

Figure 11 Diagram of FI specimen in Group 2

Table 6 Results of SW-Iron in Group 2

SW-Iron	Maximum Load (kN)	Failure Type
01	5.3735	FT
02	6.2885	FT
03	5.7586	LFT
04	5.2244	FT
05	5.5550	LFT
Average	5.6400	X

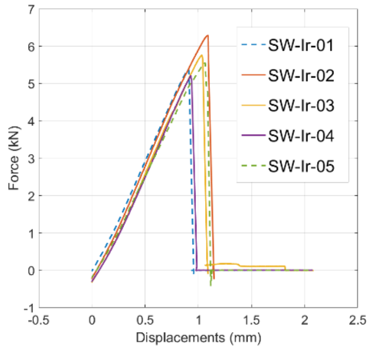

Figure 12 Diagram of SW-Iron specimen in Group 2

4 DISCUSSION

From the results section, we can learn that the typical failure of the composite single-lap joint is the FT failure. The reason for FT failure is that the shear capacity of the structural adhesive is better than the composite material. On the contrary, if the adhesive's shear capacity is worse than the composite material, the specimen will lead to ADH failure. Hence, the stable quality of the structural adhesive is necessary for this research.

In the Group 1, the average maximum load of the SW-Nylon specimens were higher than the FI specimens' were. The strength improvement rate was about 30%. In the Group 2, the average maximum load of the SW-Iron specimens were higher than the FI specimens' were. The strength improvement rate was about 40%. This experiment proved that this method could successfully enhance the joint strength of the single-lap joint by embedding material under the top fabric before the curing process. This simple process could easily make non-flat surface of the composite material without a customized mold. Furthermore, if the embedded material were harder, the average maximum load would become higher. In several papers review, the researchers used the specialized mold that may increase the costs to fabricate the non-flat interface specimen. However, we do not need to worry about it in this research. This experimental method applied the SCRIMP process which was commonly used in the composite material manufacture process. Hence, this experimental method can make the wrinkled interface without a special mold in the process and is easier to promote this technique to the industry.

5 CONCLUSION

In this work, we investigate the effect of the symmetry wrinkled interface on the tensile strength of the composite single-lap joint. The proposed experimental method was to embedded enhanced materials under the top fabric in the SCRIMP process to make the wrinkle surface composite material. The wrinkled surface composite specimen would be combined with a corresponding specimen to form a symmetry wrinkled interface single-lap joint. There were two groups of specimens in this research. The difference between two groups was the different embedded material. Each group had two type of the specimen, the symmetry wrinkled interface, and the flat interface. All specimens were subjected to the tensile shear test by MTS810. From the experimental results, failure type of the composite single-lap joint was FT failure in general. The wrinkled interface specimen proved that the proposed experimental method could successfully improve the strength of the adhesively bonded single-lap joint. In addition to enhancing the strength, this experimental method applied the SCRIMP process which was commonly used in the composite material manufacture process. It was needless to increase the cost to make a non-flat surface for the adhesively bonded joint with this simple method. Hence, this experimental method can make the wrinkled interface without a special mould in the process and is easier to promote this technique to the industry.

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