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Friction Crush Welding (FCW): An Experimental Study of Trapezoidal and Spherical Profile of Rotating Tool over the Bond Strength of Weld

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Abstract - **Friction Crush Welding (FCW) is a new technology of joining thin sheets in the field of friction welding, which is based on the relative motion of tool and work-piece. In friction crush welding, calculated flanged part of sheet is compressed into the specified gap between the two sheets, with the help of rotating tool. In this research paper, trapezoidal and spherical profile of rotating tool are designed and an experimental study is carried out between trapezoidal and spherical profile of tool to analyze its effect over the bond strength of weld, under a given set of input parameters like speed (RPM) and feed (mm/min). The results of experimentation revealed that under a given set of input parameters, trapezoidal profile of rotating tool gives maximum bond strength in terms of breaking load in comparison to spherical profile.**
Keywords: **Friction Crush Welding, Trapezoidal Profile, Breaking Load, Spherical Tool, Bond Strength**

I. INTRODUCTION

Friction crush welding (FCW) comes under the solid state welding in which flanged part of parent material is not melted, however it is crushed to its plastic state and finally pushed into the gap between the two plates by the help of rotating tool. Generally, friction welding is divided under two heads. One is on the basis of relative motion of work-pieces while other one is on the basis of relative motion of work-piece and tool. Figure 1 shows the classification of friction welding.

In 1999, journal of science and technology of welding and joining published the work of Thomas *et al.,* related to feasibility of friction stir welding of steel [7]. They investigated the various critical input specifications like rotation of tool, plate thickness etc. for friction stir welding of steel. In 2013, researcher Y.S. Sato and H. Kolawa studied the distribution of tensile property and micro-structure in friction stir welding of 6063 aluminum [8]. Scientist Yusof *et al.,* in 2013, carried out various experimental works over ultra-thin friction stir welding (FSW) between aluminum alloy and copper to investigate the characteristics of weld joint [2]. In 2016, Besler *et al.,* performed friction crush welding experiment by using semi-circular groove and analyzed the bond strength and micro-structure of weld zone [1]. In this research paper, trapezoidal profile of rotating tool is designed and experiments were carried out by using two profiles of rotating tool i.e. spherical and trapezoidal under a given set of input process parameters like feed rate (mm/min) and speed of rotating tool (RPM).

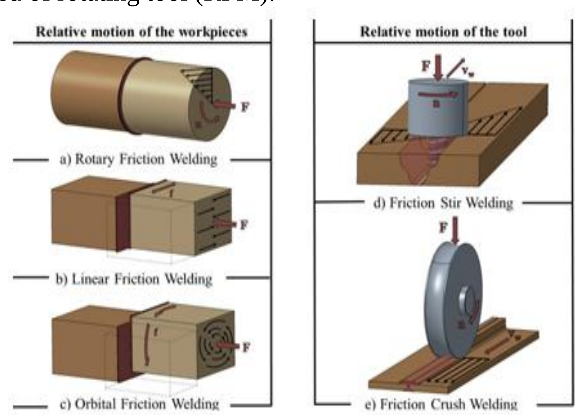

Fig. 1 Various types of classification of Friction welding by Besler *et al.,* 2016 [1]

A. Mechanism of Friction Crush Welding (FCW): Principle of Friction crush welding basically depends upon two processes;

1. Heating due to friction
2. Crushing mechanism of material.

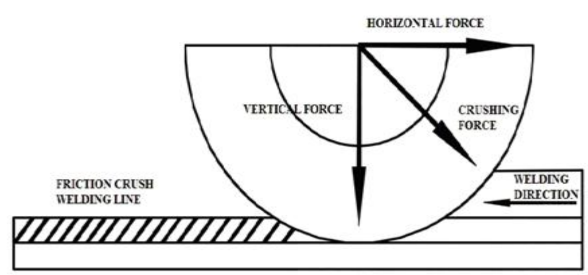

Fig. 2 Mechanism of Friction Crush welding

Due to friction between tool and work-piece, heat is produced which brings the parent material into their plastic state. On the other hand, variation in input parameters i.e. rotation of tool and welding feed rate produces the pressure variation at contact zone. From the fig.1, it is depicted that at contact zone, three forced simultaneously acted. Crushing force helped in crushing the material while horizontal force opposes the welding direction and vertical force provides thrust to plastic material, which pushes it into the gap between the plates.

B. Advantages of Friction Crush Welding (FCW): In 2016, Besler and Paul Schindele [1] use this welding technique over thin sheet, in which frictional-contact occurred due to relative motion between tool and the work-piece. This technique is having some advantages, which makes it more economical and practical in industrial field like;

1. No filler is required during the process.
2. It is environmentally friendly having no radiations hazards.
3. Set-up cost of the welding technique is low.
4. Also applicable for dissimilar materials.
5. Compatibility to automation.

II. DESIGNING OF TOOL

In his experimentation work, Besler *et al.,* [1] used the spherical profile of rotating tool. But in this research work, trapezoidal profile of rotating tool is designed on the basis of Besler's spherical one. Figure 3 shows the tool geometry of spherical profile of rotating tool.

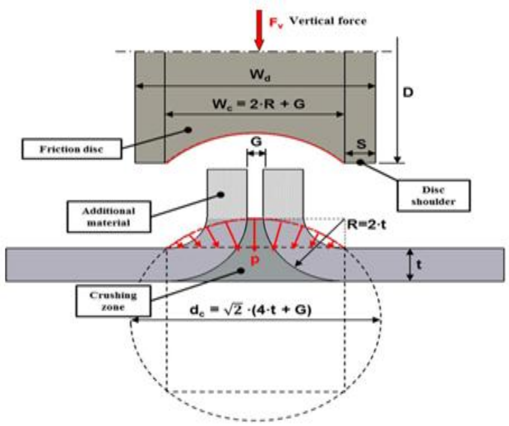

Fig. 3 Tool geometry by Besler *et al.*, 2016 [1]

From the fig.4, it is depicted that volume of calculated flanged length must be equal to volume of space in which the crushed material is pushed.
i.e. $V_3 = V_1 + V_2$ ---------- Eq. 1

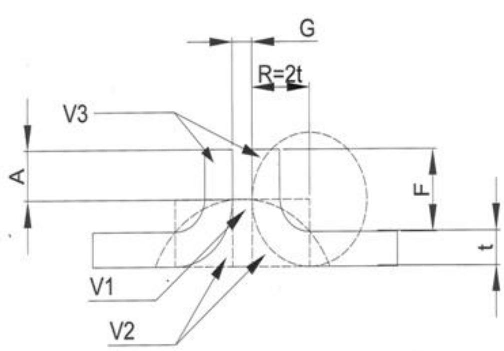

Fig. 4 Front-view of rotating tool

For designing the trapezoidal profile of rotating tool, consider the height of tool as unity and then equate the area of spherical tool with the trapezoidal tool area.

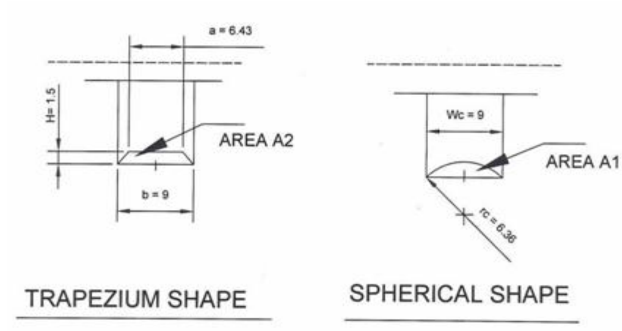

Fig. 5 Pictorial view of tool area

From the fig.5, we can say that,
Area of trapezoidal = Area of spherical
Area (A_2) = Area (A_1) -------Eq. 2
With the help of fig.3 of tool geometry, area (A_1) can be calculated as;
$A_1 = \{(0.25 * 3.14 * r_c) - (4.5 * (6.36^2 - 4.5^2)^{0.5})\}$
$A_1 = 31.75 - 20.22 = 11.53mm^2$
Where, Radius of sphere (r_c) = 6.36mm
Now, area of trapezoid is;
Area $(A_2) = 0.5 * h * (b + a)$
Where, height of trapezoid (h) = 1.5mm
Base of trapezoid (b) = 9mm
Putting all these value in the above eq.2;
$0.5 * 1.5 * (9 + a) = 11.53mm^2$
Solving the above equation,
Minor side of trapezoid (a) = 6.43mm

III. DATA COLLECTION

A. Material Specifications

In the above experiment, aluminum plate is used as a work-piece while rotating tool is made up of high speed steel. Table I shows the detail of material specification of tool as well as work-piece.

TABLE I MATERIAL SPECIFICATION

S. No.	Item	Material Details	Specification (mm)
1.	Rotating tool	Aluminum 6061 T-6	150 * 75 * 2
2.	Work-piece	HSS	Outer diameter = 120
			Internal bore= 25.5

(a) Spherical (b) Trapezoidal

Fig. 6 Profiles of rotating tool

Fig. 6 shows the trapezoidal as well as spherical profile of rotating tool with the above specified dimensions.

B. *Input and Output Process Parameters*

Input process parameters are the variables which have the ability to change the output values. In above performed experimental work, there are mainly three input process parameters, which can affect the output variables. Table II shows the input as well as output process parameters, which are involved in the above experiment.

TABLE II PROCESS PARAMETERS

Output Parameter	Input Parameter		
Breaking load or Bond -strength (N)	Profile of rotating tool	Speed (RPM)	Feed rate (mm/min)

IV. EXPERIMENTAL SET-UP

For carrying out experimental work, horizontal milling machine was used, in which rotating tool was mounted over the spindle while work-pieces were clamped over the bed. The In this research work, output is measured in-terms of breaking load, which indicated the bond strength of weld. Fig.7 shows the experimental set-up of horizontal milling machine over which the experimental trial had been performed.

Fig. 7 Set-up of work over milling machine

V. RESULTS AND DISCUSSION

In this research work, output is measured in-terms of breaking load, which indicated the bond strength of the weld area. Table III shows the experimental output response in terms of input and output variable.

It has been found that as we increases the value of feed rate (mm/min) and RPM of rotating tool, the value of bond strength of weld also increases.

At a particular input parameter i.e.740 Speed (RPM) and 45mm/min feed rate, maximum value of bond strength is achieved under different profile of rotating tool.

TABLE III OUTPUT RESPONSE TABLE

Exp No.	Profile	Speed (RPM)	Feed rate (mm/min)	Breaking Load (N)
1	Spherical	220	15	5096
2	Spherical	410	30	6500
3	Spherical	740	45	7358
4	Trapezoidal	220	15	9100
5	Trapezoidal	410	30	13104
6	Trapezoidal	740	45	14794

Due to the trapezoidal profile of rotating tool, greater amount of thrust is generated, which forms the weld stronger in strength in comparison to spherical profile.

VI. CONCLUSION

By the experimental trails, it has been revealed that maximum bond strength of weld is achieved at trapezoidal profile of rotating tool in comparison to spherical profile at same input process parameters i.e. 14794 Newton of bond strength in case of trapezoidal profile while 7358 Newton in case of spherical one at 740 RPM and feed rate of 45mm/min.

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