EFFECT OF TOOL PIN PROFILE ON MECHANICAL PROPERTIES AND MICROSTRUCTURE ON AA6061 AND IS319 BRASS

G. Sunny Kumar[1], Dr. P. Prasanna[2], & G. Ananda Rao[3]
1. M. Tech. Student, Dept Of Mech. Engg., JNTUH, Hyd.
2. Asst. Prof., Dept Of Mech. Engg., JNTUH, Hyd.
3. Assoc. Prof., Dept Of Mech. Engg., MLR Institute of Technology, Hyd.

Abstract- Copper and its alloys have special properties such as high electrical and thermal conductivities, good combination of strength and ductility, and excellent resistance to corrosion. AA6061 Aluminium Alloy has good mechanical properties and exhibits good weld ability. In fusion welding process high temperature is generated this leads to melting of zinc which is unnecessary leads to difficulty. This make use of non-consumable tool to generate frictional heat in the abutting surfaces. The welding parameters such as tool rotational speed, welding speed, axial force, etc., and tool pin profile play a major role in deciding the joint properties.

In this investigation, an attempt has been made to study the effect of tool pin profile on mechanical properties and microstructure of dissimilar AA6061 and IS319 Brass. Four different tool pin profiles (triangular, square, conical and hexagonal) have been used to fabricate the joints at constant rotational speed, different welding speeds and constant axial force. Tensile properties, hardness and microstructure of the joints have been evaluated. From this investigation it is found that the joints fabricated using different pin profile tools. The results obtained are found that square pin profile at 500rpm and at 40mm/min shows superior mechanical properties that other profiles.

1. INTRODUCTION

In the friction stir welding the two work pieces to be welded, with square mating (faying) edges, are fixture (clamped) on a rigid back plate. The fixture prevents the work pieces from spreading apart or lifting during welding. The welding tool, consisting of a shank, shoulder and pin, is then rotated to a prescribed speed and tilted normal with respect to the work piece. The tool is slowly plunged into the work piece material at the butt line, until the shoulder of the tool forcibly contacts the upper surface of the material and the pin is a short distance from the back plate. A downward force is applied to maintain the contact and a short dwell time is observed to allow for the development of the thermal fields for preheating and softening the material along the joint line. At this point, a lateral force is applied in the direction of welding (travel direction) and the tool is forcibly traversed along the butt line, until it reaches the end of the weld; alternately, the work pieces could be moved, while the rotating tool remains stationary. Upon reaching the end of the weld, the tool is withdrawn, while it is still being rotated. As the pin is withdrawn, it leaves a keyhole at the end of the weld. The pin may have a diameter one-third of the cylindrical tool and typically has a length slightly less than the thickness of the work piece. The pin is forced or plunged into the work piece until the shoulder contacts the surface of the work piece. As the tool descends further, its shoulder surface touches the top surface of the work piece and creates heat. As the temperature of the material under the tool shoulder elevates, the strength of the material decreases. Shoulder of tool contacts plate restricting further penetration while expanding the hot zone; plate moves relative to rotating tool creating a fully re-crystallized, fine grain microstructure.

2. PARAMETERS TO STUDY

Tool: The rotating device between the machine spindle and the work piece is referred to as the 'tool'. The part which creates stirring action is referred to as the 'pin'. The part of the tool, which is pressed on to the surface of the work piece during welding is referred to as 'shoulder'.

Leading Edge and Trailing Edge: In a non-cylindrical tool the terms 'leading edge' (front face of the shoulder during welding) and 'trailing edge' (rear face of the shoulder during welding) are used, where as in cylindrical profiled tools there is clearly no edge and so the terms 'leading face' and 'trailing face' may

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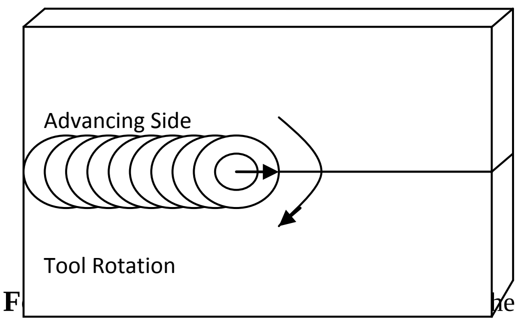
be preferred. 'Pin leading face' is the front face of the pin during welding. Similarly 'Pin trailing face' is the rear face of the pin during welding.

Advancing side and Retreating side: The side of the weld where the direction is same as the direction of rotation of shoulder is called the 'Advancing Side' (AS) and where the direction is opposite to direction of rotation of shoulder is called the 'Retreating Side' (RS) (as shown in fig below). The total area of the tool on the work piece surface is described as the 'tool shoulder foot print'.



F he force with which the two plates to be joined are kept in contact at the time of process are important in FSW process. The force applied parallel to the axis of the rotation of the tool (Z-direction) is the 'down force'. The force applied parallel to the welding direction (X-direction) is the 'traversing force'.

Welding speed and Rotational speed: The term 'welding speed' is referred to travelling speed or traversing speed, which is the rate of travel of tool along line of joint. 'Tool Rotational Speed' is the speed at which the friction stir welding tool rotates.
In recent years, many researchers studied various aspects of Friction Stir Welding process. These works can be broadly classified as follows

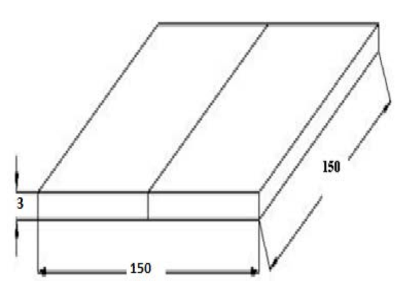
3.Literature review

Friction-stir welding of aluminum alloys has been employed in many industries to improve the production quality of the weld joint. The friction stir welding process to face automation and aviation structural joining difficulties as FSW. The production of welded aluminum structural sheets with high, reliable tensile and fatigue properties are very important in commercial and military applications. Joining technologies for the 2XXX and 7XXX aluminum sheet alloys is important as it directly affects the material choice for the future modern aircraft and automobile, so[1] P.Cavaliere, R.Nobile, F.W. Panellaa and A. Squillace recognized the need to implement advanced joining technologies. The application fields of FSW are marine (hulls, superstructures, decks, and internal structures for high speed ferries and LPG storage vessels for the shipbuilding industry), aerospace (Airframes, fuselages, wings, fuel tanks), railway (high speed trains, railway wagon and coachwork, and bulk carrier tanks), automotive (chassis, wheel rims, space frames, truck bodies), motorcycle, electrical and refrigeration industries.In FSW, as in Elangovan et al.[2] , a non-consumable rotating tool with a specially designed pin and shoulder is inserted onto the butting edges of sheets or plates to be joined and moved along the line of joining. The heat is generated between the wear resistant welding tool and the material of the work-pieces. The heat causes the latter to soften without reaching the melting point and allows traveling of the tool along the welding line. Comparing the velocity of the tool and the time required for the pieces to reach softening temperature, the optimal tool velocity has been provided by Chien et al.[3].The percentage of the generated heat from the tool shoulder or the tool pin was investigated by Song and Kovacevic (2003).The tool serves two primary functions: (a) heating of work piece, and (b) movement of material to produce the joint. Thermal analysis process in the work pieces is one of the most important aspects in the FSW study, as in Schmidt et al. (2008) and Hamilton et al. (2007)[5]. A good understanding of the thermo mechanics in the work pieces can be helpful in evaluating the process as well as the weld quality as pointed out in Mandal and Williamson (2006)[6]. The study of the heat flow into FSW tools is also helpful in evaluating the weld quality as in Chao et al. (2003).

Furthermore, the controllable parameters for FSW processing as in Chen (2009), Wang et al. (2004) and Chien et al. (2006) are not only the moving tool velocity as mentioned above, but also the rotation speed of the tool, tool pin length, with respect to the work piece surface, stirrer geometry, and so on. There is no literature survey on process parameters like offset distance and tool pin length of FSW

4.Experimental models.

Objective of the experiment is to establish the friction stir welding process on 5mm thickness of AA6061 aluminum alloy plate butt joint using the parameters of different tool profiles like Triangular, Square, conical and hexagonal for different rotational speeds by keeping constant welding speed and axial force and to study the effects of different tool profiles (Triangular, Square, conical and



hexagonal) for various rotational speed on yield strength, ultimate tensile strength, percentage of elongation. Further the hardness and micro structure of the different joints has been evaluated.

A Conventional vertical 3 axis milling machine was used for friction stir processing (FSW) of AA6061-T6 and IS319Brass. The machine could achieve the maximum speed of 3000rpm and 10-horse power. The AA6061-T6and IS319Brassplatedimensions of 150 mm (L) 75mm (W) 3 mm (T) were used in the present study. The plates were clamped rigidly on backup plate to produce butt joint using the FSW technique as shown in Fig. 3.1.The experiments were conducted on the dissimilar metals AA6061-T6 and IS319Brass. Before the friction welding, the weld surface of the base material was cleaned. The FSW tool is then placed in to the bit and zero tilting angle is applied because FSW tool shoulder is flat. The Sample plunged with down ward feed rate in to the sample then moves linearly through rotating tip along butt line with certain feed rate of 20,28,40,56mm/min. When the central point of the tool reaches the given welding length of 75mm, the linear movement stops and the tip is lifted out of the sample with a certain upward feed. Undesired the rotating pin was inserted into an initially predrilled hole. Butt joint was made using HCHCr (Hardness 55 RC) under controllable process parameters like tool profiles (Triangular, conical, Square, and hexagonal), rotational speed range (800-1600 rpm) by keeping the constant welding speed 20,28,40,53mm/min and axial force 7kN. The range of values of each factor was set at different levels. Based on this, a total of 4experiments in each tool profile, having a combination of different levels of factors were carried out.

Brass is an alloy of copper and zinc. The proportions of zinc and copper can be varied to create a range of brasses. By varying the proportions of copper and zinc, the properties of the brass can be changed, allowing hard and soft brasses. Brass bars are the most widely used and least expensive of copper-based alloys. They have relatively good corrosion resistance, moderately high strength, and in some compositions exceptionally good ductility and excellent forming characteristics. After cold working, they can be softened and recrystallized by appropriate annealing. Adding lead to the brasses results in free cutting of free-machining alloys in which the elemental lead is present as uniformly dispersed particles. The high content of lead results in a relatively low ductility and plasticity. The AA6061 series alloys have good corrosion resistance, surface finish, formability and medium strength, thus making suitable for decorative architectural sections and structural applications. The formation of stoichiometric compound, magnesium silicide makes the AA6061 series alloys heat treatable and capable of achieving medium strength in T6 condition. By taking various applications into consideration we have chosen 6061 series aluminum alloys as the base material. Regarding the base material a market survey was done and it was found that AA6061 was found available from 3mm to 50mm thickness ranges.

In the present work, AA6061-T6 aluminum alloy was selected as base material of 5mm thick. The base material plates were prepared with the dimensions of 150x70x3mm whose properties

5.Tool Design

Three tools are designed by varying the tool pin profile. The configuration of the design FSW tools is

1. Tool pin profiles of Triangular, Square, conical and Hexagonal
2. Tools having D/d ratios of three.

Out of various tool materials like tool steel, High speed steel, High carbon high chromium steel, carbide and carbon born nitride, High carbon high chromium chosen as a tool material because of it s high strength, high temperature resistance, easy to process, easily available and low cost. The tools oil hardened to obtain a hardness of 60-62HRC.

Tool Dimensions:

Tool length= 140mm, Shoulder dia: Φ 18mm

Tool pin length: 2.8mm, Tool pin dia: Φ 6mm

Process parameters	**Values**
Rotational speed (RPM)	500 rpm
Welding speed (mm/min)	20,28,40,56 mm/min
Axial force	7 kN
Tool material	High carbon High Chromium with 60-62 HRc
Tool dimensions	Shoulder dia 18mm, pin dia 6mm and pin length 2.8mm.
Tool pin profiles	Triangular
	Conical
	Square
	Hexagonal

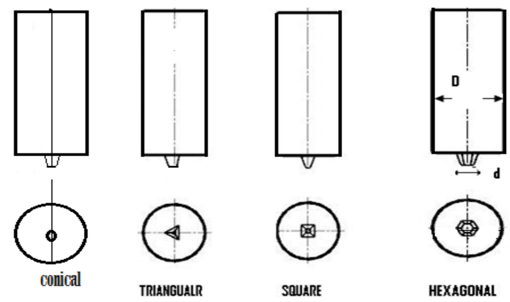


Fig 3.4. Schematic representation of line diagrams of FSW Tool

6.Experimental Data after Tensile Test

6.1 Tensile Properties

Mechanical properties are obtained by square tool pin profile for constant tool rotational speed (500rpm) and axial force (7KN)

Welding speed (mm/min)	Yield Strength (M Pa)	Ultimate Strength (M Pa)	% Elongation
20	121	152	2.6
28	130	163	3.4
40	140	184	4.09
56	117	146	3.04

Mechanical properties are obtained by conical tool pin profile for constant tool rotational speed (500rpm) and axial force (7KN)

Welding speed (mm/min)	Yield Strength (M Pa)	Ultimate Strength (M Pa)	% Elongation
20	99	120	1.2
28	106	128	1.6
40	120	140	2.4
56	104	121	1.7

Mechanical properties are obtained by triangular tool pin profile for constant tool rotational speed (500rpm) and axial force (7KN)

Welding speed (mm/min)	Yield Strength (M Pa)	Ultimate Strength (M Pa)	% Elongation
20	109	140	2.2
28	120	150	2.8
40	130	165	3.48
56	110	137	2.6

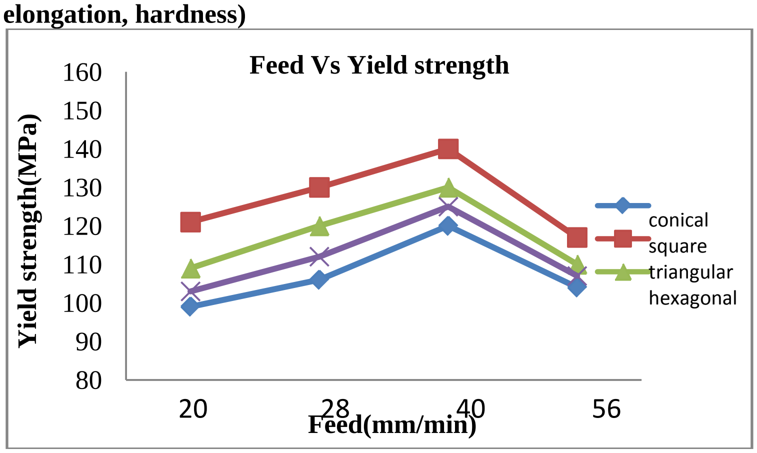
Mechanical properties are obtained by hexagonal tool pin profile for constant tool rotational speed (500rpm) and axial force (7KN)

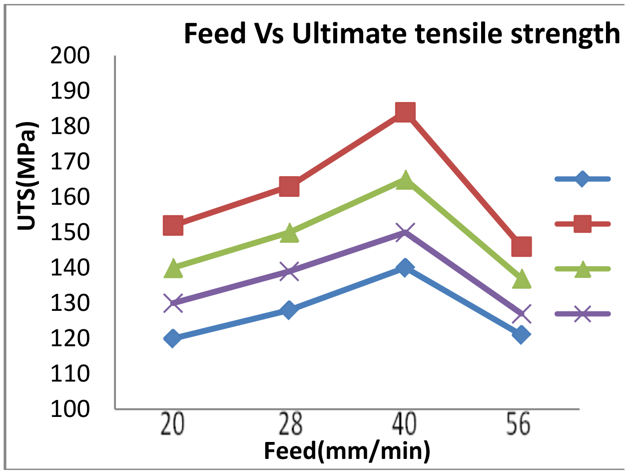
Welding speed (mm/min)	Yield Strength (M Pa)	Ultimate Strength (M Pa)	% Elongation
20	103	130	2
28	112	139	2.5
40	125	150	3.2
56	107	127	2.4

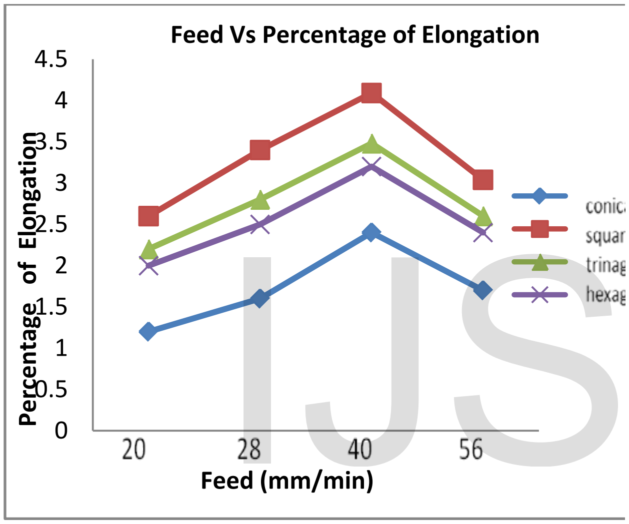
6.2 Experimental hardness values

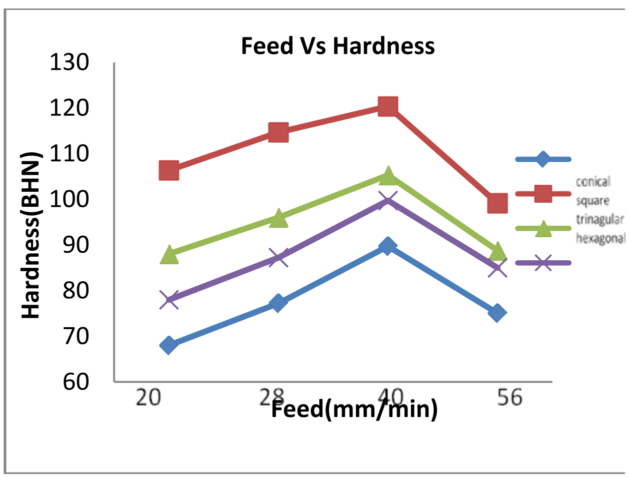
Welding speed (mm/min)	conical	square	triangular	hexagonal
20	68	106.33	88.03	78
28	77.23	114.67	96	87.23
40	89.73	120.33	105.3	99.73
56	75.06	99.13	88.76	85

Comparative graphs between feed VS (YS, UTS, elongation, hardness)





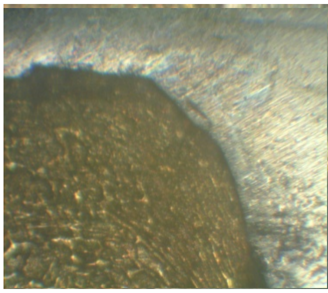




7. Microstructure

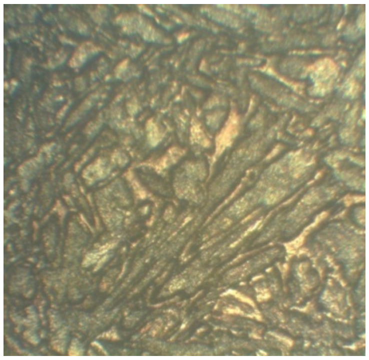
Samples for microstructure observations were cut from both the FSW plates. The cut samples, 0.5 in. square in cross-section, were mounted in Bakelite and then dry ground on progressively finer grades of silicon carbide impregnated emery paper. Fine polishing to a perfect mirror-like finish of the surface was achieved using disc polishing kerosene solution as the lubricant.

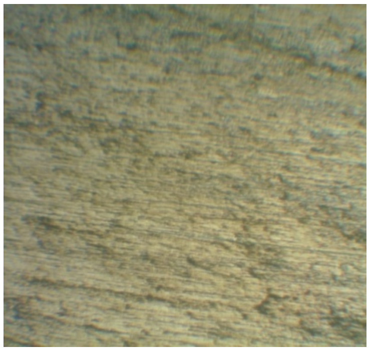
The polished aluminum alloy sample of Plates was etched using Keller's reagent (a solution mixture of 1 drop hydrofluoric acid, 25ml concentrated nitric acid, and 25ml methanol). The etched surface of each sample containing the weld region was observed in an optical microscope and photographed using a bright field illumination (AVER CAP software) technique.



Micro test results of friction stir welding

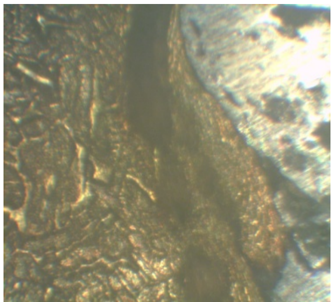
S.NO	Feed(mm/min)	ASTM Grain size#	Intercepts	Mean Int.Length (µm)
1	20	6	174	40.7
2	28	6	174	40.7
3	40	5.5	147	48.1
4	56	5.5	147	48.1

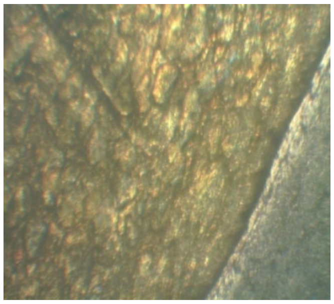




Effect of Tool pin profiles on microstructure:

Al alloy base metal Fig IS319 Brass





8. RESULTS AND DISCUSSION

8.2. Mechanical properties obtained by different tool pin profiles for constant rotational speed (500rpm),tool feeds 20,28,40,56 and axial force (7kN).

The material flow behavior is predominating influenced by FSW tool profiles, FSW tool dimensions and FSW process parameters. Rotational speed appears to be the most significant process variable since it also tends influence the translational velocity. Very high rotational speeds could raise the strain rate, and there by influence the recrystallization process, which in turn could influence the FSW process. Higher weld speeds are associated with low heat inputs, which resulting faster cooling rates of the welded joint. This can significantly reduce the extent of metallurgical transformations taking place during welding and hence the local strength of individual regions across the weld zone. At low axial force, the formation of non symmetrical semi circular features at the top surface of the weld shown poor plasticization and consolidation of the material under the influence of the tool shoulder. A pin profile place a crucial role in material flow and in turn regulates the welding parameters of the FSW process. Friction stir welds are characterized by well defined weld nugget and flow contours. Almost spherical in shape, these contours are dependent on the tool design and welding parameters and process condition used

8.3 DISCUSSION:

From the experimental results the better performance of FSW joint is explained below.

8.5.1. Effect of tool pin profile:

The primary function of the non consumable rotating tool pin is to stir the plasticized metal and move the same behind it to have good joint. Pin profile plays a crucial role in material flow and in turn regulates the welding speed of the FSW processes. The pin generally has cylindrical plain, frustum tapered, threaded and flat surfaces. Pin profiles with flat faces (square and triangular) are associated with eccentricity. This eccentricity allows incompressible material to pass around the pin profile. Eccentricity of the rotating object is related to dynamic orbit due to eccentricity. This dynamic orbit is part of the FSW process. The relationship between the static volume and dynamic volume decides the path for the flow of plasticize the material from the leading edge to the trailing edge of the rotating the tool. This ratio is equal to 1.56 for square,1.3 for triangular profile and 1.09 for hexagonal profile. The triangular, square and hexagonal profiles produce a pulsating stirring action in flowing material due to flat faces. The square pin profile produces more pulsating action compared to other two profiles.

During tensile test most of the specimens failed in FSP region but the exact location of failure is at retarding side or advanced side and it is also evident from the fracture surface analysis. Hence micro hardness measurement and microstructure analysis were carried out in the FSP region of all the joints. Out of the three joints the highest hardness value has been recorded in the joint fabricating using square pin profile tool and lowest value has been recorded in the joint fabricated using Triangular pin profile tool. Similarly, the FSP region of the joint fabricated using square profile contains very fine equiaxed microstructure compared to other joints. The higher number of pulsating action experienced in the stir zone of square pin profile produced small grains with uniformly distributed very fine strengthening precipitates and in turn yielded higher strength and hardness.

8.4. CONCLUSIONS

The butt joining of dissimilar IS319 Brass and AA 6061 aluminum alloy was successfully carried out using FSW technique. The samples were characterized by mechanical properties like yield strength, ultimate tensile strength, hardness, Percentage of elongation. The following conclusions were made from the present investigation.

The optimum operating conditions at 500rpm and 40mm/min of FSW have been obtained for two plates of aluminum alloy AA6061and IS319 Brass welded in butt joint.

From the experimental results, the better performance was achieved by the SQUARE tool pin profile followed by TRIANGULAR,HEXAGONAL and CONICAL pin profile.

The optimal FSW process parameter combinations are rotation speed at 500rpm, axial force 7 kN, welding speed at 40mm/min.

Out of the four profiles, the maximum yield, ultimate tensile strength and percentage of elongation are 140,184 M Pa and 4.09% respectively was observed for square tool pin profile at 40mm/min.
Out of the four profiles, the maximum hardness is 120.33 at weld center for conical tool pin profile was observed. By the grain size lower grain size has superior mechanical properties.

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