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Friction Crush Welding of Similar Metals: An Overview

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***Abstract* - Friction Crush Welding (FCW) is a newly developed technique which can be used for welding of similar materials with or without filler metal. In this process, welding between two work pieces occurs due to relative motion between work pieces and rotating cylindrical tool, which causes crushing of material to produce weld. Similar weld which include welds of aluminium, steel and copper and their alloy have been successfully produced by few researchers. This review covers the work conducted in the field of FCW and throws light on the future use of FCW for welding similar and dissimilar materials.**
***Keywords:* Friction Crush welding, Aluminum, Steel, Microstructure, Scanning Electron Microscope.**

I. INTRODUCTION

Friction Crush Welding (FCW) is a newly developed technique by Besler et al. (2016) using crushing of metal and was initially applied to weld simlilarsheet metals of aluminium, steel and copper without filler material. In this process, welding between two work pieces occurs due to relative motion between work pieces and rotating cylindrical tool having specific profile shape as shown in Fig. 1.

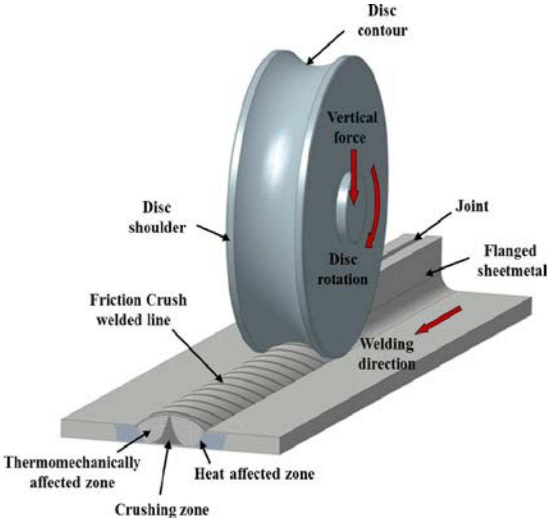

Fig. 1 Schematic illustration of FCW [1,2,3,4]

The workpieces having flanges on it are positioned adjacent to each other with a gap. The relative motion between tool and workpieces causes crushing of material and crushed material is filled into the gap between the two workpieces through the tool and produces weld.

FCW joints commonly consists of different microstructural zones as shown in Fig. 2. Which consists of unaffected material or original material, the heat affected zone (HAZ), thermo-mechanically affected zone (TMAZ) and crushing zone (CZ).

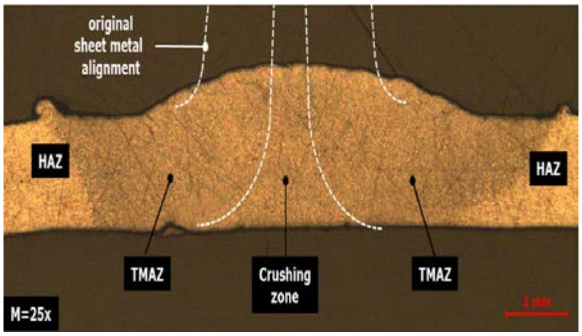

Fig. 2 Illustration of different microstructural regions in the transverse cross section of a FCW material (Steel) [2]

Prior to the development of FCW, conventional fusion welding processes along with friction stir welding (FSW) processes were used to join similar and dissimilar materials. Reviews have been conducted on various aspects of FSW by different researchers. This paper presents a review of published literature in FCW of similar materials. The review was conducted by focusing on FCW between similar material of aluminum, steel and copper.

II. FRICTION CRUSH WELDING MECHANISM

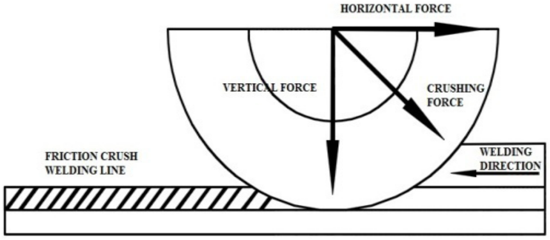

Fig. 3: Mechanism of friction crush welding [1,2]

Friction crush welding mainly depends upon a) frictional heat produce due to relative motion between the work piece and the tool and b) crushing forces were developed by tool movement due to variation in welding speed and rotation of tool. The flanges of work pieces are crushed and filled into the gap between to plates to produce weld joint.Tool rotation and movement between tool and work piece cause development of tree types of forces in tool namely i) Horizontal force (F_h), which acts in opposite to the welding direction, ii) Crushing force (F_c), which crush the material and iii) Vertical downward force (F_v), which held to fill the crushed material into gap between the two plates to produce weld.

III. TOOL GEOMETRY AND JOINT DESIGN:

Tool geometry and joint design plays an important an important role to produce good weld joint. Tool geometry or tool profile is described by various parameters like Outside dics diameter (D), Disc width (W_d), Profile or curvature of disc (d_c),Groove width (W_c) and disc shoulder (S).

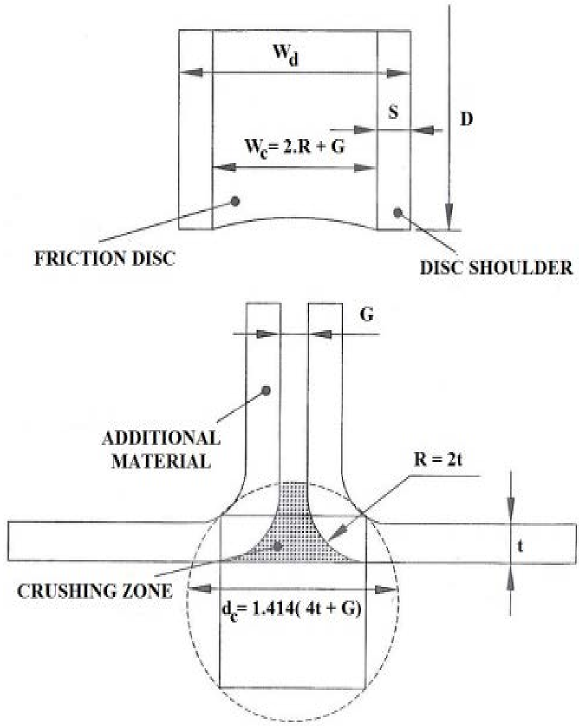

Fig. 4 Tool geometry and joint design [1,3,4]

With the help of tool geometry (Fig. 4), the curvature of disc (d_c) is given as,

d_c= 1.414 × (4t + G)

where, t = thickness of plates

G = gap between to plates

R = Outer radius of work piece when flanged = 2t

Joint design plays an important role in FCW because additional material required to fill the gap between the two plates to be welded will be provided from the calculated height of flanges of plates. The height of flanges can be calculated by equating the volume of material required in crushing zone to produce weld from volume of material from flanges of plates.

Let F = Length of flange

A = Excess length of flange

V_1 = Volume of gap between to plates

V_2 = Volume of material under the curvature of bend plates

V_3 = Volume of additional material required

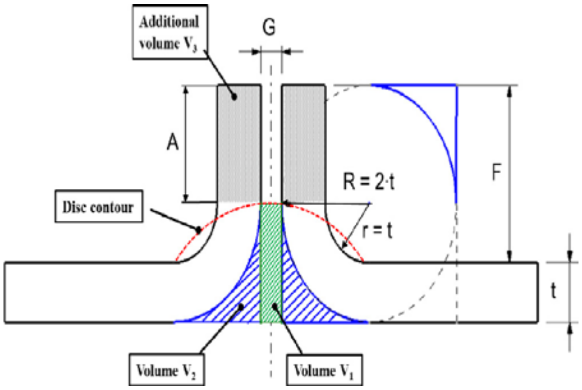

Fig. 5 Additional material volume [1,3]

As the volume of additional material required in crushing zone is to be supplied from volume of extra flange length, so

$$V_3 = V_1 + V_2$$

From Fig. 5,

$$V_1 = 2t \times G \times L$$

$$V_2 = 2\,(2t\times2t\times L - \tfrac{1}{4} \times \pi \times R^2\times L)$$

$$= \tfrac{1}{2}\times L\,[(4t)^2 – (2t)^2\times\pi]$$

$$V_3 = A\times2t\times L$$

Where, L = Length of weld

Using above relations, length of additional flange required to provide material in crushing zone can be described in terms of thickness of plate and gap between the plates as

$$A = G + (4t - \pi t)$$

Total length of flange, F = A + t

IV. RESEARCH ON FSW OUTSIDE INDIA

Besler et al. [2,3] successfully demonstrated the butt joining of similar materials like Aluminium, steel and cooper by FCWwith and without additional material.Quality of weld was measured in terms of bond strength and microstructural analysis as per DIN EN ISO 4136 and EN ISO 17639 European standards respectively.

A. Bond Strength

Welding joints ofAluminium (EN AW5754 H22), steel (DC01) and cooper (DHP) were prepared with FCW at different welding speed (mm/min) and result of weld bond strength were compared with respective bond strength of base material.

Table I shows the tensile/bond strength of aluminium material joint at different welding speed with and without filler material, maximum bond strength with and without filler material observed was 190 N/mm^2 and 220 N/mm^2 at weld speed of 1000-1500 rpm/min and 500 rpm/min respectively. Aluminium weld shows maximum bond efficiency of 78% and 90% with and without filler material.

With varying welding speed from 500 rpm/min to 3000 rpm/min, range of bond strength changes from 70-220 N/mm^2 to 135-190 N/mm^2.

TABLE I TENSILE/BOND STRENGTH OF ALUMINIUM MATERIAL JOINT AT DIFFERENT WELDING SPEED WITH AND WITHOUT FILLER MATERIAL (ALUMINIUM PARENT BOND STRENGTH = 245 N/MM^2)

Welding speed (mm/min)	Tensile/bond strength (N/mm^2)	
	With filler material	Without filler material
500	180	220
1000	190	172
1500	190	150
2000	160	132
3000	135	70

Table II shows the tensile/bond strength of steel material joint at different welding speed with and without filler material, maximum bond strength with and without filler material observed was 325 N/mm^2 and 305 N/mm^2 at weld speed of 2000 rpm/min and 1500-2000 rpm/min respectively. Steel weld shows maximum bond efficiency of 96% and 90% with and without filler material. Bond strength improves with filler material at respective weld speed.

TABLE II TENSILE/BOND STRENGTH OF STEEL MATERIAL JOINT AT DIFFERENT WELDING SPEED WITH AND WITHOUT FILLER MATERIAL (STEEL PARENT BOND STRENGTH = 338 N/MM^2)

Welding speed (mm/min)	Tensile/bond strength (N/mm^2)	
	With filler material	Without filler material
1000	225	150
1500	308	305
2000	325	305
2500	318	158
3000	218	--
3500	192	--

TABLE III TENSILE/BOND STRENGTH OF COPPER MATERIAL JOINT AT DIFFERENT WELDING SPEED WITH AND WITHOUT FILLER MATERIAL (COPPER PARENT BOND STRENGTH = 264 N/MM^2)

Welding speed (mm/min)	Tensile/bond strength (N/mm^2)	
	With filler material	Without filler material
1000	--	82
2000	--	107
3000	150	116
4000	178	144
5000	167	162
6000	178	156
7000	195	--
8000	164	--

Table III shows the tensile/bond strength of copper material joint at different welding speed with and without filler material, maximum bond strength with and without filler material observed was 195 N/mm^2 and 162 N/mm^2 at weld speed of 7000 rpm/min and 5000 rpm/min respectively. Copper weld shows maximum bond efficiency of 73% and 61% with and without filler material. Bond strength improves with filler material at respective weld speed.

B.Macro-structural and Visual Inspections

The geometry of the weld joint profile with its dimensions and surface characterization giving the average roughness value with and without filler material is given in table IV. The root sides of the three welded materials revealed a sound bond without any grooves or irregularities.

TABLE IV MACRO-STRUCTURAL ANALYSES OF WELD (LENGTH OF WELD = 15 MM, WIDTH OF WELD = 6MM)

Materials	Average Roughness (Ra) in µm	
	Without filler material	With filler material
Aluminium	6.64	6.44
Steel	3.55	3.55
copper	2.78	2.78

Surfaces of weld prepared with and without filler material shows same quality as shown in table IV. Author reported minimal indications of material distortion after welding specially in case of weld produced with filer material.

V. RESEARCH ON FSW IN INDIA

Brar and Jamwal[3] prepared a weld joint of aluminium alloy (6061 T-6) with FSW at three tool rotating speed (220 rpm, 410 rpm and 740 rpm) along with three different feed rate (15 mm/min, 30 mm/min and 45 mm/min). The bond strength of the weld is measured by UTM machine. The result (Table 5) reveals that maximum bond strength was achieved with increase in rotational speed of tool as well as feed rate.

Brar *et al.*[4] optimized the process parameter of FSW of stainlesssteel (AISI 304) with the help of analysis software MINITAB 15 for design and analysis of experiments in order to perform Taguchi L9 orthogonal and ANOVA analysis. Result shows optimum welding conditions for AISI 304 stainless steel were 740 rpm with feed rate 45 mm/min for B profile rotating tool. The predicted and experimental bond strength at optimum weld conditions is 13.69 kN and 10.03 kN respectively with 4.84 % error.

TABLE V VARIATIONBOND STRENGTH OF ALUMINIUM ALLOY (6061 T-6) WITH RESPECT TO TOOL ROTATIONAL SPEED CORRESPONDING TO FEED RATE

Tool rotational speed (rpm)	Feed rate (mm/min)	Bond strength (kN)
220	15	5.1
410	30	6.5
740	45	7.4

VI. CONCLUSIONS

In conclusion, an overview of friction crush welding of similar materials focusing on aluminum, steel and copper and there alloys has been conducted along with fundamental of FCW mechanism, tool geometry and tool design. Furthermore most of the cited research studies are more focused on understanding the microstructure properties, bond strength of welds and evaluation of optimum welding parameters. A maximum bond strength of order of 96% with respect to their base metal shows on of the positive aspect of FCW as compare to other welding option available today.

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