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RESEARCH ARTICLE

SIMULATION STUDIES OF FRICTION STIR WELDED ALUMINIUM 7075 ALLOY.

*** G. Venkateswarlu[1], and Ch. Hareesh Kumar [2].**

1. Department of Mechanical Engineering, Sree Chaitanya College of Engineering, Karimnagar, India
2. Department of Mechanical Engineering, Vaagdevi college of Engineering, Warangal, India.

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******Corresponding Author***

G. Venkateswarlu.

Abstract

In this research work, the virtual experiments were carried out to investigate the influence of friction stir welding process (FSW) parameters on output variables such as peak temperature and flow stress of friction stir welding of aluminium alloy AA7075. The process parameters considered in this investigation were rotational speed, traverse speed and shoulder diameter. Friction stir welding simulations were performed using Hyper works (Hyper weld). The results indicate that the FSW process parameters influence the temperature distribution and flow stress during the process. It is found that peak temperature increases and flow stress decreases with increase of rotational speed with varying traverse speed and also found that the peak temperature decreases and flow stress increases with increase of traverse speed with varying rotational speeds. The temperature and flow stress distribution increase with increase of tool shoulder diameter.

Introduction:-

Friction stir welding is a new solid state welding technique which was developed by The Welding Institute (TWI) for joining of aluminium alloys and other metallic materials (Thomas and Nichlosa, 1997). In this process, a non consumable rotational tool pin moves along the joint interface and a tool shoulder applies a severe plastic deformation (Mishra, and Ma, 2005). It offers numerous benefits in the welding of aluminium alloys and also used for other metals difficult to weld such as copper, magnesium, titanium, etc. It has become a major joining process in the aerospace, railway and ship building industries especially in the welding of aluminium alloys. Aluminium alloys are used in many engineering applications, compared to other engineering materials due their good thermal properties, weldability and brazability, excellent machinability, formability, low specific weight and high strength to weight ratio (Xiaocong et al., 2014 and Arora et al. (2012) investigated load bearing capacity of tool pin in FSW and found that total traverse force increases significantly with increase in pin length of AA7075. The effect of heat input and temperature distribution during friction stir welding of A 6061alloy was investigated by Tang et al. (1998). The results indicated that temperature distribution was symmetric around the weld centerline and the peak temperature at the weld centre of the specimen was predicted about 450^0C. Siddiqui et al. (2015) conducted a virtual experiment of friction stir welding for variable tool rotational speeds with the constant travelling speed and studied the simulation results of variation in temperature distribution along the weld line of the butt joint. The results of simulation showed that the temperature is symmetrically distributed along the weld line. Buffa et al. (2009) focussed on the effect of the thermal and mechanical actions on the residual stress field occurring in friction stir welding (FSW) of AA7075-T6. Jata Semiatin (2000) proposed CDRX as an operative dynamic nucleation mechanism during FSW and suggested that the low angle grain boundaries in base materials can be replaced by high angle grain boundaries in the nugget zone due to continuous rotation of the original low angle boundaries during FSW. Bhatt and Pillai (2012) studied simulated peak temperature and distribution of flow stresses produced during the FSW of AA7050-T7451 aluminium alloy and concluded that the flow stress at a lower peak temperature of 340°C as 720MPa but low as 680MPa at a higher peak temperature of 360°C. Chao et al. (2003) investigated an integrated experimental and numerical analysis to study the heat transfer aspect of the friction welding process in a normal and a cold FSW weld. Selvamani et al. (2008) developed a three-dimensional thermo mechanical model and the thermo mechanical effect of the welded material for the FSW of an Al-alloy, in order to build a qualitative framework to understand the thermo mechanical process in FSW. Jweeg et al. (2012) performed three-dimensional non-linear thermal simulations for the FSW of AA7020-T53 using ANSYS. The results showed that the material flows on the retreating and front sides are higher. Kiral et al. (2013) performed the modelling of friction stir welding using transient finite element analysis and observed that the maximum temperature near the weld increases and temperature decreases as the tool transverse speed increases. Scialpi et al. (2008)] investigated both similar and dissimilar joint configurations in 6082-T6 and 2024-T3 alloy sheets. The results showed that the failure occurs in the welded zone due to irregularities in the thickness rather than by the presence of defects. Patil and Soman (2010) performed FSW of AA 6082-O alloy. Two different friction stirs profiles were modelled to study the influence of the pin geometry of the weld shape and mechanical properties.

In this research work, simulations were performed to investigate the influence of FSW process parameters on output variables such as peak temperature and flow stress for aluminium alloy AA7075.

Modelling of Welded Joint:-

Finite element modelling of friction stir welding was done using the finite element software Altair Hyper works (Hyper weld). Hyper Extrude solver was used to develop a three dimensional thermo-mechanical model for joining of aluminium plates. The peak temperature and flow stress for aluminium alloy AA7075 during the joint formation were predicted for a varying range of process parameters. The thermo-mechanical modelling and simulation of the friction stir welding necessitated thorough description of certain critical parameters, specifying boundary conditions, post processing etc.

Process modelling input:-

It is very important to prepare correct input for process modelling. Process modelling input parameters was discussed in terms of the geometric parameters, process parameters, and material parameters during the friction stir welding process.

Geometric parameters:-

The length, width and thickness of the plate geometry and the tool pin diameter, pin height, shoulder diameter and shoulder height of tool were selected as geometric parameters for butt weld joint modelling. Aluminium alloys (7XXX) are widely used for many applications of high strength, strong corrosion resistance, etc. Aluminium alloy AA7075-T6 size 380 mm x 120 mm x 4 mm was selected. The properties of materials are shown in Table 1. The Friction stir welding tool was considered of chromium-molybdenum hot-worked air hardening steel (H-13). The tool geometry is presented in Table 2.

Table 1: Physical & thermal properties of AA 7075-T6.

Property	Value
Density (kg/m^3)	2810
Thermal Conductivity (W/m-K)	173
Specific heat (J/kg-K)	960
Yield stress (MPa)	200-600
Coefficient of thermal expansion (1/K)	1e-005
Poisson Ratio	0.35
Liquidus Temperature (K)	908

Table 2- Tool geometry.

Tool	Cylindrical
Pin length	3.5mm
Pin diameter	6mm
Shoulder diameter (SD)	15mm,18mm,21mm
Shoulder length	70mm
Tool tilt angle	3^0

Process parameters:-

The parameters were considered in a friction stir welding process include the work piece temperature, tool translation speed, tool rotation speed, coefficient of friction between tool and workpiece, normal force applied by a shoulder on the work piece and top and bottom surface heat losses.

In this work, four levels of tool rotational speed (700, 900, 1100 and 1300 rpm) and traverse speed (25, 40, 55 and 70 mm/s) have been selected as shown in Table 3 to study their effects on the output variables like peak temperature and flow stress with the help of simulations. The work piece and tool details in Hyper weld software is shown in Fig.1

Table 3:- Process parameters for simulation of FSW.

Variables	Levels			
Rotational speed (RPM)	700	900	1100	1300
Traverse speed (mm/sec)	25	40	55	70

Figure 1. Process parameters in Hyper weld software.

Element type:-

Hexahedra 20 elements with 20 nodes ordered were used for thermo mechanical modelling.

Boundary conditions:-

The thermal and mechanical boundary conditions applied are Tool and work piece interface conditions, Coefficient friction (μ), Thermal boundary conditions etc. as shown in Fig.2.

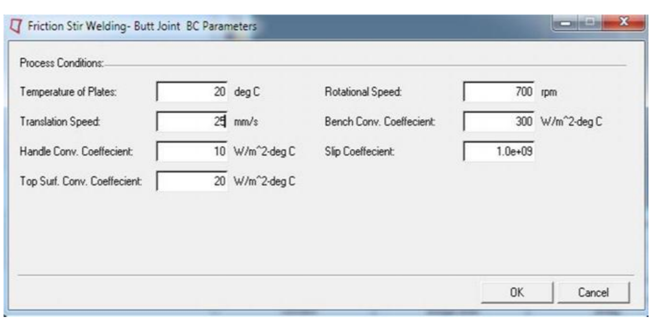


Figure 2. Friction stir welding-Butt joint Boundary conditions.

Post processing:-

Post processing is an important part for analysis of data. After describing the necessary parameters and boundary conditions, the post processing was carried out in the Hyper works software. The temperature distribution contours and flow stress contours were obtained.

Results and Discussion:-

In this present investigation, simulation of finite model was done to find out the influence of input FSW process parameters such as rotational speed of 700rpm, 900rpm, 1100rpm and 1300rpm, Traverse speed of the 25mm / s, 40mm/s, 55mm/s and 70mm/s and shoulder diameter, 15mm, 18mm and 21mm on the output variables like temperature and flow stress.

Effect of process parameters on temperature:-

In friction stir welding process, rotational tool pin generates a sufficient amount of heat between tool work piece to plasticize the material, which allows mixing of material to form a good weld. The heat generated during FSW directly influences the grain refinement, grain size, grain boundary character, coarsening and dissolution of precipitates, and resultant mechanical properties of the welds (Field et al. (2001), Ponda et al. (2006) Oosterkamp et al. (2004)). Therefore, it is important to obtain the peak temperature during the FSW process. The variation of peak temperature with respect to increase in tool rotational speed at constant traverse speeds for different shoulder diameters is shown in Fig. 3. The variation of peak temperature with respect to increase in traverse speed at constant rotational speeds for different shoulder diameters is shown in Fig. 4.

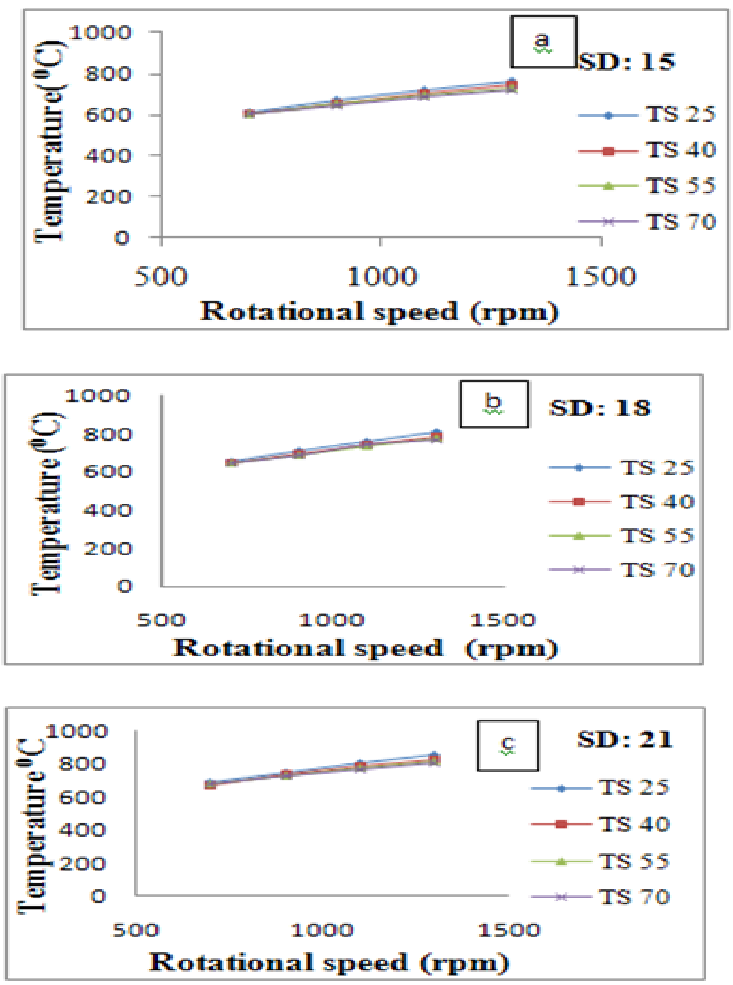


Figure. 3: Variation of peak temp with respect increase in rotational speed at constant traverse speeds for (a) SD 15mm (b) SD 18mm (c) SD 21mm.

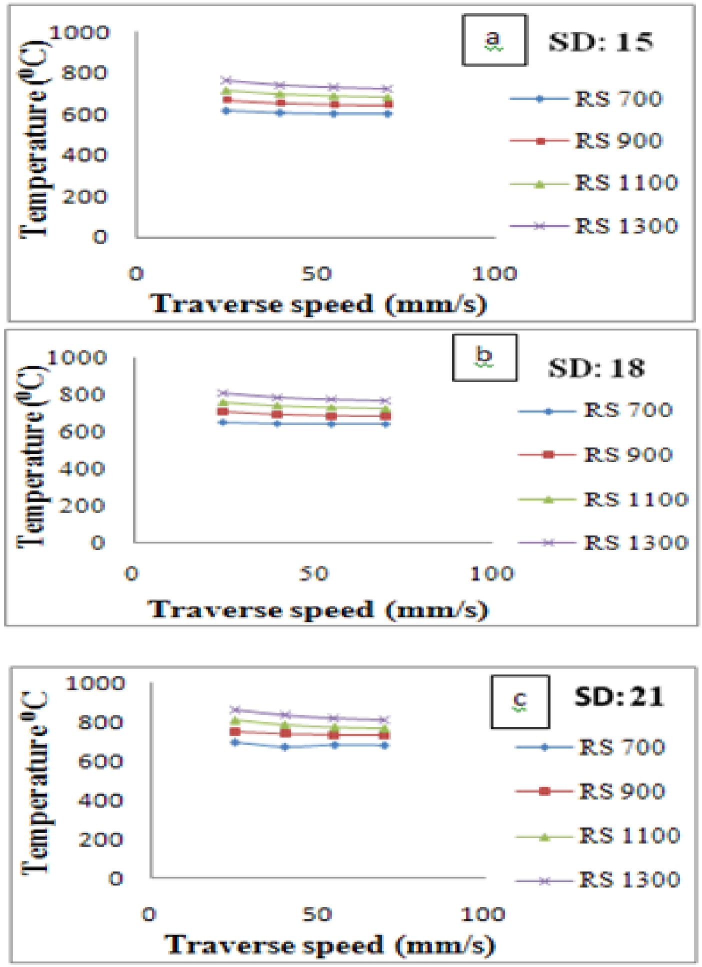


Figure 4: Variation of peak temp with respect increase in traverse sped at constant rotational speeds for (a) SD 15mm (b) SD 18mm (c) SD 21mm.

Fig.3 and Fig. 4 shows that rotational speed, traverse speed and shoulder diameter influence the peak welds temperature. Fig.3 indicates that the peak temperature increases with increase of rotational speed with varying traverse speeds for all shoulder diameters. It is noted that at a rotational speed of 700rpm for varying traverse speeds of 25mm/s, 40mm/s, 55mm/s and 70mm/s, the peak temperature values are 614.24^{0}C, 605.41^{0}C, 601.62^{0}C and 606.06^{0}C, respectively. When the tool rotational speed increases to 1300rpm, the peak temperature distribution values increased to 761.91^{0}C, 740.03^{0}C, 727.96^{0}C and 720.48^{0}C. Increase in tool rotational speed increases frictional heat results in stirring and mixing of the material around the rotating pin which in turn increases the temperature of the metal. It is observed from Fig.4 that the peak temperature decreases as traverse speed increases with varying tool rotational speeds for all shoulder diameters. This is due to reduced heat input per unit length and dissipation of heat over a wider region of work piece at the higher traverse speed (Padmanaban et al. 2014). It is noted that at traverse speed of 25mm/s for varying rotational speeds of 700rpm, 900rpm, 1100rpm and 1300rpm, the peak temperature distribution values are 691.34^{0}C, 750.80^{0}C, 806.71^{0}C and 857.41^{0}C respectively. When the traverse speed increases to 70 mm / sec, the peak temperature distribution values decreased to 677.51^{0}C, 726.20^{0}C, 768.23^{0}C and 805.49^{0}C. It is also observed that the shoulder diameter of the tool greatly influences peak temperature due to the amount of heat generated. Fig.3 and Fig.4 also indicate that peak temperature increases gradually with the increase of shoulder diameter from 15mm to 21 mm. The amount of heat generation during processing is directly proportional to the shoulder diameter (Thomas and Nichlosa, 1997). Therefore, the larger tool shoulder diameter generates a more amount of heat due to wider contact area and vice versa. The contour plot of temperature distribution in combination of rotational speed, traverse speed and shoulder diameter is shown in Fig.5.

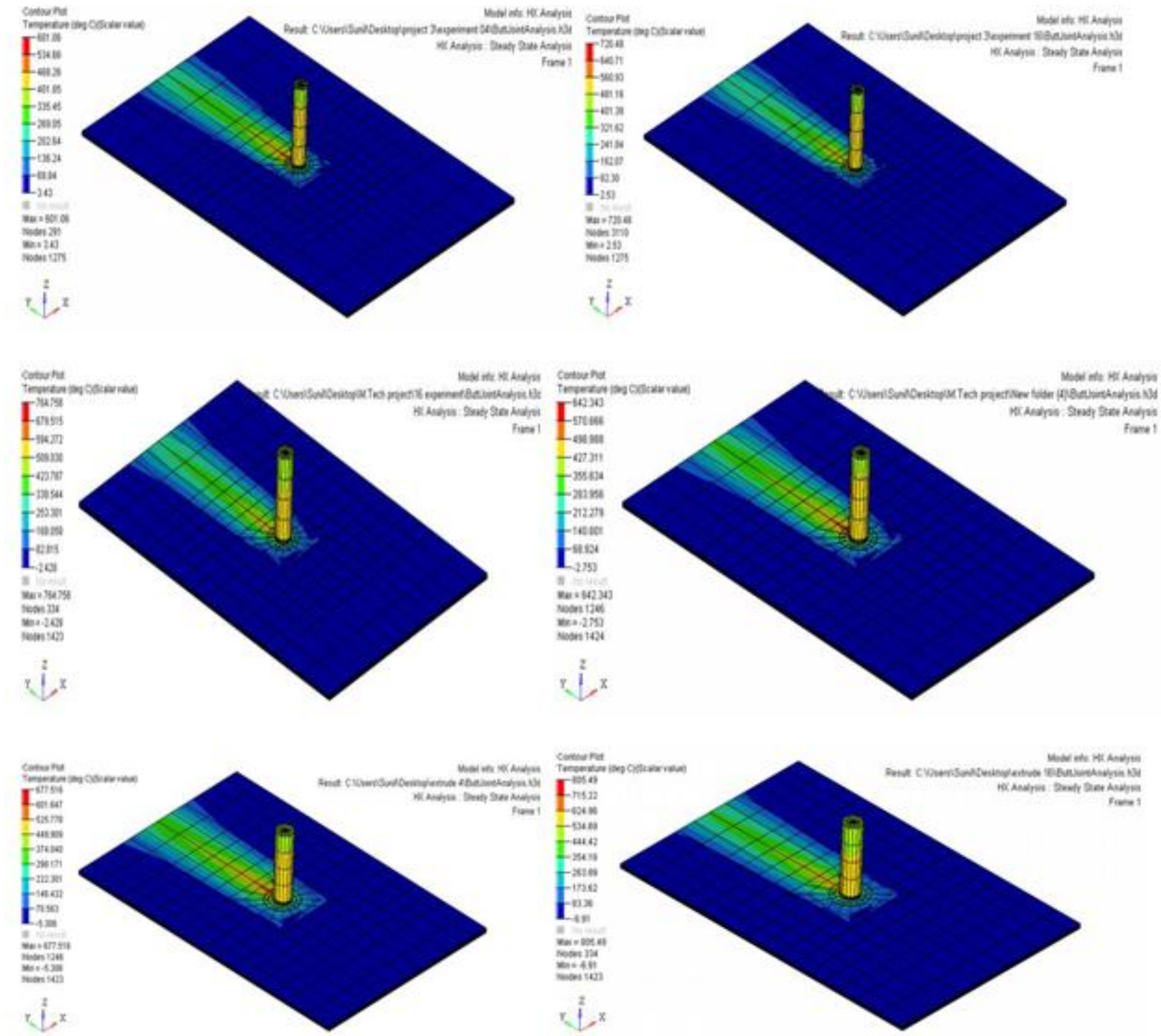
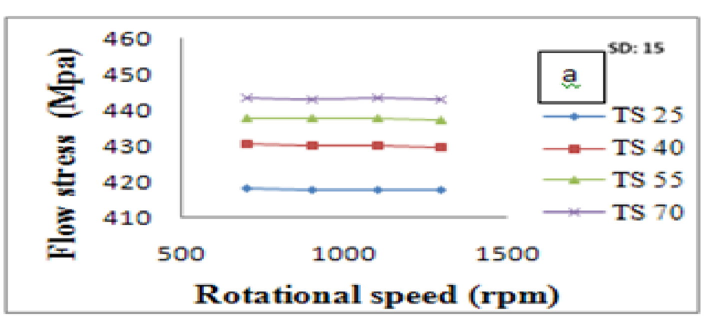


Fig.5: Temperature distribution contour plot in a combination of Rotational speed (RS), Traverse speed (TS) and shoulder diameter (SD)

Effect of parameters on flow stress:-

The factors of tool geometry, process parameters and materials influence the metal flow during friction stir welding. Material flow is one of the important parameters to determine because which directly influences the weld quality, therefore, it is very important to understand the material flow characteristics.



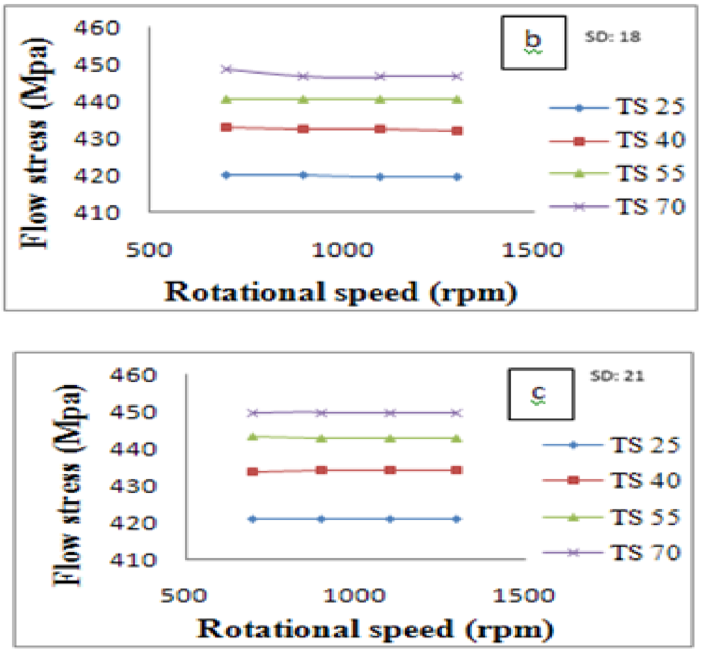


Figure 6: Variation of flow stress with respect increase in rotational speed at constant traverse speeds for (a) SD 15mm (b) SD 18mm (c) SD 21mm.

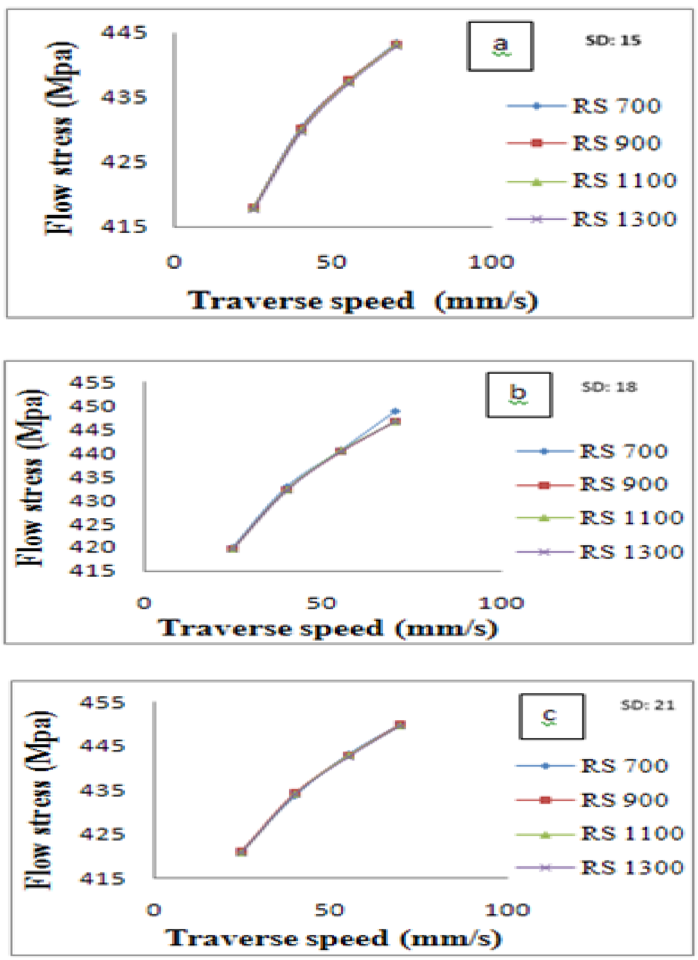


Figure 7: Variation of peak temp with respect increase in traverse sped at constant rotational speeds for (a) SD 15mm (b) SD 18mm (c) SD 21mm.

Fig.6 and Fig.7 show that flow stress increases with increase of rotational speed with varying traverse speeds for all shoulder diameters. Fig. 6 indicates that the flow stress decreases when the tool rotation speeds increases with varying traverse speeds. This happens due to increased temperature at higher rotational speeds resulting good material flow. It is observed that at a constant tool rotational speed of 700rpm for varying traverse speeds of 25mm/s, 40mm/s, 55mm/s and 70mm/s, the maximum flow stress distribution values are 418.06MPa, 430.54MPa, 437.65MPa and 443, respectively. When the rotational speed increased to 1300 rpm, flow stress values decreased to 417.73MPa, 429.78MPa, 437.20MPa and 442.96MPa. It is observed from Fig. 7 that flow stress distribution increases with increasing traverse speed. This is due to the lower amount of heat generation at higher traverse speed due to quick movement of the tool in less time over an area of work piece. This results in difficult to material flow. It is noted that at traverse speed of 25mm/s for varying rotational speeds of 700rpm, 900rpm, 1100rpm and 1300rpm, the flow stresses are 418.06MPa, 417.96MPa, 417.85MPa and 417.73MPa, respectively. When the traverse speed increases to 70 mm/sec, flow stress values increased to 449.89MPa, 449.91MPa, 449.72MPa and 449.54MPa. It is also observed that flow stress increases gradually with the increase of shoulder diameter. The contour plot of the flow stress distribution in combination of rotational speed, traverse speed and shoulder diameter is shown in Fig.8.

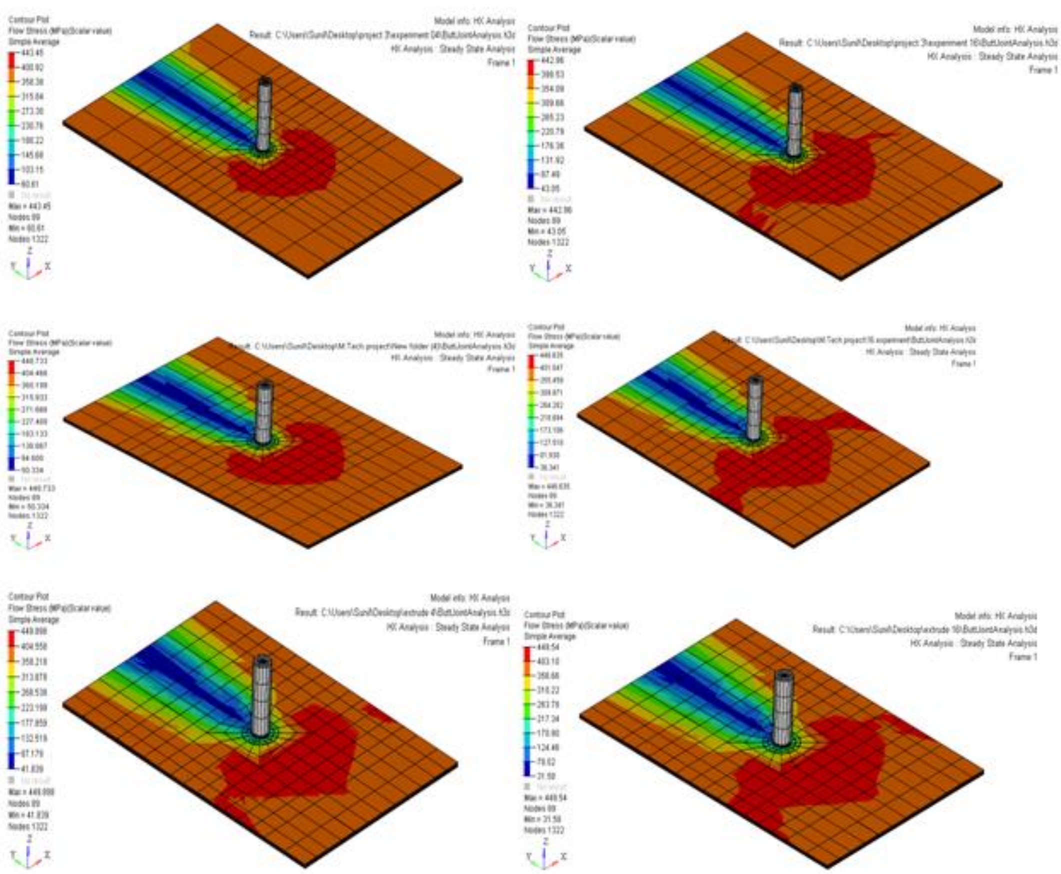


Fig.8 Temperature distribution contour plot in combination of Rotational speed (RS), Traverse speed (TS) and shoulder diameter (SD).

Conclusion:-

The following conclusions drawn from this investigation are as follows.

1. Peak temperature increases with increasing of rotational speed and decreases with increasing of traverse speed for all shoulder diameters.

2. The maximum peak temperature of 857.41^{0}c is achieved at a higher rotational speed (1300 rpm), lower traverse speed (25mm/sec) and larger shoulder diameter (21mm) and minimum peak temperature of 601.6^{0}c is obtained at 700 rpm rotational sped, 70mm/ sec traverse speed and 15 mm shoulder diameter.
3. Flow stress decreases with increase of rotational speed and increases with increase of traverse speed for all shoulder diameters.
4. The maximum peak temperature of 857.41^{0}c provides high flow stress of 449.54 MPa and low flow stress 418.06 MPa is obtained at minimum minimum peak temperature of 601.6^{0}c.

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