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UNDERSTANDING THE EFFECT OF MULTIPLE TRAVERSE FEED DURING FRICTION STIR WELDING PROCESSES

The scope of this paper is to understand the effect of multiple pass of the tool during friction stir welding process of Al-17Si alloy and evaluate its microstructure and tensile strength. The rotational speed of 900 rpm with three different feed rates (50, 100, 150 mm/min) was selected for this process. The weld gap seen below the tool tip has been reduced drastically during the multiple pass and after the third pass the weld gap was invisible. With the increase in the feed rate, the adhesion was reduced between the tool pin circumference and diffused material, hence a small increase in the weld gap was observed. The substantiate changes in the microstructure was observed due to the severe formation of the metal during low feed rate. With the increase in the feed rate, some coarse grains were observed near and below the tool pin. The tensile strength during the multiple pass of the tool was studied and found better for lower feed rate. Further, the variation of the tool speeds (600, 900 and 1200 rpm) for constant feed rates of 100 mm/min were discussed. The more heat input improves plunging depth thereby reduces weld gap, but for higher heat input (tool rotation: 1200 rpm; feed rate: 100mm/min) increase in weld gaps was seen. The tensile properties for all the cases were discussed. The diffusion process, friction force and relative velocity pertaining to this process were highlighted finally.

Keywords: Friction Stir Welding, Multiple pass of tool, Micro structure, Tensile Strength

1. Introduction

Now-a-days, Al-Si alloys are used in various fields of automobile, aerospace and other industries. They are chosen as an important material in the process due to its light weight, high wear resistance and high strength. Friction stir welding is one of the emerging processes of joining aluminum alloys because of its poor joining capacity with fusion welding. The change in the mechanical properties of aluminum alloys is studied by various authors [1-3]. H.J. Liu [1] mentioned that there is elimination of voids in this process and the mechanical properties are improved in comparison with the base material. Also at TMAZ, there is much improvement in the mechanical properties when compared with the other regions. Saktivel [3] mentioned that there is a decrease in the mechanical properties with an increase in the welding speed of the tool. Also there are studies in understanding the mechanical properties of the weld joint of dissimilar materials. M Ghosh [4] explained the microstructure and mechanical properties on joining A356 and 6061 aluminum alloys. The reduction in the temperature on the nugget zone and the effect of heat transfer in joining process to increase in feed rate are explained. Guo [5] studied the effect of process parameters of dissimilar materials between AA6061 and AA7075 alloys. He discussed about the material flow, microstructure and tensile properties during this process.

A hyper eutectic alloy is one of the promising materials used in defense and automobile sector. FSW is one of the processes used to join these alloys during fabrication. From the literature, only few studies are reported in understanding the strength of the weld joint on hyper eutectic Al-Si alloys[20]. The proper plunging of the tool in the weld joint, by proper heat input improves the weld quality. The coarse grains may form due to higher or lower heat input and a proper method in determining the balance heat input for a given alloy needs to be studied. Also, the mechanical properties like ductility and toughness of the weld joint depends on the formation of microstructure during the welding process. The intense plastic deformation and proper mixing leads to a finer grain structure in the weld joint and improves mechanical properties [7]. Several techniques like improvement in the tool design, cooling/heating the base material, increasing plunging pressure helps in improving the grain refinement during the welding process [8,9].

Earlier, there are various modification and thermal techniques used for forming finer Si particles during the casting process [2]. In the modification techniques, the use of refiners such as sodium, strontium helps in improving the grain size of silicon particles [10,11]. The formation of porosity is a major problem in this process. There are some heat treatment methods by varying speeds and feed based on the composition in refining the Si particles. This method eases the porosity problem at the cost of ductility and fatigue properties. In general, the fluidity of

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the metal, changes with the variation in the functional parameter, which modifies the cooling rate and changes the mechanical properties in the weld zone. Here even some attempts in improving the microstructure and mechanical properties in the weld region are carried out, a process that exhibits a proper dynamic recrystallization and in turn improvements in the mechanical properties needs to be explored. There are some work carried by Garcia[12] to study the strain path and microstructure formation during multiple tool pass for hypo eutectic alloys and mentioned some improvement in grain refinement in Al matrix. A.G. Rao [23] performed the multiple tool pass in the welding process for hyper eutectic Al-Si alloys and noted the improvement in the grain refinement due to improved dynamic recrystallization process. During the single tool pass, the improper plunging depth leads to the formation of weld gap below the tool pin. This may act as crack initiation, which decreases the tensile properties of the specimen. In the case of multiple tool feed, the addition of cyclic thermal energy may help in refining the grains during the welding process, cover up the weld gap and improve mechanical and tensile properties. It is to be noted that the presence of large number of silicon results in poor cooling rate and thus a balance optimum process are required for improving the weld quality by refining Si particles There may be a possibility of grain improvement during the multiple feed given in the weld line. This may lead to the proper refining of Si particles and improve ductility. The increase in the tool rotation increases the heat energy in the weld joint, but, as mentioned earlier more heat input leads in the poor solidification rate and thus reduces weld joint quality. In this direction, understanding the change in the grain structures during the multiple tool pass for various tool rotations and feed needs to be explored.

In this paper, the effect of increase in the feed rate (50, 100 and 150 mm/min) for constant tool speeds of 900 rpm are carried out initially. The tool is passed for the second and third time for the same weld that was joined earlier. The microstructure formation below the tool pin and nugget zone are taken for our studies and discussed in detail. The tensile strength for the entire specimen are tabulated and narrated. Moving forward, the effects of different tool rotation (600, 900 and 1200 rpm) for a constant feed rate of 100 mm/min are carried out. The tensile strengths are also found for these weld joints. The metal movement during the multiple tool pass and its effect on the microstructure and tensile properties are discussed in details.

2. Experimental details

Al 17Si alloys were prepared by melting commercially pure aluminum (99.7%) and silicon (99.5%) in a graphite crucible in an induction furnace. The temperature of the melt was held at 800°C for homogeneous composition. After proper degassing and stirring the melt, the cast tube was machined to form 150 mm × 50 mm × 6 mm size billets. A High Density Tool with pin tapering from ϕ4 to 6 mm, shoulder of ϕ20 mm and height of 25 mm was used as a tool for the process. The specimen are processed with plunging force of 40 kN, three feed rate, i.e. 50, 100 and 150mm/min and tool speed of 900 rpm. Microstructure studies of the samples were observed under computerized optical microscope (Model: METZ 780/1000X). Initially the samples were polished using standard techniques before the examination. The etching was done using the Keller's reagent. Tensile properties of the alloys were analyzed by carrying out test on the universal testing machine (Model: UTM 40T).

3. Results and discussions

The understanding of grain formation has been carried out for the multiple passes on the weld zone. The microstructure of the base Al-17Si alloy is shown in Fig.1. A huge number of primary silicon and needle shaped silicon in the microstructure with small amount of porosity are found.

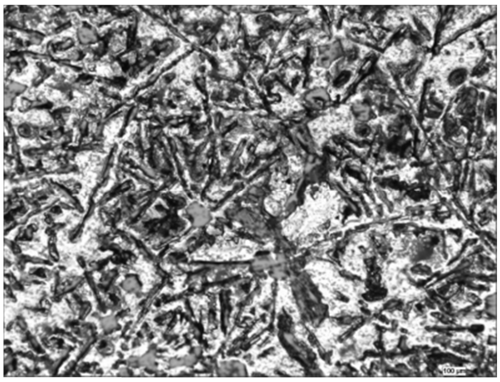

Fig. 1. Microstructure of the Base Material Al-17Si alloy

The microstructure on the nugget and its below areas are observed through the microscope as seen in the Fig. 2. In the entire feed rate, fine recrystallized grains with small amount of primary silicon are formed in the nugget zone. Small primary silicon is seen with the increase in the feed rate, which is due to a probable reduction in the contact time between the tool and the base material. Below the nugget zone, Needle shaped silicon and a small weld gap are seen in all the process. This indicates that not much diffusion has happened in this zone during the process. Also, the weld gaps are widened with the increase in the feed rate due to improper stirring of the tool, which leads to poor weld joint. There was formation of a tunnel like defect during the tool rotation speed of 900 rpm during the single pass and agreed accordingly with M. Jayaraman [9].

The effect of stirring and mixing has a profound influence in the formation of microstructure at the weld zone. Already accumulated heat in the weld zone makes the alloy to stir the tool easier during the second tool pass on the weld line. Fig. 3 shows the microstructure during double pass of the tool. The improved stirring action and heat input makes the alloy to undergo improved diffusion process and even fine grains are seen at the nugget zone. The reduction in the primary silicon formation and weld gap are seen during this process. Some filling of weld gaps are seen during the double pass of the tool due to higher heat

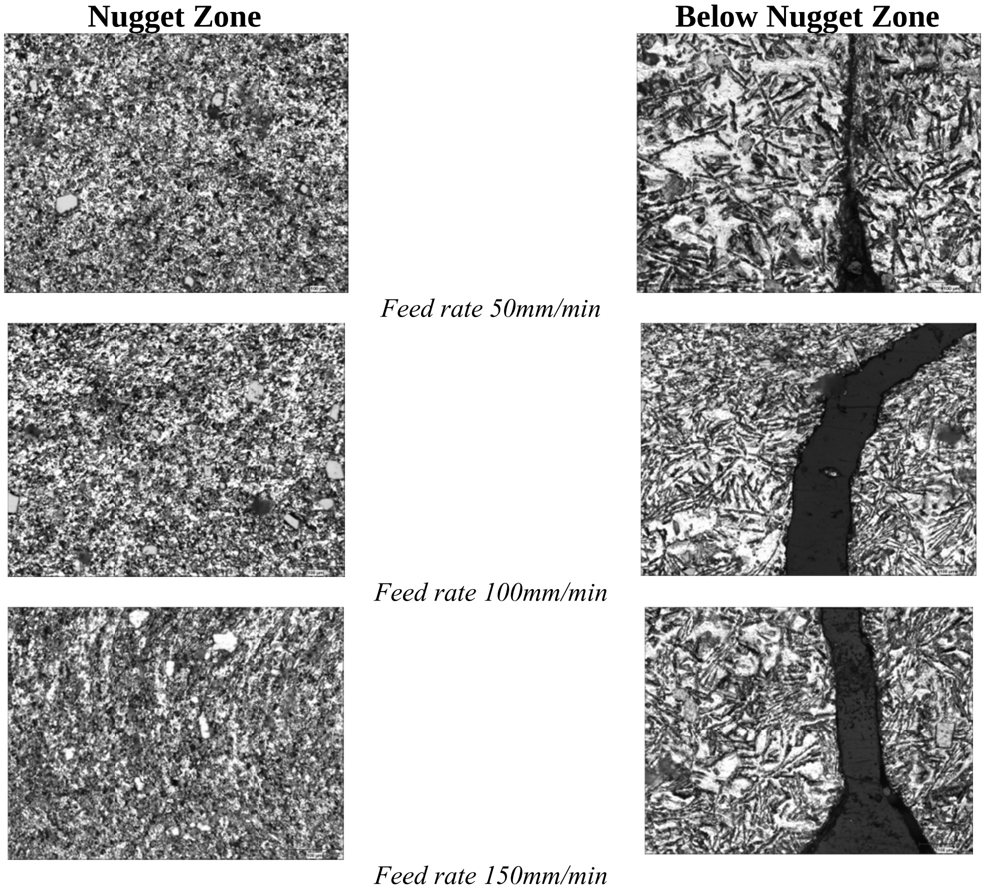

Fig. 2. Microstructure during the single pass of tool

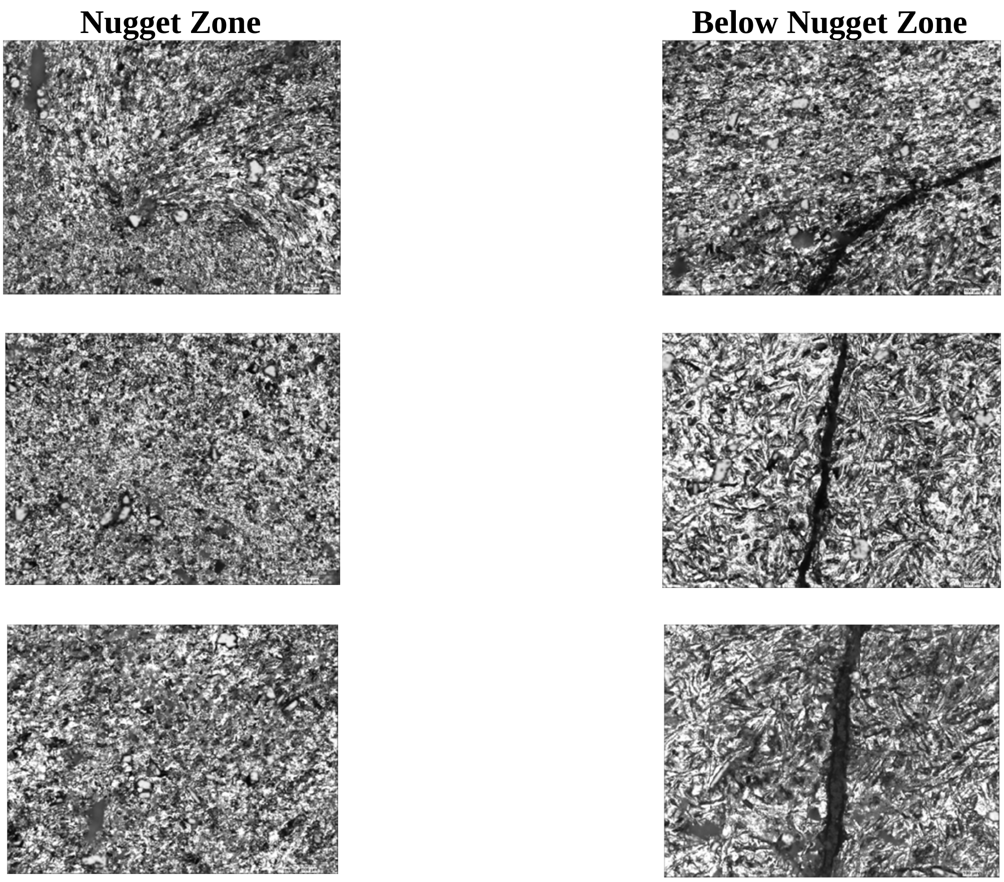

Fig. 3. Microstructure during tool rotation 900 rpm and feed rate 50,100,150mm/min during double pass of tool

Nugget and Below Nugget Zone

Fig. 3. Microstructure during tool rotation 900 rpm during triple pass of tool

input and proper alloy mixing making a proper bond in the weld zone. Increase in the feed rate makes less contact time between the tool and the alloy which in turn reduces the filling of the weld gap. A proper filling of the weld gaps are seen during the triple pass of the tool. The overall microstructure formation on the nugget and its below portion during these process are shown in Fig. 4. It is inferred that the proper heat formation helped in bonding the alloys below the nugget zone. The thermal cyclic process makes an improvement in the diffusion process, which helps in the formation of fine grains in the nugget zone. The higher heat input during low rotational speed causes defect in the weld zone [13,14] due to the poor stirring action of the tool. The accumulation of heat due to cyclic process helps in diffusing the alloy easily and hence higher heat input helps in making a proper bond in the weld joint. A minimal weld gap is seen with the tool feed rate of 100 and 150 mm/min, which is again due to less contact time during the process which makes a small imbalance in the heat transfer.

Fig. 4 shows the tensile properties of the base Al-17si alloys during the multiple feed of the tool. For single and double pass of the tool, an improvement in the ultimate tensile strength is observed. The formation of the weld gap becomes a media for crack propagation and a fracture has occurred. There is improvement in the tensile strength for the feed rate at 50 mm/min

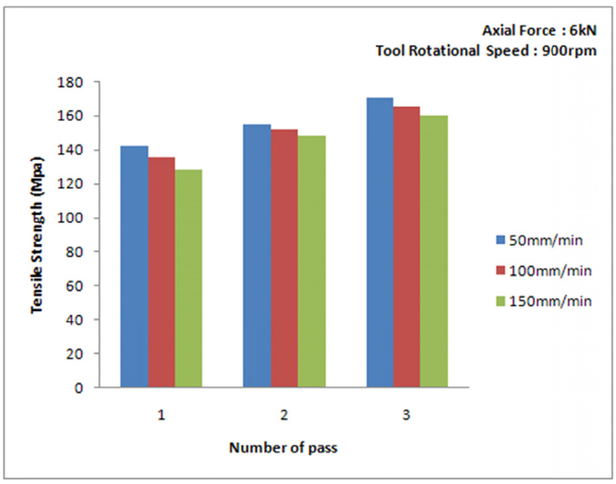

Fig. 4. Effect of process parameters on tensile properties of Al-17 Si alloys

due to proper diffusion because of more contact time between the tool and the alloy. There is 10% improvement in the tensile strength for the triple pass of the tool. A proper heat input and stirring action helps in proper diffusion of the alloy making the bonding between the alloys. This helps in improving the tensile properties of the specimen.

3.1. Effect of Multiple pass on Weld Mechanism

The friction force generated between the tool surface and work piece strongly affects the flow patterns of the alloy. For the tool feed rate of 50 mm/min, the tool rotation and sliding creates a resistance in the tool by the work material and hereby creates friction and heat. The improper plunging depth generates more friction and heat in the work piece during the single pass of the tool. The increase in the alloy temperature due to low tool feed rate and high tool rotation reduces its strength, sticks on the tool circumference and rotates around the tool. This causes a high shear between the material layer interfaces [15]. Large localized heat is formed in the weld material, which weakens the alloy further. This localized heat is retained even away from the tool rotation due to dynamic velocity differences and sliding conditions [15,18]. The increase in the heat makes the alloy to soften and allows the tool to move downwards. The shear force exerted between the tool circumference and hard alloy makes it difficult to move the tool further. The thrust force exerted by the alloy also restricts tool motion. The rotating tool pierces the alloy to certain depth and creates a low temperature on the hard work material below the tool point. This develops a transient heat generation between the tool and the alloy. In the dwell period, the high tool rotation makes the alloy to lose its strength. During the tool travel, since not much penetration happens in the process, the soft alloy rotates around the tool and moves towards the retarding side of the weld zone. The diffused alloys are then forged severely at the weld center and forms nugget zone. The improper plunging depth creates a wider weld gap below the tool position and is clearly visible in Fig. 2. The bonding of the two alloys happens after the tool passes and gains some strength after the heat loss in the weld zone. The heat generation in the weld zone strongly depends on the contact surface, time during contact between the tool circumference and alloy and relative speed. The contact time decreases with the increase in the feed rate. This reduces the transient temperature and in turns the plasticity of the alloy during the tool movement. The uniform contact may also reduce with the increase in the feed rate which leads to improper bonding of the alloys. The soft material formed behind the tool movement also may not be squeezed properly by the tool shoulder. The increase in the weld gap is seen in this process. The improvement in the joining process can be done by increments in the tool movement. During the second tool traverse, it re-introduces the heat in the weld zone for the alloy that has already undergone plastic deformation. This cyclic heat generation helps in improvement in the shearing mechanisms and plunging depth. During the tool motion, an improvement in the positioning of the diffused material, reduction in the thrust force and a proper stirring of the alloys take place in the process. This helps in the reduction of the weld gaps below the tool position as seen in Fig. 3. Even improvements in the weld gaps are seen in this process, but weld gaps are increased with the increase in the feed rate. This is again due to improper contact time and squeezing of the alloys by the tool shoulder in the processes. Proper bonding is seen during the third tool movement in the weld zone. In the process, the weld gaps are merely visible for the higher tool feed rates (100 and 150 mm/min). The cyclic heat generation helps in improving the shearing mechanism between the tool and the work piece and reduces the thrust during its motion. The proper stirring action makes the alloy to rotate easily around the tool circumference. The severely plastic deformed alloys are then squeezed easily in the weld zone and bonds uniformly.

3.2. Effect of Multiple pass on the Microstructure formation

The weld mechanism and metal movement play a major role in the formation of microstructure in the weld zone. During the single pass and feed rate of 150 mm/min, drastic increase in the heat is developed during the plunging force [17]. This develops a high pressure on the asperities of the soft alloy which is in contact with the tool circumference. The difference in the velocity during the alloy motion develops more heat to plough the soft material. The formation of high localized thermal energy creates a dislocation and mismatch between the grains in the nugget and TMAZ zones. A maximum strain rate occurs at the tool pin and decreases gradually away from the tool axis. The velocity gradient reduces towards the tool shoulder and strain rate decreases towards the tool depth [18].The increase in the velocity gradient deforms the alloy severely at the weld line and forms fine structures at the nugget zone. The formation of rapid heating during the plunging moves to slower cooling rate after the tool movement and small numbers of primary silicon are observed in the nugget zone. There is improvement in the grain size at the TMAZ zone with the reduction in the feed rate. A relative velocity of the diffused material is much encouraging in circulating around the pin periphery. The more adhesion between the tool and work piece improves the diffusion process and hence small improvement in the grain sizes are observed. An increase in the strain rate has helped in stirring action and forming fine grains near the tool tip. Here the improper plunging force, diffusion and increased thrust has not helped in proper bonding and minimal change in the coarse microstructures are seen in the tool tip position of the work piece. Increased strain rate and velocity gradient helped in some mixing to butt the alloys, but as understood did not bond properly. With the increase in feed rate, improper diffusion, poor plunging depth and less contact time leads in increasing the weld gap.

During the second processes, cyclic heat formation helps in improving the strain rate at the tool bottom. The alloy deforms severely in the tool bottom helps in the proper mixing the alloys in the process. During the feed rate of 50 mm/min, improved adhesion helps in exerting less pressure in the asperities of the alloys thereby creating less heat and uniform softening of the alloy. This increases the strain rate which helps in improving stirring action and proper mixing between the alloys. This may improve the relative velocity which leads to the formation of fine grains in the nugget and below its portion of the weld zone. Some joining of the alloys is also seen in this process due to the improvement in the tool penetrating the weld line. The repeated heat formation helps in the change in grain morphology and proper diffusion during the process. The refinements in the grains are seen below the tool surface, which understand that the proper stirring took place during the process. Also the weld gap widths are also reduced in these processes. The gradual changes in the grain size are formed between the nugget and TMAZ zone due to proper stirring of the alloys. The increase in the feed rate did not help in the proper joining of the alloys below the nugget zone. Even tool has plunged properly, the increase in the feed rate helps in increasing the friction and tool may exhibit dynamic movement. This creates a decrease in the strain rate and improper mixing of the alloy below the tool portion. Some weld gaps without much modification in the grain structure are seen in these processes.

The improvement in the strain rates are seen during the triple pass of the tool. A profound increase in diffusion leads in improving the strain rate along the pin surface forming perfect dynamic recrystallization process. The high plastic flows with proper bonding are seen in these processes. An improved strain rate during less viscosity state (under plastic condition) of the metal is seen in triple pass. The cyclic heat accumulation further helped in proper diffusion in the process. A proper stirring action helps to form finer grains in the nugget and below tool position. A smoother variation in the grain size from nugget to TMAZ understands the proper diffusion process that carried out. A less contact time during the feed rate of 100 and 150 mm/min leads to the formation of minimal weld gap between the work pieces.

3.3. Effect of Multiple pass on the Tensile Properties

The tool feed has a major influence on the joining mechanism of the alloys. The improper stirring makes diffusion difficult and this has profound influence in the determination of tensile properties. At single pass and tool feed rate of 50 mm/min, high heat formation, lower stirring, and increase in thrust develops some shear on the edges rather than mixing around. This creates dislocation between the nugget and TMAZ zone. The microstructure formation due to excess heat also reduces tensile properties of the weld alloy [19]. The tensile strength of 145MPa and fracture at the junction of TMAZ and nugget zones are evident for this process. The welding quality depends on the contact between the tool and the alloy during the process which are determined by the tool rotation and feed rate. The increase in the feed rate reduces the contact at the tool- alloy interface hereby reducing metal flow around the tool circumference. In the wide weld gap initiates some stress at the contact point and breaks at very low strength. The tensile strength reduces here due to improper diffusion and weld gap formation.

During the initial tool pass, the wide gap in the weld joint initiates the crack and starts rupturing during the low tensile strength value and breaks from the weld joint. This happens to the entire specimen, where minimum plunging depth of the tool forms weld gap and makes easier to rupture the weld joint at very low strength. The increase in the feed rate reduces the tool adhesion with increase in the weld gap, which makes the low tensile strength to break the specimen easily. The bonding between the weld joint is improved with the increase in the multiple tool pass. The thermal cyclic affect helps in improving the plunging depth thereby size of the silicon particles are easily reduced. The uniform transformation of grains between the nugget and TMAZ zone, with minimum grain dislocation helps in improving the tensile strength in the weld joint. The steady strain rate of the metal during the multiple pass around the tool circumference helps in improves the solidification rate. This helps in improving the weld strength and is recorded by the tensile test as seen from the figure.

3.4. Effect of Variation of Tool speed during Multiple Tool Traverse

The increase in the tool rotation, improves the stirring action and mixing of the alloy thereby generates more heat in the weld zone. The microstructure below the nugget zone for the multiple tool pass and a constant feed rate of 100 mm/min are shown in Fig. 5. There is an adverse change in the microstructure and joining process, particularly below the nugget zone. For the tool rotation at 600 rpm, a wide gap near the tool pin is observed in the microstructure. During the penetration of rotating tool between the weld joint, the thrust force induced resists the tool moving downwards. This increases the temperature in the weld zone considerably and makes the alloy to become soft and reduce its strength. The tool moves on its midway till the thrust force becomes greater than the plunging force. The weld gap is formed below the tool pin as seen from the figure. The tool rotation increases the sliding friction between the soft and hard alloy and creates a heat in the weld zone. An improper diffusion in this process leads in the difference in the relative velocity between the diffused layer alloys. A long dendrite and needle shape silicon are seen below the tool pin.

The increase in the tool rotation reduces the weld gap as seen for the tool rotation at 900 and 1200 rpm. The more heat input helps in more diffusion of the alloy and improves the stirring action of the tool. This helps in improving the joining process, but still weld gaps are seen below the nugget zone. Increase in the tool rotation to 900 and 1200 rpm, the localized thermal energy helps in increasing the temperature. The heats generated further soften the material with enhanced plunging depth. The weld gap reduces in these processes. The formation of silicon particles depends on the amount of silicon present and its cooling rate during solidification. In general, larger silicon content lowers the cooling rate during the solidification process [22]. Some primary silicon is noticed at higher tool rotation and this may be due to higher heat input and lower cooling rate.

With the secondary tool feed by the rotating tool, the thermal cyclic affect promotes the further diffusion in the already diffused alloy. The cyclic heat transfer in the process reinitiates friction and helps in improving the mixing of the alloy that is being already diffused thereby recovering its strength. The process increases the heat energy in the process, making more alloys to slip from the nugget and TMAZ zone. The plunging force improves in this method; thereby the weld gap beneath the tool point reduces gradually as seen from the microstructure. Increase in tool rotation at higher speeds, makes more alloys to slip due to enormous heat generated during the process. This improves the sticking condition of the diffused alloy that is rotating around the tool circumference. The solidification process improves in this process where refined and small primary silicon is observed in the microstructure.

The next increment on the tool feed, improves the diffusion process of the alloy in the weld joint. The plunging depth improves in this process even at lower tool rotation of 600 rpm. A mere weld gap with fine silicon grains are seen in the weld cross section. The proper weld joint did not happen for the tool rotation at 1200 rpm. Even severe diffusion makes the alloy to move in the plastic state, a small weld gap is seen below the tool position. This may be due to excess heat failing in sticking the diffused alloy around the tool circumference. This creates a difference in the relative velocity of the diffused alloy between its layers thereby disturbing its solidification process.

The tensile strength for the weld joint are performed and tabulated in Fig. 6. In the present investigation, the increase in the multiple tool feed exhibits an improved weld strength during the increase in the tool rotation from 600 to 1200 rpm. It is understood from the experiments that, the tensile strength increases by 10 to 15% during the increase in the tool pass for an increase in the tool rotation. The proper stirring action makes the alloys to slip easily, thereby reduces the weld gap, and improves the grain structure in the weld joint. This understands that there is a proper diffusion and mixing of the alloy taking place in the process, which leads in improving the tensile strength of the joint. All the fracture happens in the weld centre, where the

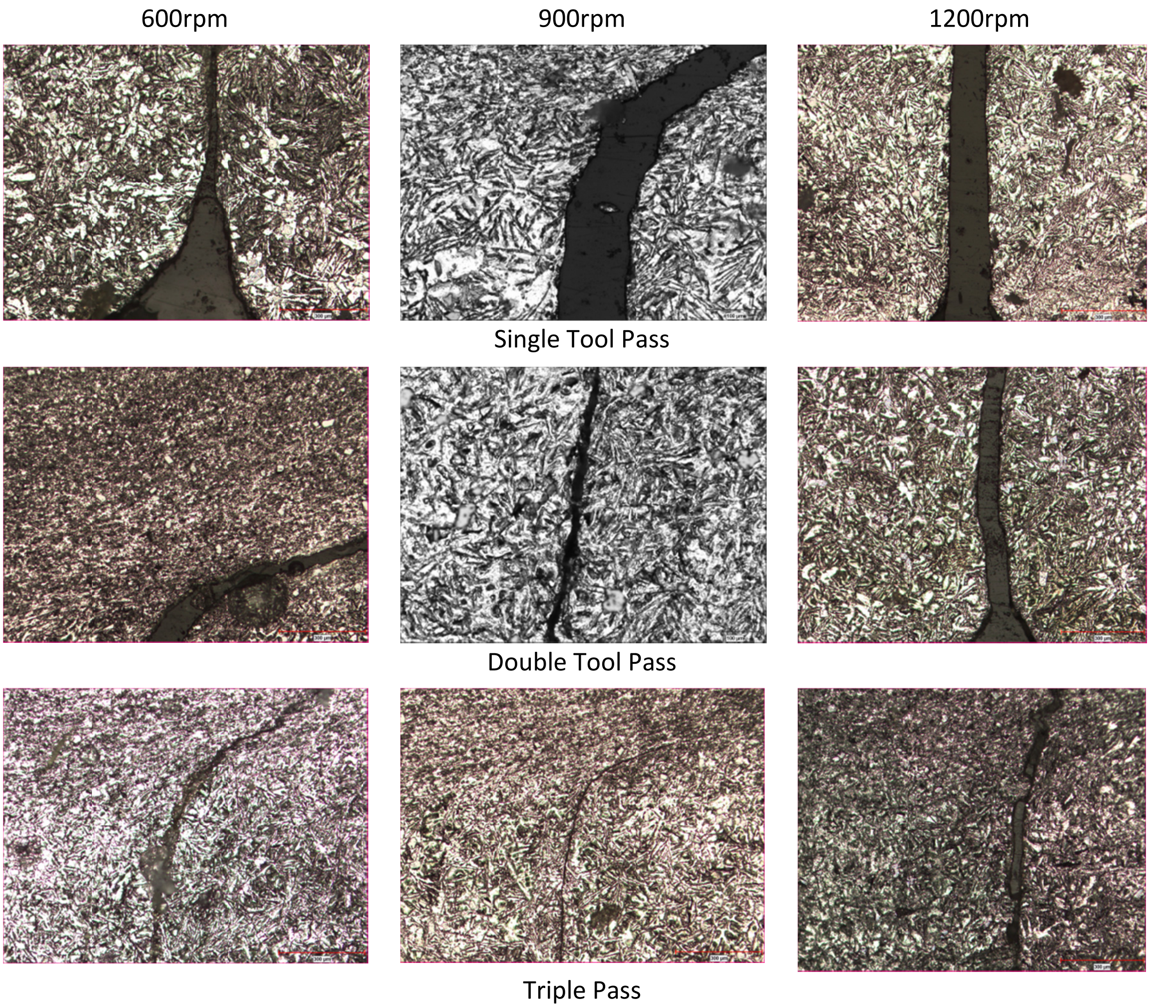

Fig. 5. Microstructure during the tool feed of 100 mm/min with various tool rotations

weld gap acts as point of fracture and initiates the fracture with further applied load. For higher tool rotation of 1200 rpm and triple tool pass, the proper sticking of the plastically deformed alloy could not happen thereby reducing the sliding velocity between the weld layers. The obstruction in the proper mixing of the alloy generates some weld gap and reduction in the tensile strength is recorded during the testing procedure.

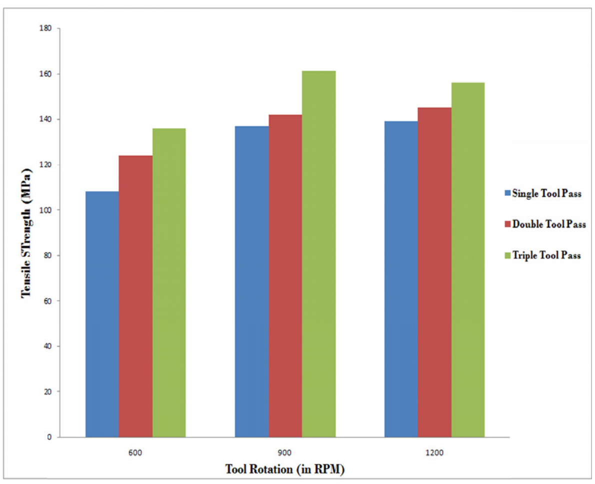

Fig. 6. Tensile Strength of the weld Joints during the various processes

4. Overall inference from the process

The overall implication understands that the multiple tool pass is being found an effective process during the friction stir welding process. The significant results are found, where a better approach and more effective joining process are seen during the multiple tool feed. The proper dynamic recrystallization happens during the multiple tool feed resulting in fine grains and improved tensile properties.

During the single tool pass, the tool plunging for the entire section of the specimen did not happen in the process. The thrust force forming from the specimen resists the tool penetration further and forms weld gap below the tool pin. At a lower feed rate, more frictional force and improper plunging depth makes difficulty in joining especially below the tool pin. The increase in the temperature in the weld zone develops coarse grains near the weld gap. The diffusion of the metal during the process forms fine grains in the nugget zone, but due to more heat developed, minimal primary silicon are observed in the weld structure. The tool penetration improves with the multiple tool pass due the thermal cyclic effect formed on the weld zone. The preheated weld zone loosens its strength during tool penetration and reduces the weld gap. The stirring action improves during the process, which makes a proper bonding between the weld joint. Uniformity in the grain formation in the nugget and below tool pin position is seen during the process.

An improvement of 15% in the tensile strength is recorded for triple pass in comparison with single tool pass. The uniformity in the grain size and improvement in the tensile strength indicates a better method for the joining process. During the tool feed rate at 100 mm/min, there is decrease in the adhesion between the tool and diffused material. This creates an improper mixing and in turn increases the weld gap during the alloy joining. A wider weld gap is noticed when compared with the earlier process. The improper mixing generates heat within the weld zone and some coarse primary silicon is observed. The difficulty on stirring results in the poor tensile properties and is recorded during the testing process. Some coarse grains are seen in the nugget zone. Even some improvement in the joining process is observed during the multiple tool pass; an increase in the weld gap due to improper adhesion is observed during the process. A larger weld gap is seen during the feed rate of 150 mm/min. the improper stirring, adhesion makes difficult in the joining process and hence larger weld gap is formed.

The investigation has demonstrated that the multiple tool pass has profound influence in the grain refinement and improving the mechanical properties. For hyper eutectic alloys, the silicon content if not refined properly leads in the poor cooling rate during the solidification process. This results in the formation of the poor weld joint. In this case, the repeated thermal heat in the process makes the alloy soften and ease in refining the Si particles. The dislocation of grains in the TMAZ and nugget zone reduces in this process, thereby improves the mechanical properties. The multiple tool pass are also found positive with the change in the welding process parameters. Overall, the improved plunging depth, proper metal mixing, refined Si particles and improved mechanical properties are observed and demonstrated in this process.

5. Conclusion

The effect of the multi pass of the tool during friction stir welding is carried out and the following conclusion can be drawn

1. During the single pass, improper stirring action and increased friction force leads to the formation of improper grains in the nugget and below the zone. There was weld gap in this process due to improper plunging depth.
2. There was some improvement in the joining process during a second tool pass. The preoccupied heat helped in improving the diffusion process. This led in improvement in grain refinement and ultimate strength
3. Further improvement in the tensile properties was seen during the triple pass of the tool. Increased diffusion process, proper mixing due to pre accumulation of heat leads in proper mixing and fine grains are formed in the nugget and it's below portion.
4. The tensile is increased with the increase in the tool pass from one to three. But for a given process, it was decreased due to less contact time between tool and the work piece.

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