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Analysis Of Heavy Alloy Tool In Friction Stir Welding

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Abstract : Friction stir welding(FSW) is a new solid state welding is the renowned technology widely that has been used successfully in many joining applications.. It avoids many of the common problems that persist in fusion welding. It is most suitable for joining soft materials like Aluminum and Magnesium alloys. Though this technology has been proven commercially feasible for soft materials, the same for harder alloys is yet to be established. The development of cost effective and durable tools, which lead to structurally sound welds, is still awaited. Material selection and design intensely affect the performance the tools.. Investigation effort has been made for newer compositions of heavy alloy tool manufactured through powder metallurgy route. Establishing welding parameters such as tool rotations speed, traverse speed and various mechanical properties of Heavy alloy tool by numerical analysis and computational fluid dynamics model predicted values from it. Heavy alloy tool is suitable for cost effective and durable tool in hard alloys such as stainless steel.

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1. Introduction :

Many critical components are involved in Friction stir welding (FSW) and obviously tool is most critical among them to the success of the process. The tool typically consists of a rotating round shoulder and a pin that heats the work piece mostly by friction and moves the softened alloy around it in order to form the joint. There is no bulk melting of the work – piece, as such , the common problems of fusion welding such as the solidification and liquation cracking, porosity and the loss of volatile alloying elements are avoided in FSW. These advantages attribute widespread commercial success in the field of soft alloy welding. However, FSW tool is subjected to severe stress and high temperatures particularly for welding of hard alloys of steel, stainless steel and titanium alloys. The commercial application of FSW to these alloys is now limited by the high cost and short life of FSW tools.

Although significant efforts have been made in the recent past to develop cost effective and reusable tools, most of the efforts have been empirical in nature and further work is needed for improvement in tool design to advance the practice of FSW to hard alloys [Rai et al.[33]]. This paper numerically studied for the efforts made by heavy alloy tool in comparison with different FSW tools and operation parameters with stainless steel.

Table 1. Main process parameters in friction stir welding

Parameter	Effects
Rotational speed	Friction heat “stirring “ oxide layer breaking and mixing
Tilting angle	The appearance of the weld , thinning
Welding speed	Appearance , heat control
Down force	Friction heat

Table 2. Welding temperature range of various alloys:

Alloy Group	Temperature in range in °C
Aluminium alloy	440 to 550
Magnesum alloys	250 to 350
Copper alloys	600 to 900
Carbon and low-alloy steels	650 to 800
Titanium alloys	700 to 950
Stainless steel	600 to 875

Table 3. Tool materials used in FSW for soft alloys:

Sl.No	Tool Material	Work Piece Material	Tool material Characterics
1	Mild steel	Magnesium alloy	**Advantages :** Low cost , Easy machinability and Suitable for soft alloys. **Disadvantages:** Visible tool wear after welding for a certain distance**.**
2	High carbon steel	Magnesium alloy	
3	Stainless steel	Magnesium alloy	
4	Armour steel	Magnesium alloy	
5	AISI Oil hardened Tool steel	Al.matrix composite materials,	**Advantages :** • Easy machinability • Good elevated temperature strength. **Disadvantages:** Severe tool wear for high strength materials or MMC **Comments :** Surface hardening coating will increase wear resistance**.**
6	AISI4140	dissimilar materials	
7	Tool Steel	Aluminum alloy, dissimilar materials	
8	High speed steel	Magnesium alloy	
9	SKD 61 Tool steel	dissimilar materials	
10	H13 steel	Magnesium alloy, Al. alloy, Al.matrix composite materials, dissimilar materials	
11	High Carbon high chromium Steel	Al.matrix composite materials	

Materials such as aluminium or magnesium alloys, and aluminium matrix composites (AMCs) are commonly welded using steel tools. Steel tools have also been used for the joining of dissimilar materials in both lap and butt configurations.

Tool wear during welding of metal matrix composites is greater when compared with welding of soft alloys due to the presence of hard, abrasive phases in the composites. Total wear was found to increase with rotational speed and decrease at lower traverse speed, which suggests that process parameters can be adjusted to increase tool life.

Arora et al (2011)[1] states that computed temperatures for optimized shoulder diameters were in the range of peak temperatures commonly encountered in the FSW of AA606.Bhatt et al (2012) [2] studied constant tool rotational speed and tool with the same geometry, variation in tool traverse speed has prominent effects on temperature and flow stress during FSW of AA7050- T7451 Aluminums alloy . Biswas et al (2011)[3] analysis is concave shoulder and conical pin was found to be preferable for FSW of AA1100 to keep the tool pin diameter as small as possible to avoid occurrence of a wormhole defect. Choi et al (2009)[5] experimentally proved that the joint strength of the weld was affected by the number of welds, which was attributed to the effect of tool wear on the tool shape.

Chuan –song et al (2011)[6] studied that the strong plastic flow takes place in the shear layer near the tool, and the tool rotation speed has significant effect on the velocity field. Dongun Kim et al (2010)[7] analysis the CFD is a useful tool to understand the FSW process since this model handles large deformation of materials and A drawback of CFD is that it is difficult to handle realistic frictional boundary conditions at the interface, such as slipping. Edwards et al (2009)[8] proved that Low spindle speed lead to a fine grained microstructure high process loads, decreased penetration and greater amount of tool wear. Higher spindle speed welds cause larger grains that are less super plastic than the base material , lower process loads, Increased penetration and less tool wear. Elangovanet al (2008) [9] states irrespective of welding speeds tensile properties varying. Among the five tool pin profile using square pin profiled tool at a welding maximum tensile strength , higher hardness. M. Geigera et al (2008) [10] studied the qualitative ratio between the forces, which are transferred by form clamping amounts about 70% and 30% due to chemical bonding. Thermal flux and teeth geometry influence the metallurgical and mechanical phenomena occurring during the Friction Stir Knead Welding process.

Gianluca Buffa et al (2012)[11] experimentally proved tool life and weld quality satisfying the W25 Re tool and no visible sign of degradation was observed during the life cycle. The K10-K30 tool is shoulder and pin during the FSW of titanium alloys as brittle fracture occur and no weld could be obtained with the low rotational speed.Hamilton et al (2009)[12] states that a thermal model of the friction stir welding of aluminum alloys is presented that incorporates heat generation due to plastic deformation and partitions the heat flux between friction and plastic deformation based on the ratio of the plastic energy to the total effective energy. Ji et al (2012) [13] proved the shoulder geometry and the pin geometry can be good for improving the material flow behavior and then avoiding the root defects of friction stir welding joint. Jiten Das et al (2010) [14] studied the tensile properties and hardness of WNF alloy at room temperature are superior due to the presence of finer W – grain size. Lesser contiguity and porosity in its microstructure. WNF alloy fails under tension by W – grain cleavage fracture due to relatively stronger matrix phase and W/ matrix bonding.

Judy chneider et al (2006)[15] analysis the presence of banding in the well-known onion-ring structure of the weld nugget has not been shown to affect the quality of the weld , it is conceivable that the structural changes may affect the weld integrity. Kumar et al (2008)[16] conclusion that there are two different types of material flows, namely shoulder- and pin-driven material flows. Lammlein et al (2009) [17] proved the conical FSW tool could produce high quality, full penetration welds without the assistance of force control in materials which vary in thickness over their length. Lienert et al (2003) [18] viewed Feasibility of FSW of steel without loss of tensile properties . FSW of transformation hardenable steels, HSLA steels, and stainless steel may be feasible. Liguo Zhang et al (2011) [19] proved states that three-spiral-flute shoulder is much better than that by the tool with inner-concave-flute shoulder. Liua et al (2005) [20], analysis the welding speed has a decisive effect on radial wear rate of the pin.

Mandal et al (2006) [21] analysis the concept of a thermo mechanical hot channel for preheating during FSW of high hardness materials like steel is analyzed with respect to its effects on tool life improvement. Meran et al (2010)[22] proved that hard metal carbide tools (K10, 94% WC -6% Co) with triangular tool tip profiles are suitable for friction stir welding AISI 304 austenitic stainless steels. Moataz et al (2005) [23] proved that welds carried out at lower rotation speeds and higher feed rates are more susceptible to higher dominance for the AGG microstructure. Mohamed Assidi et al (2010) [24] states that the calibration of a friction model, it is first noticed that welding forces and tool temperatures are highly sensitive to small variations of friction, which allows accurate identification/ calibration of the friction coefficients.

Mushin Jaber Jweeg et al (2012)[26] verified that axial load that measured from experimental work decrease with increase in rotational speed because that decrease in strength due to temperature increases in penetration position. Nandan et al (2006) [27] analysis the computed results show that significant flow significantly affects heat transport within the work piece, rotational and linear motion of the tool and asymmetry of heat generation around the tool pin surface. Nofel at al (2011)[28] studied that the ductility of the weld joint decreases as the welding pressure increases. The elongation percent decreases as a welding pressure increase. Micro hardness of weld joint increases as welding pressure increases. The heat effected zone area increased as the welding pressure increased. Local melting process and plastic flow take place at the weld zone. Olivier Lorraina et al (2010)[29] states that unthreaded tool has the same features as the material flow using classical threaded tools. Prado et al (2003) [30] analysis the FSW tool shape changes somewhat with increasing weld speed , suggested that shape-related solid-state flow control is an essential feature of FSW and especially in assuring limited tool wear and optimum. Even in the case of very hard MMC's, FSW can afford essentially little or no tool consumption when tool shape is optimized.

Qasim M.Doss et al (2008)[32] studied the results obtained from transient thermal modeling were more accurate from fluid thermal model. Rai et al(2011)[33] comparative studied the Cost effective and long life tools are available for the FSW of aluminium and other soft alloys. Tool material properties such as strength, fracture toughness, hardness, thermal conductivity and thermal expansion coefficient affect the weld quality, tool wear and performance. There is a need for concerted research efforts towards development of cost effective durable tools for commercial application of FSW to hard engineering alloys. Rodrigues et al (2009) [34] studied that Conical shoulder (HW) displayed a larger nugget grain size with few coarsened precipitates. Scrolled shoulder (CW), which showed a smaller grain size containing many coarsened precipitates. Shigeki Hirasawa et al (2010) [35] proved for a cylindrical pin tool, the material flow at the pin periphery is in the upward direction. This material flow attributes to the formation of the 'hook' geometry. The triangular pin tool, due to its inherent geometry, shows enhanced material flow. A triangular pin with a concave results in spot welds with high strength.

Trimble et al (2012)[36] states that The Maximum forces occur during the plunge stage. Forces reduce significantly (35%) during the translational stage. Initial plunge stage of the process damage to the tool pin is most likely to occur. Translational stage damage to the tool shoulder is most likely to occur. Tozakia at al (2010)[37] says the scroll tool had comparable or superior performance to a conventional probe tool. The maximum tensile-shear strength of the welds made by the scroll tool was found to be 4.6kN that was higher than that of the welds made by the probe tool. Vijay Soundararajan at al (2005) [38] studied that the work piece surface temperature right under the tool reaches very close to the solidus temperature.

Yu Yanga et al (2008)[39] proved this paper algorithm developed monitoring friction stir butt welding operations and in performing intelligent control, where process parameters are varied when defects such as gaps are encountered It can also be used as a non-destructive evaluation technique that provides the operator with the location of a possible defect. It should be noted that this algorithm cannot detect gaps when the tool runs along the gap, since there is no sudden change in the plunge force signal. To determine the presence of a gap in this case, the plunge force signal should be compared to a plunge force signal gathered during an operation where a gap was known not to exist.

Chao et al (2003)[40] experimentally proved that 5% of the heat generated by the friction process flows to the tool and the rest flows to the work piece. The heat efficiency in FSW is thus 95% which is very high relative to the traditional fusion welding where the heat efficiency is typically 60 to 80%. Zhang et al (2012)[41] says the to date , low cost and long life welding and processing tools have been well developed for low strength materials such as Al and Mg alloys. However, long life tools with affordable costs are still unavailable abrasive materials such as particle reinforced metal matrix composites, and high strength materials such as Ti, Ni, Steels, etc. To this end , further efforts should concentrate on developing new tool materials and designing new effective special tools.

2. Tool Materials Properties :

Tool material characteristics can be critical for FSW. The candidate tool material depends on the work piece material and the desired tool life as well as the user's own experiences and preferences. Ideally, the tool material should have the following properties:

- Higher compressive yield strength at elevated temperature than the expected forge forces onto the tool
- Good strength, dimensional stability and creep resistance
- Good thermal fatigue strength to resist repeated heating and cooling cycles
- No harmful reaction with the work piece material
- Good fracture toughness to resist the damage during plunging and dwelling

- Low co-efficient of thermal expansion between the probe and the shoulder materials to reduce the thermal stresses.
- Good machinability to ease manufacture of complex features on the shoulder and probe
- Low or affordable cost

2.1 Tool materials used in FSW for Hard alloys :

Literature studies also suggest that the stirring tool material is one of the topics widely studied on friction stir welding of high melting point materials such as stainless steels. The tool material is expected to possess the desired hardness, high stiffness and sufficient wear resistance at 1000°C or at higher temperatures. Researchers studying this topic have used wolfram base alloys, specifically W-Re alloys, molybdenum alloys and polycrystalline cubic boron nitrides (PCBN) as tool materials.

2.2. Commercially pure Tungsten (Cp- W) :

Commercially pure tungsten (cp-W) is strong at elevated temperatures but has poor toughness at ambient temperature, and wears rapidly when used as a tool material for FSW of steels and titanium alloys. Cp-W is suitable for FSW tool not a durable Tool.

2.3. W – La alloy :

We dope our tungsten with between 1.0 and 2.0 percent of lanthanum oxide (La_2O_3) by weight in order to improve its **creep resistance** and increase the **recrystallization temperature**. Our WL is also **easier to machine** due to the finely distributed oxide particles in its structure. The electron work function of tungsten-lanthanum oxide is significantly lower than that of pure tungsten. Consequently, W- La alloy is used for FSW welding. Suitable for Welding Electrodes

2.4. W – Rehenium(W – Re) :

W – Re **greater ductility** and a **lower brittle-to-ductile transition temperature**, we alloy our tungsten with rhenium. Moreover, tungsten-rhenium has a higher recrystallization temperature and better creep resistance. We use the W- 3Re, W – 25Re for thermo elements in applications of over 2 000 °C. This material is also used Friction stir welding. Excessive tool wear due to lower strength.

Tungsten–rhenium alloys, with W–25 wt-%Re as a candidate material for FSW tools more recently, a variant of this reinforced with 2% of HFC.Steels and titanium alloys are successfully welded by W–25 wt-%Re tool. W–25 wt-%Re alloy tool used to make dissimilar welds .

2.5. W – Carbide (WC):

Tungsten carbide (WC) based tools have also been exploited in investigations of the feasibility of FSW of steel and titanium alloys. The toughness of WC is said to be excellent and the hardness is 1650 HV. The material is apparently also insensitive to sudden changes in temperature and load during welding trials.

WC–13 wt-%Co and WC–13 wt-% Co–6 wt-%Ni–1.5 wt-%Cr_3C_2 tools used for friction stir spot welding of low carbon steel plates. W–Fe–O compounds on the tool surface may degrade the tool. It was suggested that the addition of CrC_2 to WC–Co reduce the tool wear by reducing oxidation of WC. A WC–Co alloy tool with threaded pin has been used to weld AMCs with 30 vol.-% of SiC particulates.

This study characterized the pre- and post weld microstructures of three tungsten-based tool materials: Material A :(99% W-1% La2O3), Material B :(75% W-25% Re), and Material C : (70% W-20% Re-10% HFC). Tool degradation mechanisms were identified for each tool material based upon this characterization. Material "A" degraded by severe plastic deformation, Material "B"degraded by twinning, and Material "C "degraded by inter granular failure. [Rai et.al (2011)[33]]

2.6 Sintered TiC welding tool:

Sintered TiC welding tool, with a water cooling arrangement to extract excessive heat from the tool, has been used for successful FSW of titanium 74. Molybdenum based alloy tool has also been used to weld AISI 1018 mild steel and Ti–15V–3Cr–3Al–3Sn alloy tool materials

2.7 Polycrystalline cubic boron nitride (pcBN)

pcBN tools are used to weld materials such as Titanium and its alloys, Ferrous alloys, dissimilar materials, Stainless steel.

The pcBN tools have High strength and hardness at elevated temperatures along with high temperature stability. The low coefficient of friction for pcBN results in smooth weld surface.

The pcBN the tool have the following limitations .

- High temperatures and pressures required in the manufacturing of pcBN.
- Tool costs are very high.
- Low fracture toughness,
- Tendency to fail during the initial plunge stage.
- Maximum weld depths are currently limited to 10 mm for welding of steels and Ti alloys.
- pcBN is brittle and boron from pcBN may get dissolved into base material to form an undesirable phase.

3. Heavy Alloy Tool

Table 4. Composition of Heavy alloy Tool:

W	Ni	Fe	Co	Mo
88 – 92%	5.5 - 7.5%	2.5 -4.5%	0.2-0.4%	0.2 - 0.4%

Heavy Alloy is a tungsten-group sintered alloy consisting tungsten and binder phase with nickel, iron, cobalt , molybdenum etc.

3.1. Properties of Heavy alloy Tool :

Typical material characteristics of Heavy Alloy are following.

- High density
- Excellent radiation shielding effect
- Superior machinability to tungsten
- High mechanical strength
- Low thermal expansion and high thermal conductance
- Excellent oxidation resistance

We can find tungsten at work whenever the heat's on, because no other metal can compare with tungsten for its **heat resistance**. Tungsten has the highest melting point amongst of all metals and is therefore also suitable for **very high-temperature applications**. It is also characterized by a uniquely low coefficient of thermal expansion and a very high level of dimensional stability.

Tungsten heavy alloy material is typically vacuum annealed and quenched for maximum ductility (25-35% EL typical) and toughness due to prior cold worked by swaging. Deformation processing generates a directional microstructure, high yield strength (150-200 ksi for most designs), and elevated hardness (40-44 HRC). Even higher mechanical properties are also attainable from tungsten-nickel-cobalt compositions. These high properties provide a useful indication of the wide range of properties in which WHAs can be supplied.

Tungsten : Withstand higher temperatures, high strength, Corrosion resistance and wear resistance.

Nickel : Withstand the high temperatures , having improved strength & toughness, High modulus of elasticity and machinability.

Cobalt : Improve the Bonding with other metals, high strength and wear resistance

Molybdenum : Improve heat resistance , Toughness , High strength and rigidity at a temp up to 3000°C

Table 5. Properties of the Weld material and FSW tools:

Properties	**Unit**	**Weld Metal**	**Tool Material**			
		SS 304	**H13 Steel**	**WC–Co**	**pcBN**	**Heavy alloy Tool**
Density	g/cc	8	7.8			18.7
Red hardness Temp			550°C	900 - 1050	1100°C - 1350	975 - 1100
Melting Point	°C	1400-1455	1450 – 1600			3420
Modulus of Elasticity	GPa	193-200	210			
Poisons ratio		0.29	0.3	0.28		0.28
Coefficient of Thermal expansion / 10^{-6} K^{-1}	20°C	17.3	11	4.9 - 5.1	4.6 - 4.9	4.3 – 5.
Thermal conductivity	W/m^{-}K	16.2	24.3	76 – 95	100-250	160
	Vickers	129	549			570
	Rock – B	70	HRC -51	HRC 41-47		HRC 53
Tensile strength , ultimate	Mpa	505	1990	1050		1100
Tensile strength , Yield	Mpa	215	1650	850		850

Table 6. Dimensions of the tool:

Element	Shoulder dia	Shoulder length in mm	Dia of the pin	Dia in Pin length
Tool	19mm	30mm	Major Dia :6mm Minor Dia :5mm	3mm

4. Welding Material :

3.2 mm thickness of AISI 304 stainless steel material used for FSW welding.

Table 7. The concentrations of the main elements of the AISI 304 stainless steel are given in mass.

C	**Mn**	**Si**	**Cr**	**Ni**	**P**	**S**
0.08	2	1	18-20	8 - 10.5	0.045	0.03

5. List of Symbols.

L -- weld length (500mm)
Lp --Tool pin length (3mm)
Rp --Weld tool pin radius measured at the shoulder (3mm)
Rpt -- (Weld tool pin tip radius (2.5mm)
Rs -- Weld tool shoulder radius (9.5mm)
Q -- Heat generation rate term or energy , W
v -- Feed rate or tool travel speed (102mm/ min)
V - Volume of plastic deformation (84.7mm^3)

α - angle of FSW pin tool taper (9°)
K - Friction factor (0.4)
σ - Temperature and strain rate dependent flow stress of work piece, MPa
τ - Temperature and strain rate dependent flow shear strength work piece, MPa
ω - Spindle speed or tool rotation rate rev /mim
F - Axial Force (30 KN)

Total Area of the FSW tool	-	$361.684 mm^2$
Pin Area	-	$72.1862 mm^2$
Pin tip Area	-	$19.6349 mm^2$
Pin Rotation	-	$52.5512 mm^2$
Shoulder area	-	$283.53 mm^2$
Shoulder thickness area	-	$5.96 mm^2$

6. Heat Energy estimation model for FSW of Stainless steel.

The purpose of current modeling is to study the combined different features of the model such as Heat generated due to rotation of shoulder, Pin , Pin tip and Translation of shoulder, pin , pin tip , which can be calculated by the formula. [Edwards et al (2009)[8]]

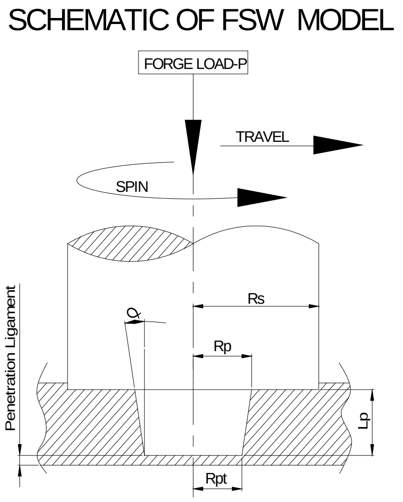

Fig. 1. FSW Tool

The total heat generated with a tapered FSW tool. The expressions for the heat generated by Rotation and translation of the FSW tool shoulder are defined in equations (1) and (2) respectively.

$$Q_{shoulder-rotation} = \frac{2\pi}{3} (Rs^3 - Rp^3) \quad \omega K\tau \text{ ----(1)}$$

$$Q_{shoulder-translation} = 2 (Rs^2 - Rp^2) VK\tau \text{ ---- (2)}$$

The frictional heat generated by the translation of the pin through the work piece material was estimated by Evaluating the normal and shear forces acting on the front face, or leading half, of the Pin equation defined in equations (3) and (4) respectively.

$$Q_{pinrotation} = 2\pi\omega K\tau(Rp^2 Lp + RpLp^2 \tan^{\alpha} + \frac{1}{3} Lp^3 \tan^2\alpha) \text{ ------ (3)}$$

Qpin.translation$= vK\tau(\sigma+\tau)(Rp\ Lp + Lp^2 \tan\alpha)$ ----- (4)

The expressions for the heat generated by Rotation and translation of the FSW tool Pin

are defined in equations (5) and (6) respectively

Q pin tip –rotation $= \frac{2\pi}{3}\ \omega\ Rpt^{\tau}\ K$ --- (5)

Q pin –tip translation $= 2R^2 ptV\ \tau\ K$ --- (6)

By combining equations (1-6) , the total heat generated by rotation and translation of the Heavy alloy tool can be obtained and is given equation (7)

$$Q\ \text{total} = \frac{2\pi}{3}(Rs^3 - Rp^3)\ \omega\ K^{\tau} + 2(Rs^2 - Rp^2)\ VK^{\tau} + 2\pi\omega K\tau(Rp^2 Lp + RpLp^2\tan^{\alpha} + \frac{1}{3}Lp^3\tan^2\alpha) + vK\tau(\sigma+\tau)(Rp\ Lp + Lp^2\tan\alpha) + \frac{2\pi}{3}\ \omega\ Rpt^{\tau}\ K + 2R^2 ptV\ \tau\ K \quad \text{---- (7)}$$

The results are obtained the above equations.

Table 8. Heat Generated Friction Stir Welding in Various Speed

Rpm	Qshoulder - rotataion	Qshoulder – Translation	Qpin - rotataion	Qpin Translation	Qpin tip - rotataion	Qpintip - Translation	Total Heat –W
500	36785	583	23438	109	1599	648	63162
600	44142	583	28125	109	1919	648	75526
700	51499	583	32813	109	2239	648	87891
800	58855	583	37500	109	2559	648	100255
900	66212	583	42188	109	2879	648	112619
1000	73569	583	46876	109	3198	648	124984
1100	80926	583	51563	109	3518	648	137348
1200	88283	583	56251	109	3838	648	149712
1300	95640	583	60938	109	4158	648	162077
1400	102997	583	65626	109	4478	648	174441
1500	110354	583	70313	109	4798	648	186805

The most striking result from the current study is that only about 5 % of the heat generated by the friction process flows to the tool and the rest flows to the work piece. The “heat efficiency” in FSW is thus 95% , which is very high relative to the traditional fusion welding where the heat efficiency is typically 60 to 80%. [Yuh et al (2003)[40]]. Therefore, based on the above reference the table -8, only 5% heat has been taken for CFD modeling.

Table 9. Heat Generated Friction Stir Welding Tool in Various Speed

Tool Travel Speed mm/Min	Rpm	Q shoulder - rotations -W	Q pin - rotations -W	Q pin tip - rotations - W	Total Heat - W	Temp in °C
102	300	920	586	48	1554	741.38
102	350	1073	684	56	1812	860.45
102	400	1226	781	64	2071	979.17
102	450	1379	879	72	2330	1098.56
102	500	1533	977	80	2589	1217.6
102	550	1686	1074	88	2848	1336.71
102	600	2207	1406	96	3709	1740.473
102	700	2575	1641	112	4328	2026.606

7. Analysis of CFD:

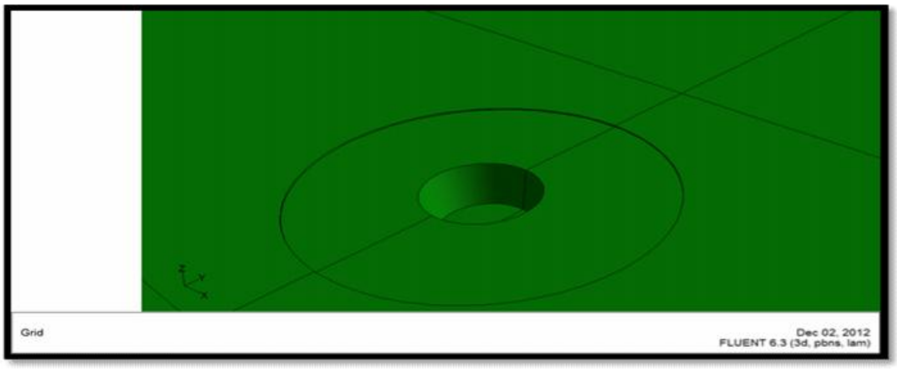

Fig.2 Fluid boundary condition

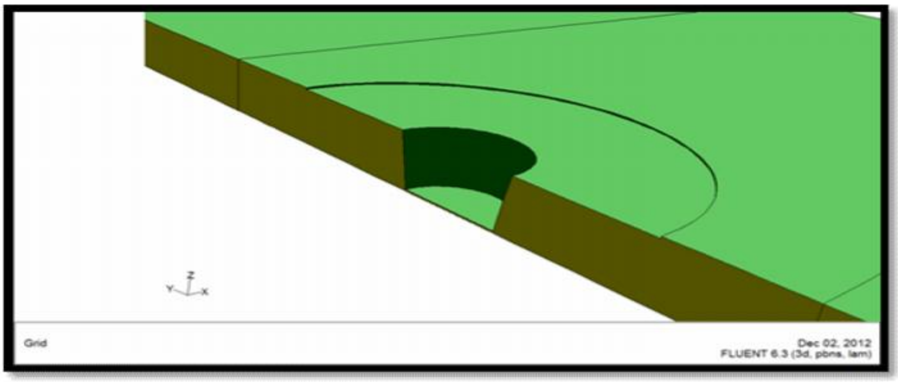

Fig.3 Fluid boundary condition in Symmetric

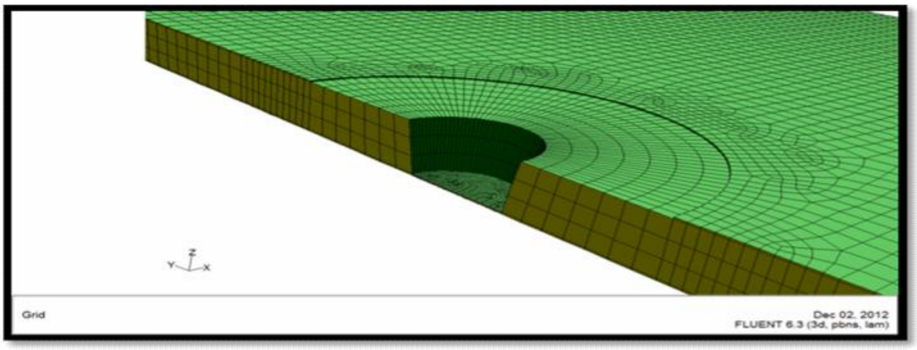

Fig.4. Mesh generation of model used in Simulation

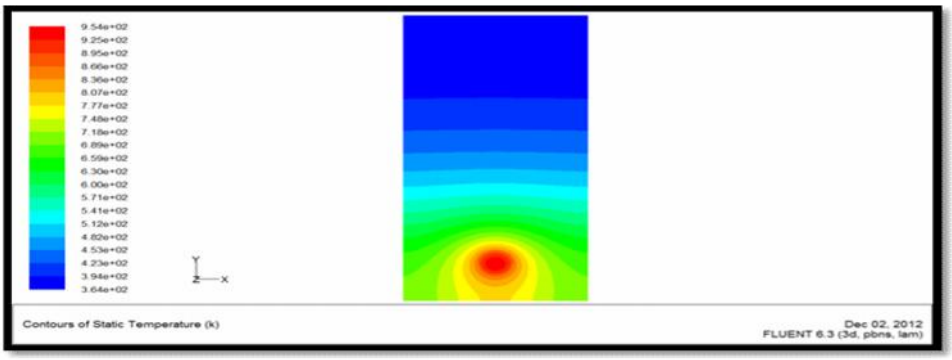

Fig. 5. -Temperature in 300 RPM & Travel speed =102 mm/min

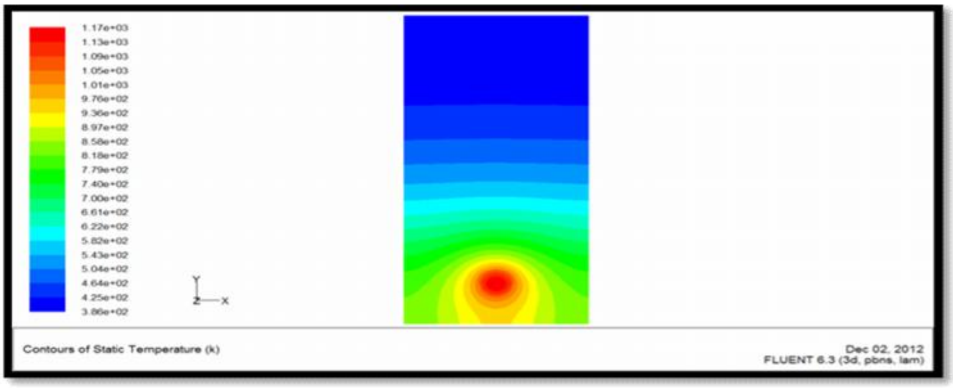

Fig :6-Temperature in 350 RPM & Travel speed =102 mm/min

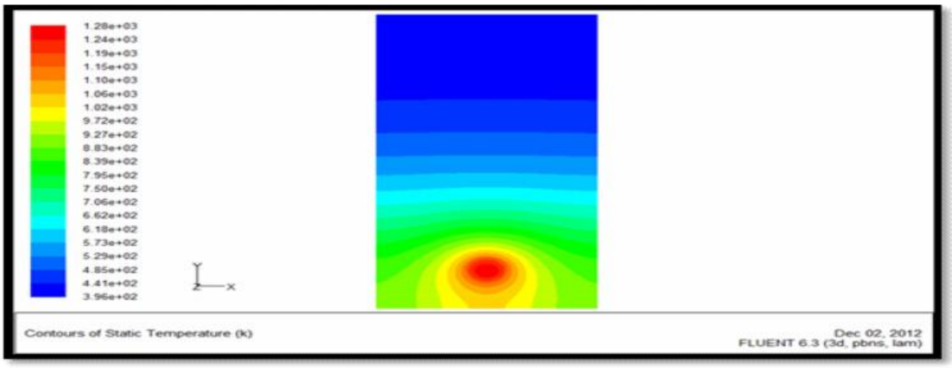

Fig :7-Temperature in 400 RPM & Travel speed =102 mm/min

8. Future:

- Heavy Alloy tool will be proved experimentally as a durable one, by further study and work on this topic.
- FSW tool using shoulder PCBN material and pin with heavy alloy tool will also be proved experimentally as a durable.

9.Conclusions:

- When we keep 8 welding different speeds for CFD, maintaining constant travel speed as 102mm / min and optimum speed as 350RPM, the tool life will increase.
- The maximum temperature in the FSW process can be achieved by increasing both welding speed and the rotating speed.
- When Travel speed is maintained at 102mm/min or more than 450 RPM, the tool will be getting deformed.
- The numerical model shows that heat produced due to rotation by shoulder is at a maximum range of 58-59% and heat produced due to tool pin rotation is 38 %.
- Long life tools with affordable costs are still unavailable for abrasive materials such as particle reinforced metal matrix composites, and high strength materials such as Ti, Ni, steels, SS etc. To end this, Heavy alloy tool described above is developed and which is most suitable for the FSW tools.

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