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# Tool Wear Characteristics on Friction Stir Welding: A Literature Review

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## ABSTRACT

*FSW* is solid state joining process. It is widely used for joining dissimilar material welding like steel with aluminum alloy which are very difficult to join by fusion welding. FSW weld quality is mainly influenced by shoulder & pin geometry, diameter, tool material, rotation speed and feed rate. Influence of each parameter on tool wear is studied from different research papers. It is observed that the effect of pin geometry and tool material selection should be based on welding materials. There is also significant improvement can be seen on the coated tools while comparing with traditional FSW tool materials which indirectly also supports weldment.

Keywords: FSW welding, FSW tools, tool materials, tool geometry, tool coating, tool life, tool wear

## INTRODUCTION

From last some years, world focus on developing efficient and environment friendly metal joining processes. So, for joining two materials focus on Friction Stir Welding (FSW) is increased now. FSW developed by W. Thomas at TWI in 1991.FSW is advance welding technology and has emerged as a solid state joining process which used to join that material which is difficult to join by fusion welding processes.

 

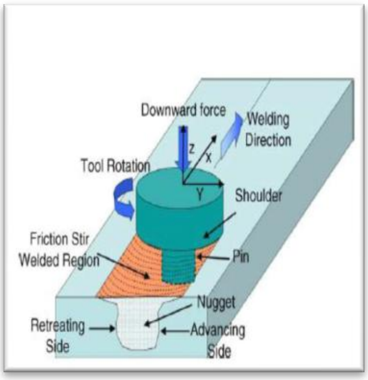


Figure 1: FSW Process Principle.

The basic concept behind the FSW process is that, after matting the two weld edges, non-consumable rotating tools is plunge between them and gives feed to it along the weld seam. In FSW 70% heat is generated by the shoulder and rest by pin probe. Here the heat generated by tool is only enough to weld material at solid state and metal flow due to stirring action of a pin. FSW process is shown in figure 1. Due to continuous good quality of weld, FSW is used for existing products or go ahead for new complex products.

## FSW TOOL

The design of the tool is a critical factor as a good tool can improve both the quality of the weld and the maximum possible welding speed. TWI has developed tools specifically designed to increase the penetration depth and thus increasing the plate thicknesses that can be successfully welded. A typical tool structure is shown below:-

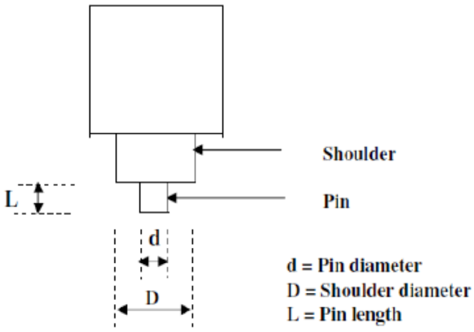


Figure 2: Typical FSW tool

## STUDY OF WEAR PROPERTIES OF VARIOUS TOOLS

Sreejith Mohan, S P Sivaprakasam, M C Santhoshkumar, M Suriyanarayan [1] conducted experiments by coating nano-tio2 on care welding wires and observed 80% of reduction in fumes and observed coating morphology and the crystallite size of the deposits.

Giuseppe Casaline, Salina Comparelli, Michilangelo mortello [2] studied the influence of shoulder geometry and tool coating.

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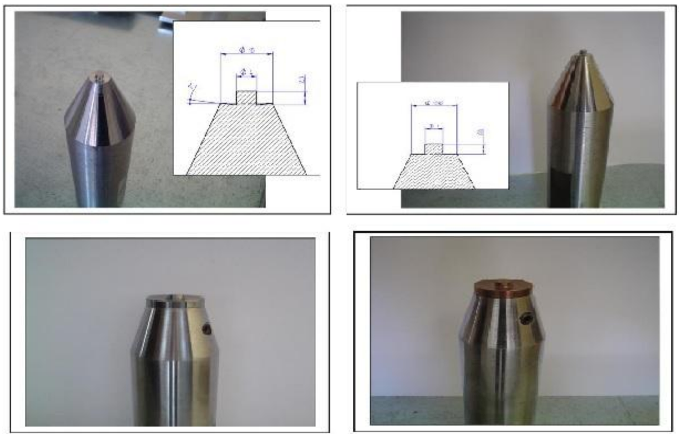


Figure 3: Tools with conic small shoulder, flat small shoulder, carbide tool large shoulder, carbide tool large shoulder with coating [2].

Uddeleholm QRO90 supreme tool steel with 10mm shoulder and 7degree conical angle, tool with flat shoulder, tungsten carbide coated tool with flat and 15 degree slope angle was used for studied. They observed AlCrN coated tool with flat shoulder improves wear resistance.

D.contorno, M.G.Faga, L.Fratini, L.Settineri and G.Gautierali Confiengo [3] coated FSW tools with MMC material (metal matrix composites).

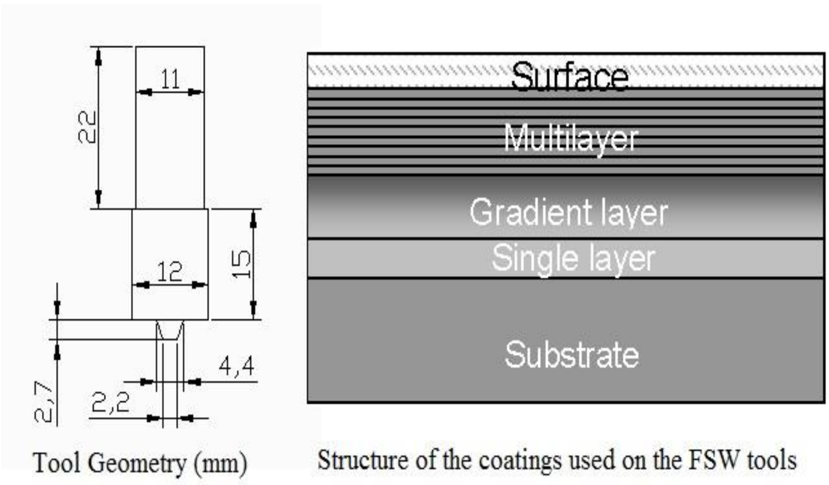



Figure 4: Tool Geometry and Structure of coating [3]

They characterized in terms of thickness, hardness, adhesion and tribological behavior for uncoated pin tools. The Increase of wears observed in second stage.

Baskaran A, K.Shanmugam K and Balasubramanian V [4] studied the effect of hard faced tools. HSS, MWC, PWC tools hard faced with powder composition of 60% WC & 40% NiCrBSi. HSS tool produced surface defects but MWC tool welded copper alloy without surface defect but threaded pin profile was worn out completely.

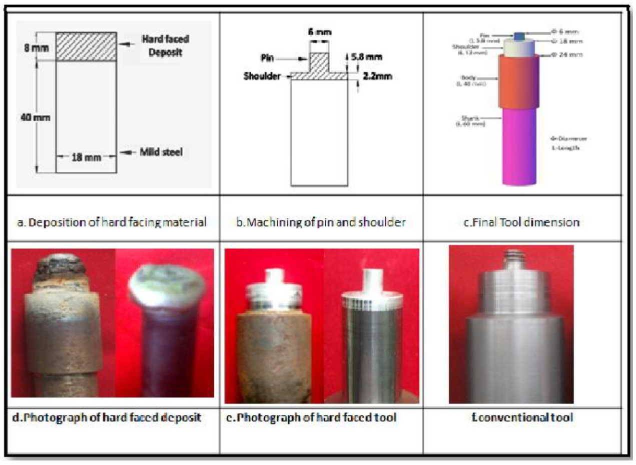


Figure 5: Schematic representation of hard faced tool fabrication [4]

Kundzanayi Chiteka[5] denoted in the proves of FSW tool material selection that High Carbon High Chromium (HCHCr) Tool Steel has high wear resistance when AA5083-H111A1 Alloys was welded.

Dr A.K.Shaik Dawood and M.Karthikeyan [6] used Aluminum alloy AA6351as base material and tools of pin profile Circle, Thread and Square with D/d ratio of 3.HSS is chosen as tool material because of its high strength and high hot hardness, easy to process, easy availability and low cost.

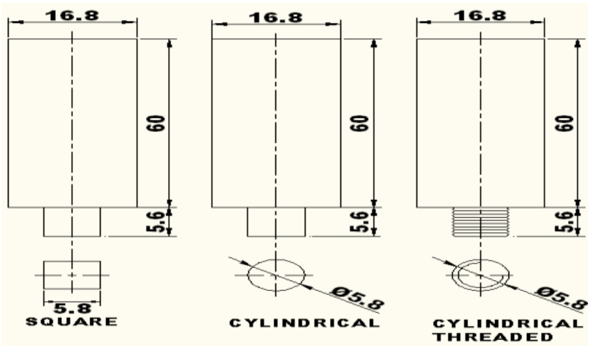


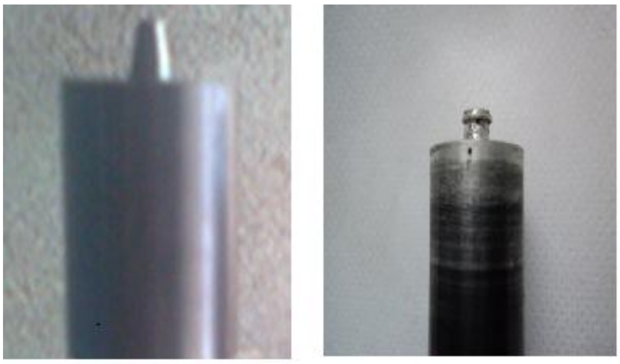

Figure 6: Schematic diagram of different tool profile [6]

The welding performed at 1350rpm and welding speed 75mm/min and found that tool pin profile square tool wears the least.

A K Lakshminarayanan, C S Ramachandran, V Balasubramaniyan [7] studied the feasibility of surface coated friction stir welding tools to join AISI 304 by using NiCrFeSiC alloy Powder coating .They identified that tool wear occurs due to large stress developed at high temperature. In this study the developed tools failed mainly due to the abrasive and adhesive wear compared to the failure due to plastic deformation.

A M Khourshial, I Sabry [8] welded Al 6061 with ceramic coated tungsten tool of generic features 1) shoulder section, 2) pin, 3) external feature on probe. The observation is that external feature with probe has more wear resistance.

Devananthan, A.Suresh Babu [9] welded MMC using coated tools. TiAlN coated tool of tool length 120 mm, shoulder diameter of 19.5mm, pin diameter of 4mm, pin length of 5.7mm, coating thickness of 4 microns. They noticed no tangible wear in tool.



Tool Before Welding Tool After Welding

Figure 7: TiAlN coated HSS tool before and after welding [9]

A.Arora, M.Mehta, A.De, T.Debroy [10] studied that tool pin with smaller length and larger diameter will be able to sustain more stress than a longer pin with smaller diameter. The proposed methodology is used to explain the failure and deformation of the tool pin in independent experiments for the welding of both L80 steel and AA7075 alloy.

S.Baragetti and G.D Urso [11] welded AA6060 (Al-Mg-Si-Cu) with two tools of standard (flat shoulder and cylindrical pin using AISI 1040 in annealed condition; shoulder and pin diameter 15 and 5 mm respectively) and threaded tool (flat shoulder and a threaded probe obtained using a commercial M5 thread forming tap).


Figure 8: Standard and Threaded tools [11]

They observed that the threaded one produce worse results than the unthreaded one.

H.J Zhang, M.Wang, Z.Zhu, X.Zhang, T.Yu, G.X.Yang [12] monitored the performance of tool with non shouldered and shouldered tools. Base metal used was an –mm thick 5052 aluminum alloy plate in H32 condition. Defect free joints are produced successfully under the condition of zero shoulder plunge depth by using a NSP welding tool.

J H Ouyang, H Mei, M Valant and R Kovacevic [13] studied the application of Laser Based Addictive manufacturing to production tools, A WC-based ceramet/tool steel functionally graded material (FGM) by controlling the amount of different supplied powders. FGM exhibits an expected gradient between super hard surface with excellent wear resistance and the inside core with a combination of toughness and hardness at elevated temperatures.

Mohamed Ackiel Mohamed, Yupiter HP Manurung and Mohamed Nor Mohamed[14] welded AA6061-T651 base material and obtained yield strength of 271 MPa using multi objective Taguchi method and response surface methodology.

G.F Batahala, A.Farias, R.Magnabosco, S.Delijaicov, M.Adamik and L.A.Dobrzanski [15] studied the wear performance of PVD coating of cemented carbide tools (WC).

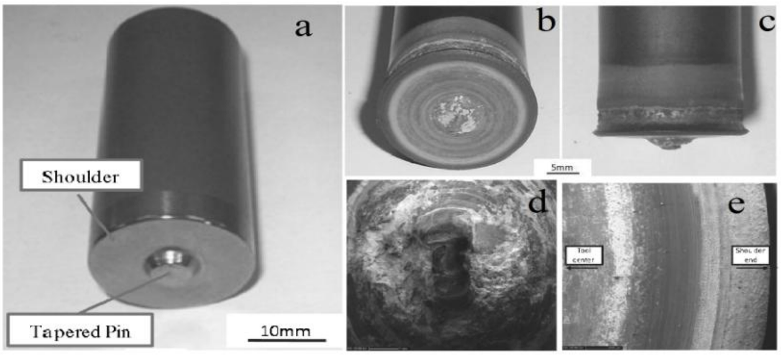



Figure 9: a) Tool design showing the pin and shoulder features, b) Front view of the worn tool after the FSW process, c) side view of the worn tool, d) Micrograph of tool pin showing a fractured region, e) Micrograph of tool shoulder showing [15]

AlCrN was coated on WC and observed that tool was worn out and some color difference was observed when not using protective gas. High deformation is found in pin and shoulder.

Akos Melinger and Imre Torok [16] studied tools with pin, probe and shoulder based on easy available, machinability thermal resistance and wear resistance. Hot-work tool steel with flat shoulder and 0.3 mm shorter pin length had less tool wear and welded with good quality.

Y.N Zhang, X.Cao, S. Larose and P. Wanjara [17] studied fixed, adjustable and self reacting tools and observed PCBN tools, wear at low tool rotation rate is caused by adhesive wear and wear at high speed is due to abrasive wear. Visible tool wear is noticed in tool steel after welding certain distance. Excellent wear resistance is observed in WC based alloys, WC-Co based alloys, TiC, Tic-Ni-W, Ti-Ni-Mo, PCBN, MP159, Inconel 718,738LC, 939, 100.

Xiaoqian Ma, Stanley M.Howard, Bharat K.Jasthi [18] used nine tools of different designation and some similar geometry and finalized an optimum parameter of shoulder diameter 17.1mm, pin diameter of 2.2, pin angle of 10° and right grooved shape made of PCBN material.

R.Karimdadashi, M.A. Mohtadi-bonab [20] used H13 hot work tool steel with cylindrical profile and a square profile produced after heat treatment of threaded and non threaded profiles in them.

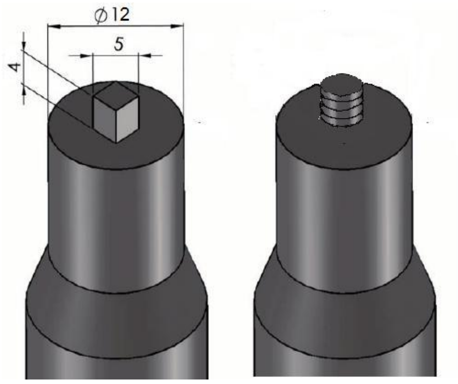



Figure 10: Square and Threaded profile Tools made of H13 hot work steel [20]

He observed fewer tools wear in non threaded tool when compared to tool with threaded profile.

Shamsujjoha, Bharat K. Jasthi, Michael West, Christian Widener[21] used friction stir welding of Aluminium to steel using Refractory metal pin tools.

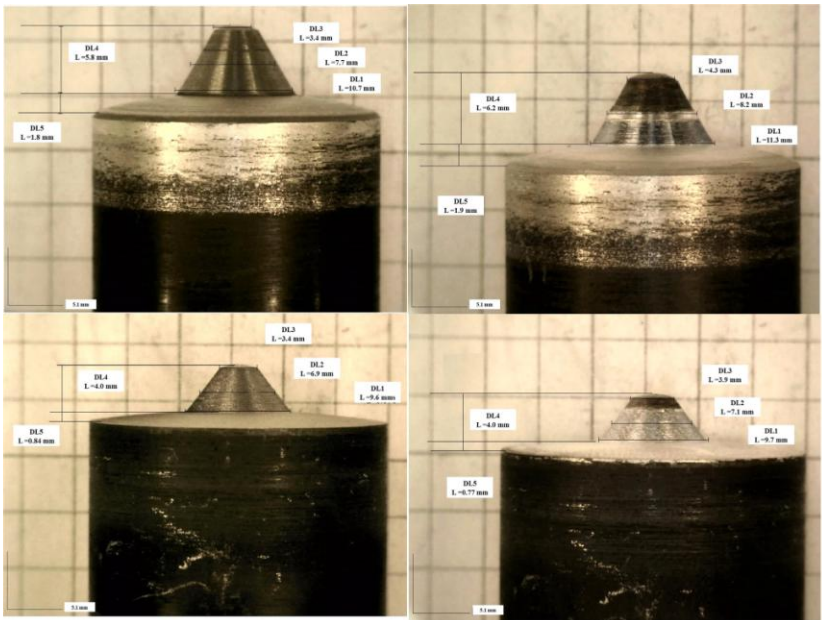


Figure 11 Dimensional analysis of pin tool A (top) and pin tool B (bottom) before and after welding [21]

A limited pin tool wear study was conducted by visual and dimensional analysis of the pin tools before and after welding. Significant sticking of Aluminum on the pin tool was observed. Measurements of different regions of the pin tool showed that a slight increase in diameter of the pin and pin length observed for both pin tools. Since no depression of the pin tools was observed, this more likely occurred because of the aluminum sticking on the pin tools. This increase in pin dimensions suggested that there was not significant pin tool wear but a more detailed analysis is needed. It should also be noted that aluminum sticking does not have any significant impact on weld properties when this same pin tool was used for welding further without cleaning.

S.Yu.Tarasov, V.E. Rubtsov, E.A. Kolubaev [22] annealed aluminum alloy sheet 5 mm thickness sheets have been welded using a FSW machine. Structurally it consists of aluminum / magnesium solid solution and inclusions basically being Mg2Si and Al6Mn. The FSW tool had shoulder's diameter 19 mm and pin's diameter 6 mm. Weld path lengths was 2000 mat 560rpm, plunge force 2600 kg, feed rate 500mm/min. SEM instrument has been used for detecting the chemical composition of the FSW tool and tribological layers. Tool wear is of different cross sections after welding

B.Thopmson and S.S. Babu [23] studied tool degradation characteristics in the Friction Stir Welding of hard metals. They studied pre- and post microstructures of three tungsten based tools. The tool composition and obtained result are as follows: - Material A (99% W, 1% $La_2O_3$) degraded by severe plastic deformation, Material B (75% W, % Re) degraded by twinning and Material C (70% W, 20% Re, 10% HfC) degraded by intergranular failure.

## CONCLUSION

From the above studies, there is a significant improvement in FSW process by altering various types of tools with different coatings and different shoulder & pin geometry with different diameters have been obtained. The selection of suitable tool material has an impact on the welded joint. Today, the main requirement of FSW tool is good material flow and less flash formation during welding process and less wear. For that effective coating with effective shoulder geometry with optimum shoulder diameter are required for improvement in tool life.

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