International Journal of Engineering

Journal Homepage: www.ije.ir

Investigation of Carbon Fiber Reinforced Polymer Composite Welding with a New Tool in Friction Stir Welding Method

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PAPER INFO

Paper history:
Received 16 February 2019
Received in revised form 09 March 2019
Accepted 03 May 2019

Keywords:
Polymer Composite
Carbon Fiber
Friction Stir Welding
New Tools
Tensile Strength

ABSTRACT

Application of thermoplastic materials has increased dramatically in recent decades due to its recyclability, low density, resistance to chemical changes. The friction stir welding process is one of the new methods of solid state welding, which has recently undergone a significant improvement. In this research, using a new tool Made of plain carbon steel st37 in friction stir welding and low cost turning machine, composite sheets of thermoplastic polymer base have 12% continuous carbon fiber in the form of buttocks with two rotational speeds of 250 and 355 rpm and two advance speeds of 5/6 and 9 mm/min Optical microscope images (OM) showed the complete connection of materials. Increasing the inlet temperature resulted in the formation and growth of cavities and converting them into tunnel cavities. In general, the parameters affecting the connection quality in this study included the main shoulder diameter and rotational speed, so that, based on the results of scanning electron microscopy (SEM), the increase in rotational speed resulted in the grinding of continuous carbon fibers and thus increased tensile strength. The results of the tensile test showed that the failure of the samples is due to microstructural changes in the HAZ, in the joint zone of the welding zone and the base materials. According to the results, it can be said that using this new tool in the friction stir welding method, because of the reduction of rotational speed compared to previous studies and the lack of use of a multi-axial milling machine, can save energy.

***doi**: 10.5829/ije.2019.32.06c.09*

1. INTRODUCTION

Due to the widespread use of polymer composites, the technologies and equipment used in the production, assembly and use of materials should be promoted and optimized. One of these is the method and tool for connecting the thermoplastic composite panels. Common types of thermoplastic composite reinforcement materials are carbon fiber (CF) and glass fiber (GF). These materials are used to create large and complex structures. Strengthened thermoplastic composites as structural materials for applications with various efficiency have advantages such as excellent adhesion and mechanical properties, resistance to a chemical reaction, recycling capability, high-temperature resistance, and unlimited shelf life. Their main advantage is the high speed of production and low prices [1].

Despite the increasing use of polymer composites in the industry, bonding methods have such drawbacks as time-consuming, structural weight gain, cost-effectiveness, and so on. One of the new methods of connecting not only metals but also polymer composites is the friction welding method of perturbation. Friction welding of perturbation is a solid state bonding method. This method is due to the tool era and the piece is warmed and softened at the contact point, the temperature of the

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Please cite this article as: M. Goli Bidgoli, A. Ranjbaran, K. Mirzavand, Y. Shajari, Z. S. Seyedraoufi, M. Porhonar, Investigation of Carbon Fiber Reinforced Polymer Composite Welding with a New Tool in Friction Stir Welding Method, International Journal of Engineering (IJE), IJE TRANSACTIONS C: Aspects Vol. 32, No. 6, (June 2019) 860-865

workpiece passes through solid temperature, and while the base material is under pressure from the friction heat, the flow of the pulp moves through the slots of the tool to both sides and fades out the connection line [2].

The friction stir welding was developed in 1991 in collaboration with the British Welding Institute (TWI), a technology that is non-polluting, low-power and highly maneuverable [3]. Friction stir welding (FSW) is widely used for fittings of aluminum alloy, titanium alloys and other materials that are difficult to use with fusion welding [3]. This process can also be one of the binding processes for polymer matrix composites such as polypropylene composites. With this technology, even a thick welded fabric can be created with high efficiency, and the main advantage of this method is its simplicity and economics. In FSW, the connection can be made by moving a rotating tool with a profiled pin [4].

When the rotary tool moves along the welding line, the material is welded by the friction produced between the tool shoulder and the workpiece surface. The pins used in this process have different shapes and geometric models, such as conical, cylindrical, square, triangular and so on. Lin et al. [5] concluded that according to the results of shear and tensile experiments Threaded-cylindrical conical tools provide better and stronger welds. Pin speed, The speed of the connection line pins, The angle of the tool deviation from the line perpendicular to the workpiece surface and the vertical force applied to the device by the device are essential parameters in the friction welding of the perturbation [6].

In this study, the function of a friction stir welding machine, used with a lathe machine, for welding and bonding of composite sheets with a polymer material of different thermoplastic materials with different parameters. The purpose of this work is to design and construct a tool to reduce energy consumption, to increase the quality of connections and to prevent waste of materials.

2. MATERIALS METHOD

In the present study, a carbon fiber reinforced composite sheet was used as the primary material for welding. The microscopic image of the composite and carbon fiber used is shown in Figure 1. In the first step, the sheets were cut at a size of 70×30 ×5 mm. In order to weld, According to the dough temperature and low strength of polymer sheets, the wear-resistance tool was made of ST37 carbon steel. In Figure 2, the tool image is shown.

Rotational velocity has a direct impact on the amount of friction between the shoulder and the workpiece. It is expected to increase with friction and as a result of the heat generated. Since the welding operation is unlike the previous work done on the Vertical Milling machine, In this research, the TN50D lathe machine was used at a rotary speed of 355 and 250 rpm. Although the linear velocity is more active on the time of the process, it is indirectly affected by heat, the surface quality, and apparent shape of the weld. In this study, two speeds of 6.5 mm/min and 9 mm/min were used.

The tool was placed in lathe chunk and fixed. The tool only has a rotational motion and is fix, the piece moves towards it. The piece can be moved at the linear velocity and angle of the instrument by a fixture and a top- support automatic motion system. The progress moving of the piece is Perpendicular to the axis of lathe chunk. In this case, the workpiece angle was assumed to be zero, which is the basis for the deviation of the workpiece. Deviation from this angle is the same angle of deviation in the workpiece. Figure 3 illustrates a schematic of the tool and the movement of the sheet relative to it.

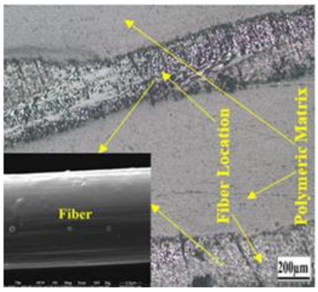

Figure 1. Optical microscopic images of polymer composite and scanning electron microscope image of carbon fiber

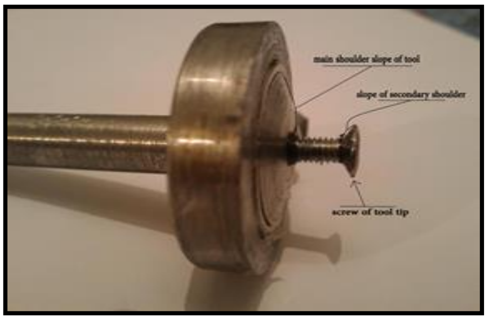

Figure 2. The tool used for friction stir welding

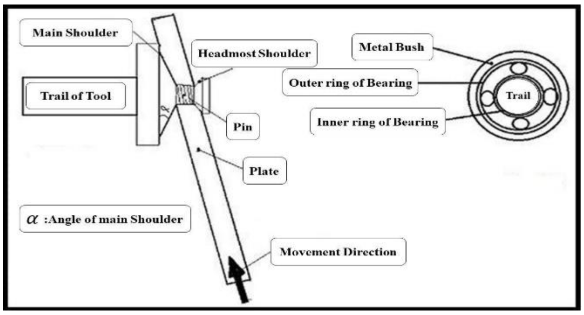

Figure 3. Schematic of tool structure and how the sheet moves towards the tool

In this study, eight samples were welded. In Table 1, the number of experiments was based on process variables including factors of tool geometry, rotational velocity, forward velocity, slope angle, work deviation angle, main shoulder diameter, forehead shoulder diameter, and pin diameter are summarized.

3. RESULTS AND DISCUSSIONS

After welding, it is usual to perform eye examinations. Therefore Samples were inspected by eye examinations after welding .The description of how to weld, the type and location of possible defects, the top and bottom of the weld are presented in Figures 4 and 5. As it is evident in these two shapes, the apparent condition of all welds is acceptable. This means that the connection is well formed. The information, obtained from Figures 4 and 5, is presented in Table 2.

As it is known, most of the defects in the region affected by welding (HAZ) can be derived from the high temperature in that area. On the other hand, the region under the influence of mechanical and thermal stresses which is called TMAZ can also cause volumetric contraction defects or longitudinal cold cracking while cooling in the common welding interface and HAZ by applying thermal-mechanical shear stress to the HAZ [7].

TABLE 1. Sample coding based on process variables

Sample Code	Pin diameter (mm)	Shoulder blade diameter (mm)	Main shoulder diameter (mm)	The angle of workpiece deviation (Degree)	Original shoulder angle (degree)	linear speed (mm/s)	Rotational Speed (RPM)
1	4	7	22	6	10	6.5	250
2	6	9	26	8	10	6.5	250
3	6	9	22	6	14	9	250
4	4	7	26	8	14	9	250
5	6	7	22	6	14	6.5	355
6	4	9	26	8	14	6.5	355
7	4	9	22	6	10	9	355
8	6	7	26	8	10	9	355

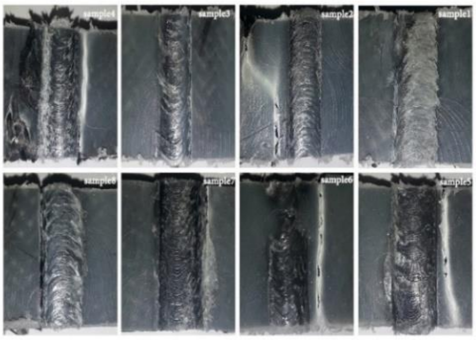

Figure 4. View of the face of the weld

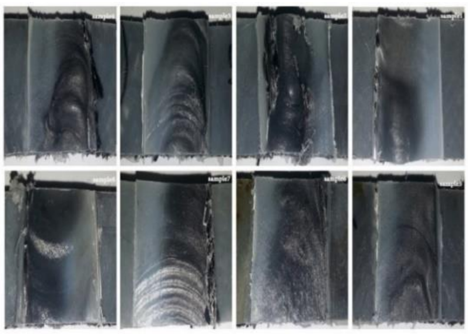

Figure 5. View of the back of the weld

TABLE 2. The location of possible defects of the welded samples

Sample Code	Type and location of the defect
1	Discontinuity on the side of the weld, behind the weld
2	Discontinuity on the side of the weld, behind the weld and crack in the HAZ region at the welding surface
3	without defect
4	crack in the HAZ region at the weld surface
5	crack in the HAZ region at the weld surface
6	without defect
7	without defect
8	Discontinuity on the side of the weld,

Another noteworthy point is that there are no tunnel defects or discontinuous porosities in the weld region. It can be deduced that, due to the low temperature for melting of polymer materials, the proper temperature has used for welding.

In Figure 6, the OM images of the welded samples are shown. Figure 6 shows the OM image of sample 2. As shown in that illustration, it is clear that the polymer coating layers are well-integrated, and that carbon fibers are continuously divided into these polymeric layers. This suggests that, by turning the tool, the carbon fiber is well distributed inside the field, and the composite is improved. In 2017, Karami Pabandi [8] showed that the rotation of the wear-resistance tool in the friction stir welding process improves the bond of carbon fiber in aluminum dissimilar welding to a carbon fiber reinforced polymer composite.

In Figure 6b the OM image demonstrates the Nugent area in sample 3. As it is evident, by increasing linear velocity with a constant rotational speed, the amount of mixing and tensile strength of the polymeric layers has increased. This conflicts with the FSW of metals. In FSW of metals by increasing the travel speed the internal temperature, strain and subsequent flowing of the base metal is going to reduce, which ultimately leads to a reduction in the mixing of metal layers [9]. In polymer materials, due to their low melting temperature, by reducing the rotational speed the internal temperature prevents their melting.

For this reason, there is a proper distinction between the polymer layers in the image. Also, there is no evidence of the integrity of the field, which is due to the melting of polymer materials and their collapse. Distinctive darkness at the interface of the two-layer polymer which is interconnected is because of the formation of the polymeric fibers between the layers and their common interface.

Figure 6c illustrates the OM image of sample 6. As can be seen, by increasing rotational speed and consequently increasing the internal temperature, the effect of local and minor melting is observable.

As the rotational speed increased in sample 6, the substrate was provided for the distribution of carbon fibers in which the crushed fibers were suspended from the molten polymer at the molten surface and had transferred to other parts of the welding region. The distribution of broken or unbroken fibers is well visible in sample 6. Figure 6d shows the microscopic image of sample 7. It is evident that at a maximum speed of rotation. As the travel speed increases, the melting effect is eliminated, and the reinforcing phases are appropriately distributed in the polymer field. It seems that the speed of 355 rpm and the travel speed of 9 mm/s are the most suitable speed parameters for bonding between carbon fiber reinforced polymer composites in which the fibers are reduced in size of the welding region, especially the nugget.

Figure 7 demonstrates the OM and SEM image of sample 8. An increase in shoulder's diameter, the shoulder's forehead, and the pin lead to more coverage of the surface during every welding pass, which will be discussed in more detail about this regard. Another difference is the deviation angle between samples 7 and

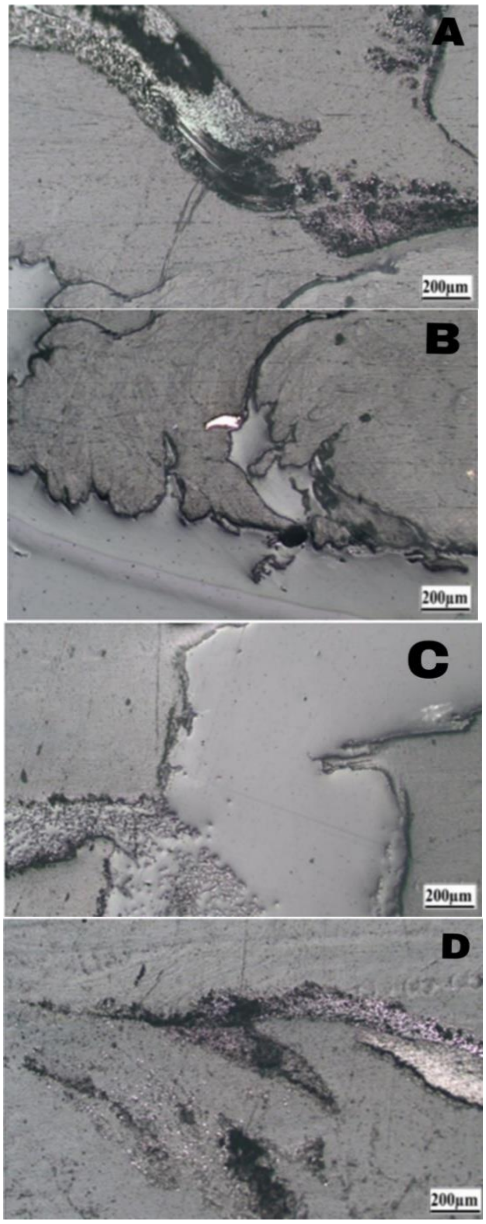

Figure 6. OM images of the polymeric weld, A) Sample 2, B) Sample 3, C) Sample 6, and D) Sample 7

8. By comparing Figures 6d and 7, it seems that an increase in the angle of the workpiece leads to a reduction of shear stress and the rise in the mixing force. An increase in mixing force leads to corrosion of carbon fibers. The returning electron method is suited to represent the color difference of the phases to indicate the distribution and precise size of the crushed particles. From the SEM image of sample 8, it can be seen that the fibers after welding and mixing experienced a reduction in size even up to nanometric scale. This reduction in the size and distribution of broken fibers, which have now become whisker, can be very useful in increasing the strength of the welding bond.

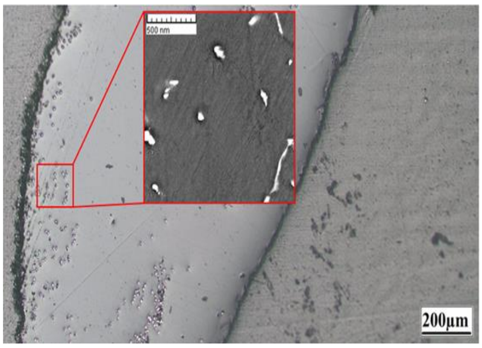

Figure 7. OM and SEM image of sample 8

In Figure 8, the pie charts illustrate the face-reinforcement and width of the welding face. At low travel and rotational speeds, an increase in the diameter of the various wear-resistance tool components, and the deviation angle of workpiece lead to a decrease in the face-reinforcement and width of the welding face. Increasing travel speed does not affect the Width of the welding face while it decreases face-reinforcement. Also, it seems an increase in the travel speed could prevent the accumulation of polymer materials. At high rotational speeds and low travel speed, increasing the diameter of the various components of the wear-resistance tool and the deviation angle of the workpiece have reduced the face-reinforcement and width of the welding face. While at the same time, by increasing travel speed, the face-reinforcement and width of the welding face have reduced. It can be deduced that the an increase in travel speed leads to a decrease in the face-reinforcement by preventing the accumulation of polymer materials.

The face-reinforcement and width of the root welding face are shown in Figure 9. At lower travel and rotational speeds, an increase in the diameter of the various components of the wear-resistance tool and the deviation angle of the workpiece lead to a slight increase in the face-reinforcement and width of the root welding face.

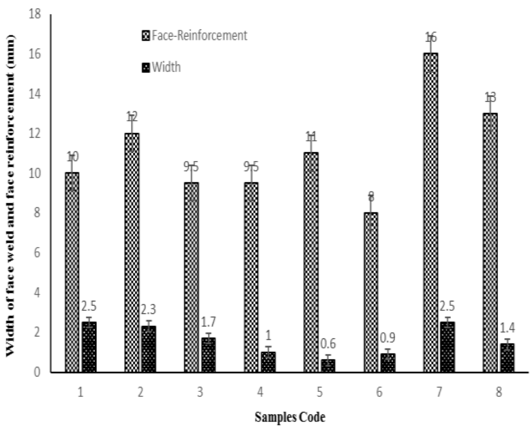

Figure 8. Bar chart of face-reinforcement and width of the welding face

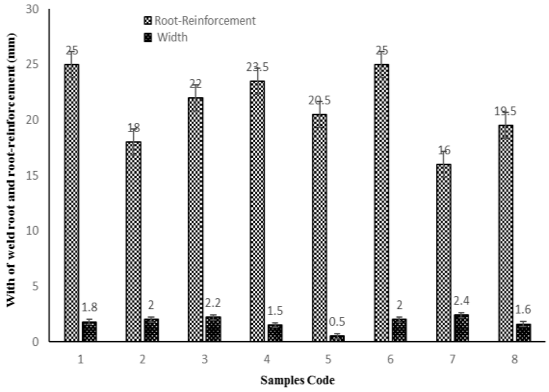

Figure 9. Bar chart of root-reinforcement and width of the root of the weld

As the speed increases, the width of the welding face increases while its face-reinforcement decreases. Higher rotational speeds, lower travel speed, increase in the diameter of the various components of the wear-resistance tool and the deviations angle of the workpiece reduce the width of the welding face and increase in the face-reinforcement. Moreover, by increasing travel speed, the width of the welding face increases and the face-reinforcement decreases. It can be deduced that higher travel speed will transmit polymeric materials further which could prevent the accumulation of polymeric materials and reduces the face-reinforcement of the weld. In general, it can be said that travel speed increases in the face-reinforcement in both the face and root face.

4. CONCLUSION

From the present research and writing of the article, we can conclude that:

a) The bond between the carbon fiber reinforced polymer composite by the FSW process was successfully existed.

b) Instead of heavy, expensive and high power multi-axis lathe machine, a simple machining device can be used to weld which is useful in cost savings.

c) The excessive increase in rotational speed caused the polymer to melt.

d) An increase in rotational and travel speed, the carbon fibers uniformly distributed in the polymeric field, and their is reduced.

e) The rotational speed of 355 rpm and the travel speed of 9 mm/s is the most suitable parameter for welding and distribution of carbon nanowhisker in the polymeric field.

f) An increase in the rotating speed leads to a decrease in the face-reinforcement of the weld in both face and root face area.

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PAPER INFO

Paper history:
Received 16 February 2019
Received in revised form 09 March 2019
Accepted 03 May 2019

Keywords:
Polymer Composite
Carbon Fiber
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چکیده

کاربرد مواد گرمانرم در دهه های اخیر به علت قابلیت بازیافت مجدد، چگالی پایین، مقاومت دربرابر تغییرات شیمیایی افزایش چشمگیری یافته است. فرایند جوشکاری اصطکاکی تلاطمی یکی از روش های نوین جوشکاری حالت جامد است که اخیرا پیشرفت قابل ملاحظه ای در آن صورت گرفته است. در این تحقیق، با استفاده از یک ابزار جدید از جنس فولاد ساده کربنی st37 در جوشکاری اصطکاکی تلاطمی و دستگاه ارزان قیمت تراشکاری، ورق های مواد کامپوزیت پایه پلیمری گرمانرم دارای ۱۲٪ الیاف پیوسته کربن به صورت لب به لب با دو سرعت چرخشی ۲۵۰ و ۳۵۵ دور بر دقیقه و دو سرعت پیشروی ۶/۵ و ۹ میلیمتر بر دقیقه اتصال داده شدند. تصاویر میکروسکوپ نوری (OM) اتصال کامل مواد را نشان داد. افزایش حرارت ورودی منجر به تشکیل و رشد حفرات و تبدیل آنها به حفرات تونلی گردید. به طور کلی پارامترهای موثر بر کیفیت اتصال در این پژوهش شامل قطر شانه اصلی و سرعت چرخشی بودند؛ به طوری که بر اساس نتایج میکروسکوپ الکترونی روبشی (SEM) افزایش سرعت چرخشی منجر به خردایش الیاف های پیوسته کربن و در نتیجه افزایش استحکام کششی شد. نتایج آزمون کشش نشان داد که شکست نمونه ها به علت تغییرات ریزساختاری در HAZ، در فصل مشترک منطقه جوش و مواد پایه صورت می گیرد. مطابق نتایج حاصل می توان بیان نمود که با استفاده از این ابزار جدید در روش جوشکاری اصطکاکی تلاطمی، به دلیل کاهش سرعت دورانی در مقایسه با تحقیقات مشابه قبلی و استفاده نکردن از دستگاه فرز چند محوره سنگین، صرفه جویی در مصرف انرژی اتفاق می افتد.

doi*: 10.5829/ije.2019.32.06c.09*