

Investigation of Metallurgical and Mechanical Properties of Brass/Steel plates joined using Friction Stir Welding

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Abstract:

The aim of the study is to show the feasibility for joining of dissimilar brass to austenitic stainless steel plates by Friction Stir Welding (FSW). In this study, dissimilar brass and steel plates were butt joined by FSW. Metallurgical and mechanical properties were investigated, in order to evaluate the joint performance and the weld zone characteristics of dissimilar brass/steel joints. Metallurgical characterizations are carried out by Scanning Electron Microscope (SEM). Mechanical characterizations such as tensile tests, Microhardness tests are carried out by ultimate tensile testing machine and Vickers Microhardness testing machine respectively. The tensile strength of dissimilar brass/steel joints was found to be lower than that of parent metal (brass and steel). The tensile strength values of 20 MPa, 122 MPa and 157 MPa were obtained for the table traverse speeds of 40 mm/min, 50 mm/min and 60 mm/min respectively. The average hardness obtained are 175 Hv, 196 Hv and 199 Hv for table traverse speeds of 40 mm/min, 50 mm/min and 60 mm/min respectively. The defect free brass/steel interfaces were seen by SEM. It was illustrated that the stirred zone (SZ) exposed to the two main structures: (1) recrystallized grains of brass (2) intercalated swirl and vortex-like structure which can be characterized both the recrystallized brass grains and steel layers. In this study, the limited FSW parameters were employed. Further studies are needed to evaluate the effects of welding parameters of dissimilar brass/steel plates on the joining properties to establish the optimal weld parameters. FSW is successfully applied to the butt joining of dissimilar brass/steel plates. This work is one of the preliminary studies on the detailed examinations of the microstructural and mechanical properties of the dissimilar brass/steel joint by FSW.

INTRODUCTION

In the present scenario joining process industries are growing rapidly in the world of work. The welding came into existence as a viable manufacturing process in the half of 19th century, thereafter lots of fusion welding techniques (e.g. arc welding, gas welding) are evolved out. Generally in fusion welding techniques energy density is high and hence heat affected zone is wider and results in solidification defects namely distortion, reduced mechanical properties, lack of penetration, poor fusion rate, etc. In the middle of 20th century plasma arc and laser beam welding techniques are developed capable of producing sound weld of thicker materials with narrow heat affected zone. Though it is found

that mechanical properties (e.g. ductility, tensile strength and fatigue strength) are altered at heat affected zone; in addition these techniques are not suitable for reactive elements such as aluminium, magnesium. These drawbacks necessitate the exploration of solid state welding techniques (e.g. resistance welding, friction welding, friction stir welding) in which joining occur at a temperature lower than the melting point of base metals without use of filler material or shielding gases. In resistance welding coalescence occurs owing to heat generated by contact resistance and applied pressure and thus, it is not suitable for materials having high electrical conductivity (e.g. copper, aluminium).

Brass materials widely used as engineering materials in industry because of their high strength, high corrosion resistance, and high electrical and thermal conductivity. They are easily shaped and they possess nice appearance. However, it is difficult to fusion welding of brasses. The main problem of these alloys in fusion welding is the evaporation of the zinc during the welding process. After the welding, the weld metal becomes porous. Moreover, since the amount of the zinc in the alloy is reduced due to evaporation, the brass material loses its physical and chemical properties which it normally possesses. Not being solved these problems good enough infusion welding of brass materials, it had been directed investigators to apply new methods. It seems that friction stir welding which is one of the new method developed nowadays, will solve these problems. So, it needs experimental investigations in this subject. Even though there are so many researches in the literature about friction stir welding in aluminum and its alloys, researches about copper and its alloys especially brass are limited.

In Friction welding two pieces are joined by frictional heat generated when a moving workpiece and a fixed component are thrust together in order to obtain the required heat and temperature for weld. The geometry of the workpiece to be joined restricts its application in industries. To overcome the difficulties in welding of especially aluminium and magnesium based alloys by fusion and other welding techniques the welding institute (TWI) invented a unique and novel welding technique named friction stir welding (FSW) after vigorous research in this area. After the invention of FSW, industries started implementing this technique for fabricating ship, fuel tanks for spacecraft, etc. It is found that application of FSW technique in spacecraft manufacturing increases joint strength by 30% to 50% and manufacturing time reduces from 23 days to 6 days; cost saving is up to 60%. Thus, its eco-friendly and energy efficient behavior establish FSW as a green technology.

Friction stir welding (FSW) process was developed first time in 1991. Since then, several attempts have been made to make this process feasible for industrial applications. Generally, these efforts can be classified into three main categories: 1) investigating the mechanism of process by means of studying pattern of material flow during welding. 2) Probing the effect

of various welding parameters on mechanical and metallurgical properties of joint, and 3) attempt to extend this process into dissimilar joining of materials. Undoubtedly, material flow features in ultimate properties of friction stir welded couples. Consequently, studying the pattern of material flow during welding has engrossed researchers. Copper cannot be "welded" to steel since copper has a significantly lower melting point than steel, and brass has an even lower melting point than copper. Therefore, traditional "fusion welding" processes would not work. It's possible to "brazing" copper to steel using brass as a "filler metal," but this is not usually done because of practical concerns. Also, "solid state welding" methods can be used to join Brass to steel. "Friction Stir welding" can be used to join brass and steel plates.

Friction Stir Welding

Friction stir welding (FSW) is a solid-state joining technique in which coalescence occurs owing to thermomechanical deformation of workpieces as the resulting temperature exceeds the solidus temperature of workpieces. It consists of a non-consumable rotating tool having a specially designed tool pin and shoulder. Tool pin is plunged into the faying faces of sheets or plates to be joined thus tool moves in the transverse direction along the length. The tool rotates in the clockwise direction and translates from front to back as shown in Figure 1. The left side where the direction of tool rotation is same of tool travel direction is termed as advancing side. It is opposite to the direction of metal flow. The side opposite to advancing side where rotation of tool is reverse of direction of tool travel is termed as retreating side. Owing to frictional heat between tool and workpiece, material around the pin is softened and a solid state joint is produced without melting.

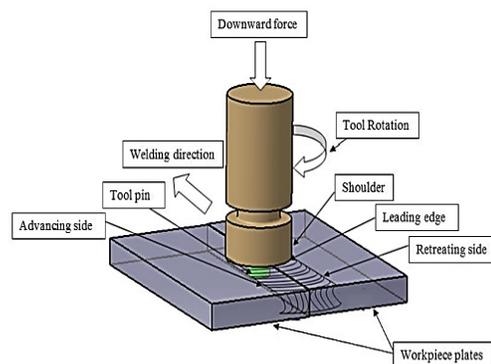


Fig. 1. Principle of friction stir welding

In FSW joints various microstructural regions can be observed as illustrated in Figure 2. The parent metal region is unaffected by heat as it is far away from the recrystallized zone and hence microstructural and mechanical properties of this region remains unaltered. The second region is heat-affected zone that is next to parent metal and is affected by heat but no plastic deformation takes place in this region; however, mechanical and microstructural property changes. The next region is thermomechanically affected zone that is very near to weld nugget and it is plastically deformed by means of tool. In this region material deforms without recrystallization.

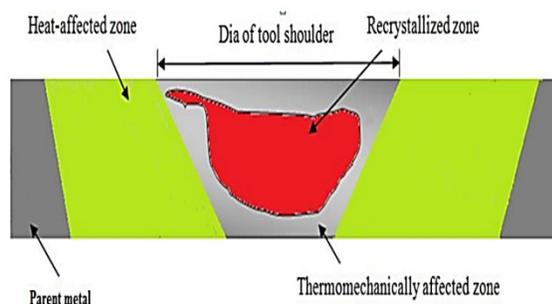


Fig. 2. Microstructural regions of friction stir welding

Next region is nugget zone or stir zone or fully recrystallized zone in which tool pin rotates and produces frictional heat; results in severe plastic deformation.

LITERATURE SURVEY

Lee and Jung (2004) carried out research on FSW of copper. The experiment is conducted on 4 mm thick copper plates with the help of steel tool. It is observed that the size of grain in the nugget zone is very fine and equiaxed as compared to base metal. It is obvious from the study that the strength obtained by FSW is higher than that of electron beam welding.

Khodaverdizadeh et al. (2012) analyzed the work hardening behavior of FSW joints of pure copper alloys. The experiments are conducted at two different rotational speeds and constant feed rate and vice versa and it is evident that both factors influence the mechanical and metallurgical properties of copper joint. The grain size in SZ and HAZ decreases with increasing rotational speed and decreases in

welding speed. Owing to this hardening capacity increases and strain hardening exponent decreases.

Lin et al. (2014) compared the properties of friction stir welded pure copper plates with TIG and it is observed that FSW of copper produced 13% more efficient weld than TIG. Fusion welding affects the microstructure of steel and owing to this steel loses their corrosion resistance and toughness properties.

Thomas et al. (1999) is probably the first one to check out the feasibility of FSW of steel. They carried out FSW technique on 12% chromium alloy and low carbon steel in a modified vertical milling machine to test the bending and tensile strength of joint.

Thereafter **Lienert et al. (2003)** experimentally analyzed the possibility of FSW of mild steel and reported the effect of process parameters on metallurgical and mechanical properties of FSW joint. Thermocouples are also used to determine the temperature distribution during the process. However, very high tool wear is observed at initial stage for plunging action of tool.

Reynolds et al. (2003) attempted FSW for 304L and experiments are carried out at constant feed rate and two different rotational speeds. It is evident that grain size of joint is less than that of base metal and existence of narrow band grain in stir zone for both rotational speeds. It is obvious that a joint with superior ductility than fusion welding is obtained.

In **2005 Sato et al.** investigated the properties of friction stir welded 2507 super duplex stainless steel using CBN tool of 25 mm diameter and at 3.5 degree tilt angle. It is observed that in SZ the microstructure of joint contains refined grains of ferrite and austenite and hence hardness and strength is increased. It is further evident that the fracture occurs between HAZ and TMAZ line on retreating side. It is witnessed that percentage of carbon content affects mechanical and metallurgical properties of friction stir welded low carbon steel joints (Ueji et al., 2006). It is found that with increase in carbon content the tensile strength increases rapidly with minor change in welding speed upto a certain limit and then starts decreasing. With increase in carbon content portion of austenite is found increasing in obtained ferrite-austenite

structure. Moreover, in case of S12C steel austenite is observed transformed into pearlite but the distribution is not uniform.

Sato et al. (2007) investigated the metallurgical properties of frictions stir welded ultrahigh carbon steels and examined martensitic structure in stir zone and mixed in the HAZ. Later in 2008, Saeid et al. described the effect of welding speed on characteristics of friction stir welded duplex stainless and stated that microstructure of stir zone consists of equiaxed grains of α and γ phases. They further reported that the size of grains decreases with increasing welding speed and the hardness and tensile strength enhances with increase in feed rate.

Cho et al. (2012) and Han et al. (2014) investigated the microstructure of friction stir welded stainless steel plates. Cho et al. observed that the hardness of nugget zone is higher because of presence of bainitic structure in nugget zone. On the other hand Han et al. witnessed formation of fine grains in nugget zone and TMAZ owing to mechanical stirring and heating. It results in joint with superior impact strength.

Experimental Procedure

Plates of commercially available brass (50 mm x 100 mm), and austenitic stainless steel (50 mm x 100 mm) were lap joined by FSW. Fig. 3 shows the photo of FSW machine.



Fig. 3 Friction Stir Welding Machine

The High Carbon High Chromium FSW tool comprises of a shoulder of 18 mm in diameter, and probe diameter of 6 mm with a probe length of 2.9 mm, which is 0.1 mm shorter than the thickness from the backing plate. The effect of welding parameters on the brass/steel dissimilar joint was studied with different welding speeds of 40, 50 and 60 mm/min and with the fixed rotational speed and axial force of 500 rpm and 9 kN respectively with the tool title angle of 2° . The welded joints were cross sectioned perpendicular to the welding direction using a wire cut electrical-discharge machine for metallographic analysis. The microstructures of the joints were studied using scanning electron microscope (SEM), The Vickers hardness profile measurements were conducted on the cross-section of the joints using a micro-hardness tester under a load of 0.1 N and a holding time of 15 s. Friction Stir Welded plates are shown in the Fig. 4.



Fig. 4 Friction Stir Welded Plates
Results and Discussion

Microhardness Survey

As shown in the Figure 5 it was understood that when the traverse speed is at 40 mm/min the hardness values are found to be less. This is due to increased heat generation, because of the slow movement of the table. When the traverse speed is at 50 the hardness values are found to be higher than the values obtained at 40 mm/min. At 60 mm/min, improved hardness values are obtained in the heat affected zone. This is due to reduction in heat input. The reduction in heat input is achieved by increasing the table traverse speed. Also the intermetallic layer have not formed at higher traverse speeds 50 mm/min and 60 mm/min (due to low heat input). The average hardness obtained in the welds are 175 Hv, 196 Hv and 199 Hv for table traverse speeds of 40 mm/min, 50 mm/min and 60 mm/min respectively. The formation of intermetallic reduces the ductility of the material and a very high hardness values can be seen at the interface of the intermetallic layer formed surface. These surface generally will have very high hardness and it will be in brittle form.

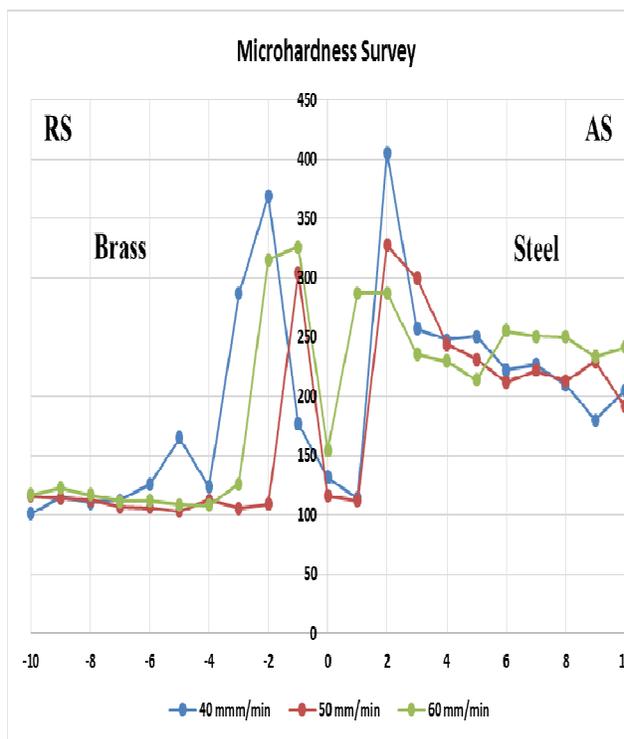


Fig. 5 Microhardness survey

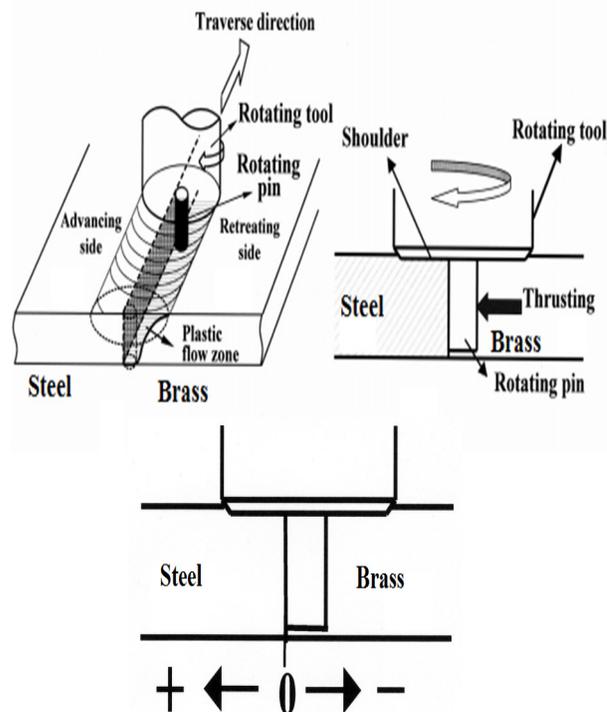


Fig. 6 Tool plunging positions

The main aim to prevent the intermetallic layer formation, this can be achieved by reducing the heat input. During stirring, some portion of the steel from the advancing side flows to the retreating side and mixes with the brass. This is the reason for obtaining higher hardness values in the stir zone of the brass. The austenitic stainless steel is harder than brass, so it is kept on the advancing side. In advancing side more heat generation occurs and in retreating side usually low heat generation occurs. The softer material brass is kept on the retreating side. The tool pin is plunged on the retreating side in the brass with zero offset from center of the workpiece and is shown in the Fig. 6.

Intermetallic Layer Formation

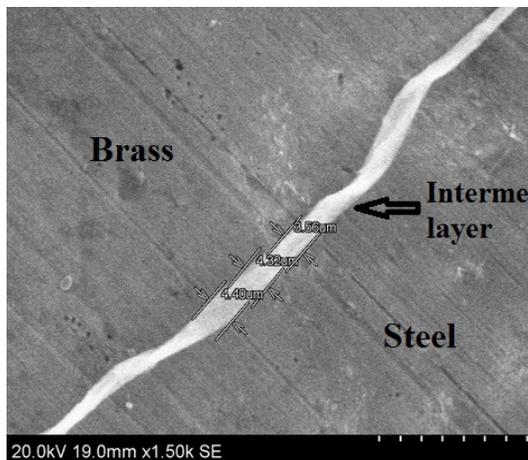


Fig. 7 Formation of intermetallic layer at the interface (a) the interface in rotation speed of 550 rpm and 40 mm/min

Fig. 7 shows the intermetallic layer formation with the average thickness of 4.09 μ m. This layer was observed for the weld carried out at 40 mm/min. This intermetallic layer forms due to high heat input. Usually intermetallic will be highly brittle. This makes the weld zone very harder and it fails in the brittle mode.

Tensile Test

Tensile test results of the specimens extracted from friction stir welded plates and the elongation values are calculated. Figure 8 shows the tensile specimens before and after testing. The specimens are cut with wire cut EDM. Figure 12 illustrate the comparison of the stress-strain curves of the welded plates (brass/steel) used in this study.

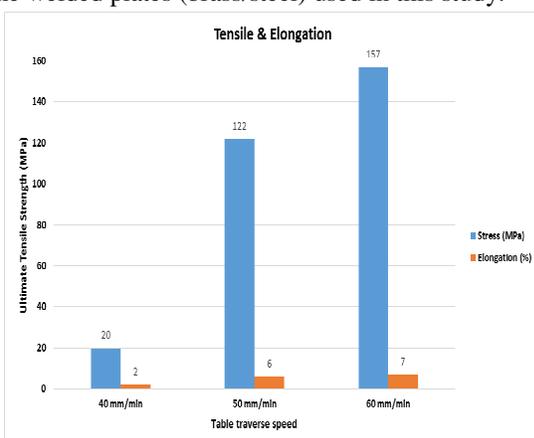


Fig. 8 Ultimate tensile strength and Elongation (Transverse direction)

The best combination of mechanical properties was obtained from the joint produced with a traverse speed of 60 mm/min and at the tool

rotational speed (i.e. 550 rpm). The fracture have not occurred in the stir zone for 60 mm/min. The specimens with a traverse speed of 40 and 50 mm/min failed in the stirred zone. Thus, the highest strength performance was obtained for the joint produced with a traverse speed of 60 mm/min.

The highest joint performance in terms of ductility was also obtained from the joint produced with this travel speed. The ductility of the joints are lower for the joints fabricated at 40 and 50 mm/min due to high heat input. Due to higher temperature zinc particles from the brass gets evaporated and hence poor mechanical properties were obtained.

The reason for this is the inhomogeneous plastic deformation of the joint due to a slight hardness increase in the stir zone and a very thin intermetallic layer formation.

The FSWed specimens fractured at the brass parent metal region (Advancing side) quite far from the weld center for the weld done at 60 mm/min, as shown in Fig. 11 (b).

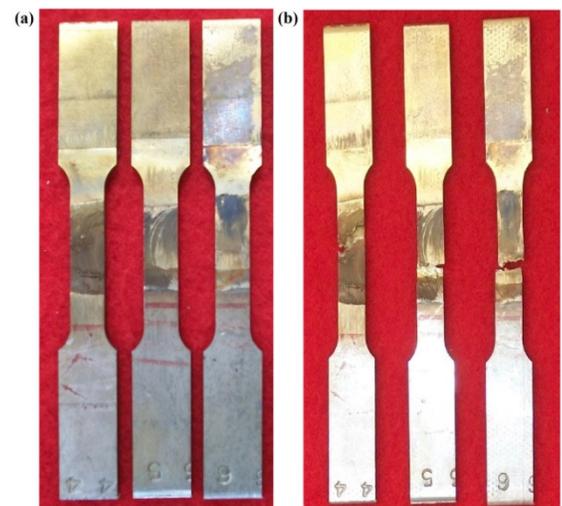


Fig. 9 Tensile samples (a) Before and (b) After fracture

From literature it was also observed, that the tool geometry has a significant effect on the weld parameters. By using a slightly conical tool instead of cylindrical one, a combination of higher rotational and travel speeds can be employed for achieving sound joints in friction stir welding. The average tensile strength and percentage of elongation of the dissimilar brass/joints are 20 MPa, 122 MPa and 167 MPa; 2%, 6% and 7% elongation for 40 mm/min, 50 mm/min and 60 mm/min respectively.

Figure 10 shows the SEM images at the weld joint interface.

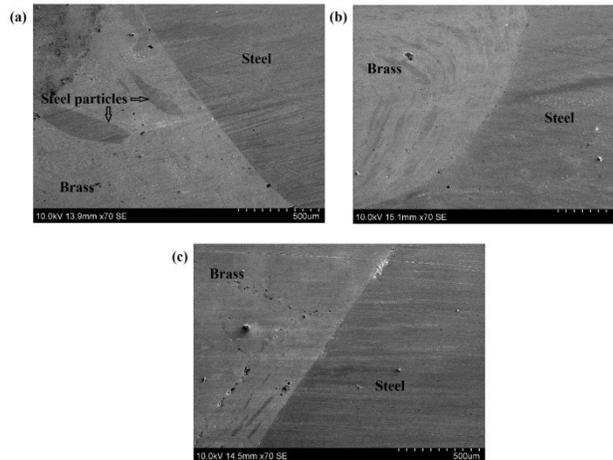


Fig. 10 Scanning Electron Microscope images at the weld joint interface (a) 40 mm/min, (b) 50 mm/min, and (c) 60 mm/min.

Tensile Fracture Surfaces

At lower table traverse speeds more heat generation occurs, and there are possibilities of the formation of intermetallic layer at the interface of the brass/steel joints. This intermetallic layer makes the metal very brittle and the failure occurred by brittle mode for the table traverse speed of 40 mm/min. At the table traverse speed of 50 mm/min in some portions of the SEM image we can observe ductile and brittle mode of failures. Comparing to 40 mm/min, in 50 mm/min the heat generation will be less. For the table traverse speed of 60 mm/min the heat generated is less and it is sufficient to bond the brass with steel and no intermetallic layer formation were observed. The mode of failure obtained for 60 mm/min was ductile. Among all the three welds, the weld joint carried out 60 mm/min is considered to be best weld. Fig. 14 shows the tensile fractured surfaces at various table traverse speeds.

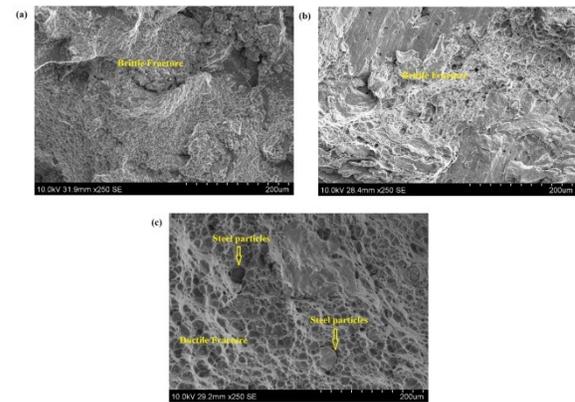


Fig. 11 Tensile fractured surfaces (a) 40 mm/min, (b) 50 mm/min, and (c) 60 mm/min

CONCLUSION

Friction stir welding method was successfully applied to the butt joining of brass/steel plates. The microhardness and tensile properties of FSWed dissimilar brass/steel joints have been studied in the present work and the following conclusions are drawn: (i) The present study has demonstrated that brass can be successfully joined to steel by FSW. (ii) The average microhardness distribution in the stir zone is 196 Hv, 247 Hv and 248 Hv for 40 mm/min, 50 mm/min and 50 mm/min respectively due to the material flow patterns. The average hardness obtained in the welds are 175 Hv, 196 Hv and 199 Hv for table traverse speeds of 40 mm/min, 50 mm/min and 60 mm/min respectively. (iii) This intermetallic layer makes the metal very brittle and the failure occurred by brittle mode for the table traverse speed of 40 mm/min. At the table traverse speed of 50 mm/min in some portions of the SEM image we can observe ductile and brittle mode of failures. Comparing to 40 mm/min, in 50 mm/min the heat generation will be less. For the table traverse speed of 60 mm/min the heat generated is less and it is sufficient to bond the brass with steel and no intermetallic layer formation were observed. The mode of failure obtained for 60 mm/min was ductile.

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