Research Paper

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Influence of Surface Roughness of Tools on the Friction Stir Welding Process

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Abstract

Most publications on friction stir welding describe phenomena or results with given process parameters like feed rate, rotation speed, angle and depth of penetration. But without a complete documentation of tool design, the results under the same process parameters are completely different.

For this purpose, the Institute of Cutting and Joining Manufacturing Processes (tff), University of Kassel investigated the influence of tool roughness on the friction stir welding process. Therefore a defined surface finish was produced by turning and die sinking. As basis of comparison the constant parameters were rotation speed, feed rate, tilt angle and a heel plunge depth. Sound butt-welds were produced in aluminium alloy 6082 (AlMgSi1) with 1.5 mm sheet thickness with a turned reference tool with a surface of Ra = 0.575 µm in position controlled mode. The surfaces are manufactured from a very fine to a very rough structure, classified by the VDI-classes with differences in the arithmetical mean roughness.

It can be demonstrated with the help of temperature measures, that less heat is generated at the surfaces of the shoulder and the pin by the higher roughness due to lower active friction contact surface. This can also be seen in the resulting wormhole defects.

Key Words : Friction stir welding, Tool design, Surface roughness

1. Introduction

The friction stir welding is one of the upcoming joining technologies of the new millennium. Since it was discovered in 1991 by Wayne Thomas at the TWI[1)], numerous research projects are engaged in the basics of the pressure welding process. Especially the amount of patents[2)] and publications[3)] in the area of the friction stir welding reveals the potential of this technology. Particularly in case of the aluminium materials, the friction stir welding has proven to be a strong alternative. This is due to the fact that a lot of the obstacles like pore formation and the risk of hot cracking, which arise when welding aluminium, are not generated because of the comparatively low joining temperatures. In addition to that, the existing oxide layers of the aluminium only disturb the process in a minor way compared to fusion welding processes[4)]. Furthermore, the friction stir welding offers, process related, a

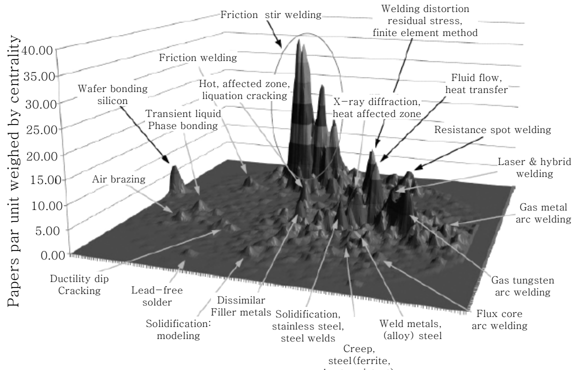


Fig. 1 State of publications in 2011[3)]

good energetic efficiency factor. As the friction stir welding generates no fumes, dusts or gases and most of the times abstains from the use of additional materials, this process offers a huge potential to cut down welding additives and additional security measures[5].

Numerous examination in the area of the friction stir welding deal with the influences of different parameters on the welding result. Thus, the different tool parameters (amongst others the shoulder diameter and forms; pin diameter, lengths and forms; radii) are as relevant as the different process diameters (amongst others rotations speeds, feed rates, forces, feed speed, dwell times). Due to a lot of interactions between the parameters, only sporadic examinations of the parameters can be found and only few have been researched in studies. A transmission of the parameters from one to another material is often difficult and most of the times impossible without adapting the parameters.

In 2009, Hatamleh et al. dealt with the roughness of resulting friction stir welds and the effects on the characteristics of the welds[6]. Arbegas mentionsthe influence of the roughness on the welding process by influencing the friction coefficient and the correlation of cold and hot welding with error emergence[7]. An experiment executed by Valentin L. Popov demonstrates how a roughened surface affects its friction coefficient. In mechanical descriptions, the friction is often related to a roughened surface,and "even" often means frictionless. But if you consider the tribological contact of two surfaces, it shows that an especially even surface can have a higher friction coefficient than a rougher one. That means, the frictional force is not directly related to the roughness of a surface. An experiment with the transmission of radioactive elements between to contact partners provides the evidence for this. In this experiment, a radioactive copper block has been pulled over a copper plate with two different types off roughness[8].

So far, there haven't been any systematic experiments in which the weld quality of the friction stir welding was considered and evaluated dependant on the tool surface. Therefore, the question is if the welding result is related to the surface condition of the used tools, and how future tools need to be constructed with regard to their surface. The examinations shall demonstrate which influence a different roughness of the tools has on the welding result; they shall also show to which extent an improvement of the weld can be reached by inserting defined surfaces.

2. Materials

The experiments were done on aluminium EN-AW 6082 T6 (AlMgSi1) (see Table 1) with the dimensions 165×35×1.5 mm. They have been jointly welded in butt-joint on a length of 100 mm.

It has a shoulder diameter of 10 mm. The pin protrudes 1.2 mm from the shoulder surface and has a medium diameter of 3 mm at the tip. The conical form with an angle of 20° makes it easy to plunge into the workpieces that are to be joined.

Table 1 Chemical composition of EN-AW 6082[9]

Content of alloy in percentage of weight			
Si	0.7-1.3	Mg	0.6-1.2
Fe	0.5	Cr	0.25
Cu	0.1	Zn	0.2
Mn	0.4-1	Others	0.15
Ti	0.1	Al	Rest

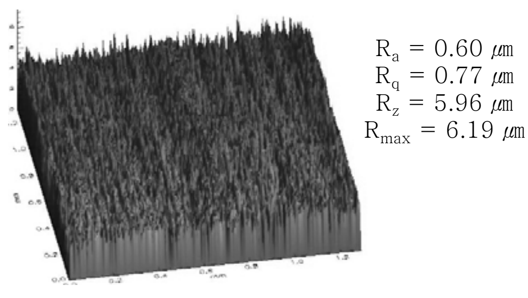


Fig. 2 3D image of the optical topography measurement of a used aluminium sheet

Table 2 Chemical composition of 115CrV3[10]

Content of alloy in percentage of weight					
C	1,2	Cr	0,7	V	0,1

3. Method

The roughness is produced by the die sinking on the tool surface. The die sinking proves to be reasonable for this purpose as the geometry of the tool can be completely recorded and the process is controllable and reproducible.

At first, a negative of the tool geometry is constructed and produced from copper for the roughening, see Fig. 3 on the right side. When eroding, the electrode is moved to the tool and a tension is generated, so that the roughness set in advance is produced due to the spark discharge.

Each of the tools has been produced with the roughness of the Verein Deutscher Ingenieure (VDI) classes VDI 18, VDI 24, VDI 30, VDI 39 und VDI 45 (Table 3). Thus, the differences can be judged step by step. An untreated tool after the turning process is used as a reference (Fig. 4) with a roughness of Ra = 0.57 μm. The comparison of the VDI classes demonstrates that it corresponds to an eroding process of the VDI 15 (Table 3). How-ever, the VDI 18 surface is distinctly defined and, for instance, it does not show first or second order discrepancies which can be the case with the turned surface.

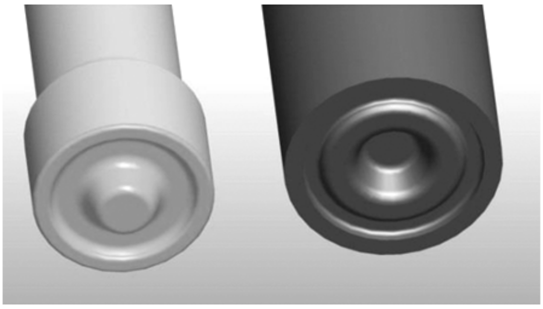
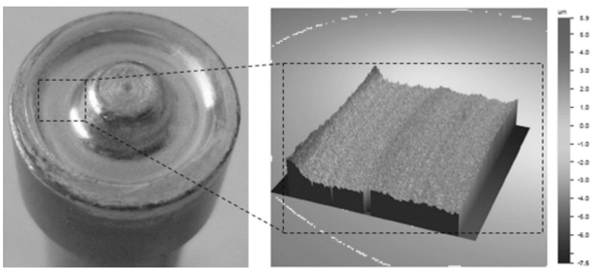


Fig. 3 FSW tool and EDM tool



R_a = 0.57 μm R_q = 0.81 μm
R_z = 8.04 μm R_t = 13.43 μm

Fig. 4 Result of the roughness measurement of the untreated tool

Table 3 Comparative table of chosen data (marked in grey)

Surface roughness	VDI class			Ra in μm		
very fine	12	15	18	0.4	0.56	0.8
fine	21	24		1.12	1.60	
middle	27	30	33	2.24	3.15	4.5
rough	36	39		6.30	9.00	
very rough	42	45		12.5	18.0	

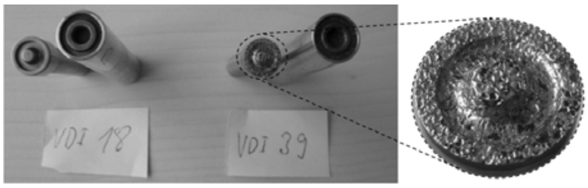


Fig. 5 Tools and electrodes after spark discharge

The results of the roughening process can already be seen optically when looking at the tools (Fig. 5).

As basis of comparison the constant parameters were rotation speed n = 1250 rpm, feed rate f = 250 mm/min, tilt angle α = 1° and a heel plunge depth hdp = 0.15 mm in position controlled mode.

4. Result

Generally, it can be noted that a rougher tool generates a rougher weld surface. Fig. 6 shows details of the welds VDI 24 and VDI 39, each at the start, in the middle and at the end, with the produced negative.

The VDI 24 shows a consistent imbrication of the weld, while samples of the VDI 39 show a very uneven surface, similar to a surface galling defect. Different to the surface galling defect, which results from a hot weld, the high roughness of the tools causes a reduced contact surface; consequently, it causes a lower frictional heat input. For this reason, the weld pitch outside the process window is moved toward the cold welds; the insufficient plasticisation causes the shearing of the joining material on the surface of the weld and of the tool, and it results in deposits/sediments of aluminium particles on the tool surface.

The weld surface, which was optically the most even, was produced with tools of the roughness VDI 18, which is the finest surface. No difference could be found between these VDI 18 welds and those welds which were produced with untreated tools. The imbrications on the weld surface continually increased from the even to the rough samples, due to the different roughness, see Fig. 7.

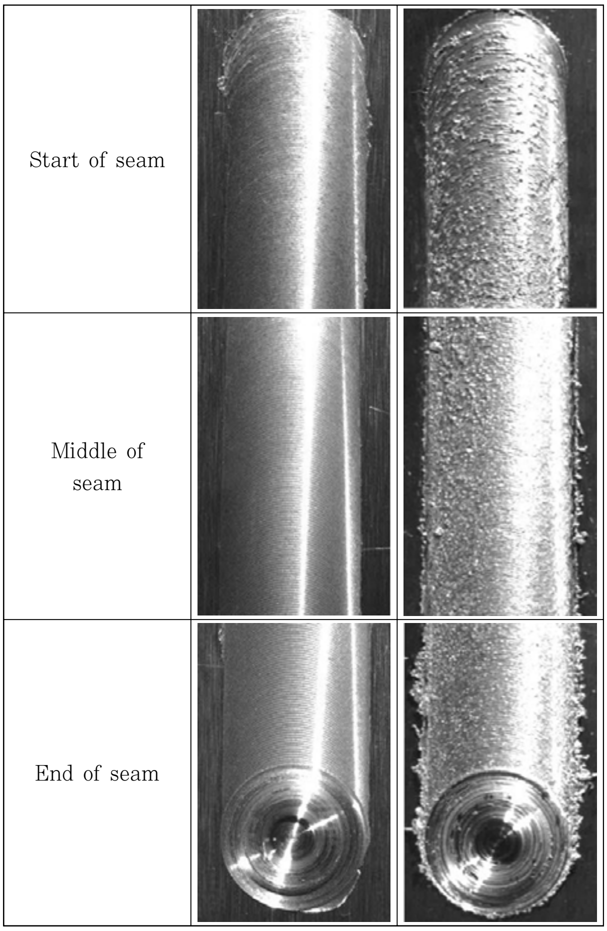


Fig. 6 Welds with VDI 24 (Left) and VDI 39 (Right)

The irregularities on the weld surfaces caused by rougher tool structures are also reflected in the tensile strength. The resulting defects, which are similar to the surface galling defects, considerable reduce the quality of welding (Fig. 8, Fig. 9). The fracture position of the samples shifts to the weld centre/middle and the maximum elongations are reduced. Each of the samples welded with the VDI 45 tool broke at the weld centre/middle (Fig. 10). The high discrepancy between minima and maxima is remarkable in the tensile tests of the VDI 45.

Additionally to the turbulent streams of the

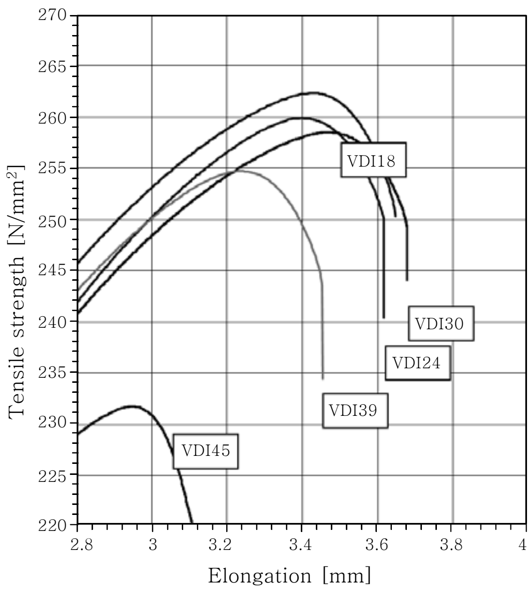


Fig. 8 Stress-strain diagram on welds with different roughness classes

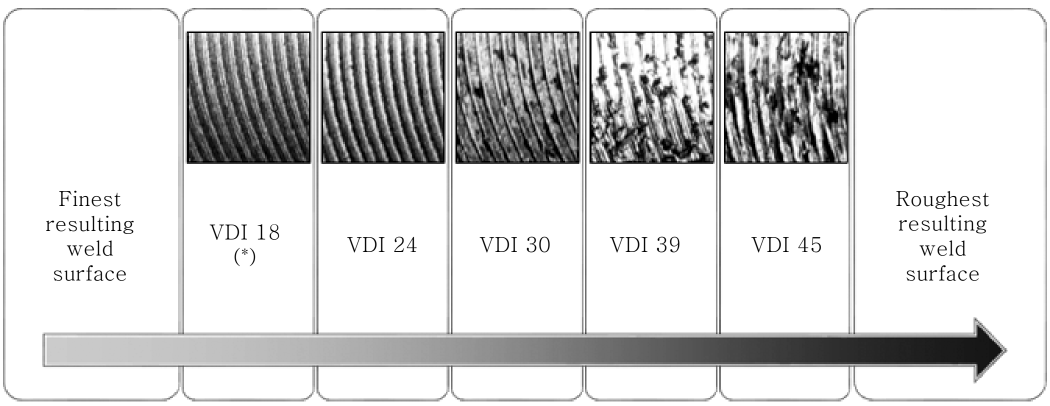


Fig. 7 Imbrication of the weld due to different tool roughness

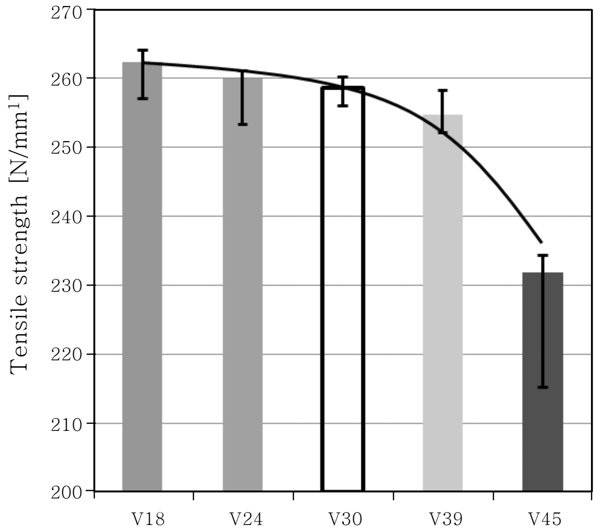


Fig. 9 Tensile strength of the tensile tests with minima and maxima on welds with different roughness classes

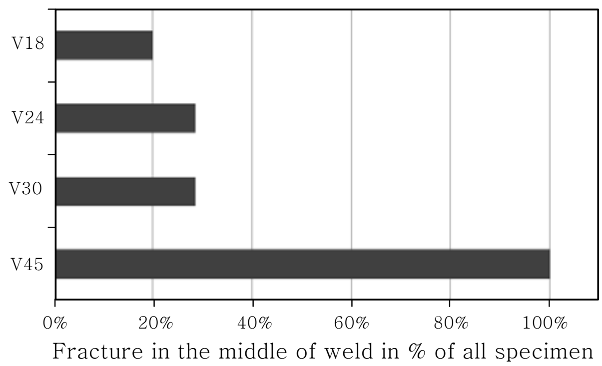


Fig. 10 Examination of the fracture positions of different roughness classes

material, the reason for this is the arising internal errors like wormholes. A worm hole is a cold weld effect which is generated due to insufficient friction. The lower process temperatures on the tool shoulder and pin, as well as on the weld could be confirmed

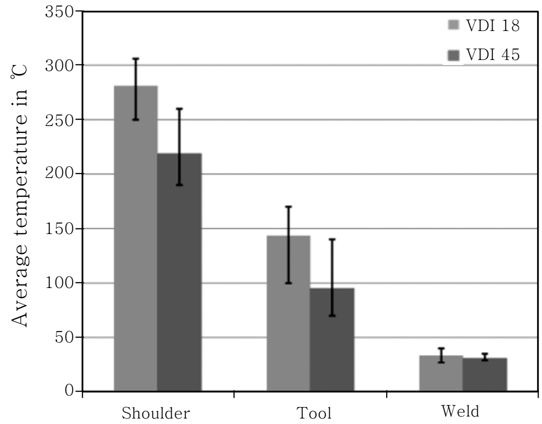


Fig. 11 Overview of process temperature with VDI 18 and VDI 45 tool

by comparative measurements with a pyrometer. (Fig. 11)

Furthermore, due to the use of rougher tools, it can be observed that the area of the thermal affected zone (TAZ) tends to decrease and the area of the thermomechanicalaffected zone (TMAZ) broadens which particularly can be seen toward the surface (Fig. 12)

With progressing welding distance, the tools have been subjected to another roughness examination in order to evaluate the clogging behaviour of the tools with regard to the arithmetic mean and to evaluate to which extent the welding influences the initially set roughness. After a welding length of 600 mm (six tests) the tools were measured, another measurement after further 600 mm did not show significant differences. (Table 4).

Contrary to the assumption, the surface roughness does not diminish during the welding but becomes higher. Due to the relatively small

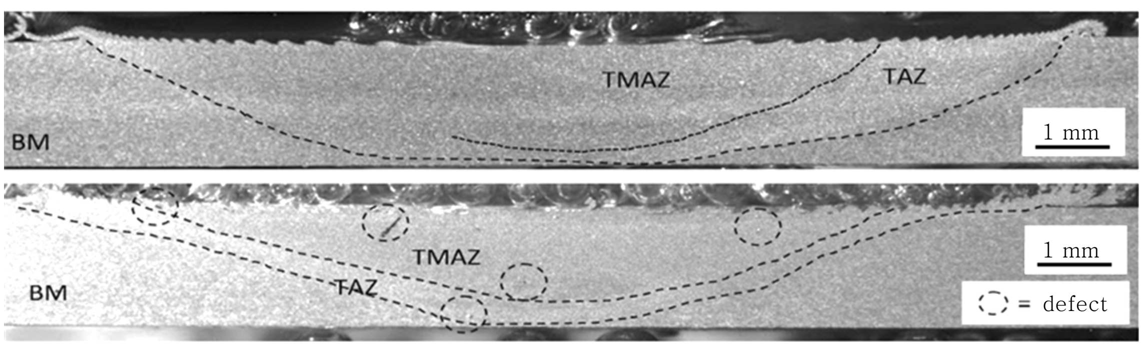


Fig. 12 Cross-section polishes of samples VDI 18 (on top) and VDI 45 (at the bottom) with worm holes (revolved)

Table 4 Comparison of roughness before and after the welding

tool class	Tool roughness Initial state	Tool roughness Used for 600 mm weld seam
	(R_a)	(R_a)
VDI 18	0.80	1.69
VDI 24	1.60	4.84
VDI 30	3.15	8.50
VDI 39	9.00	21.38
VDI 45	18.00	23.08

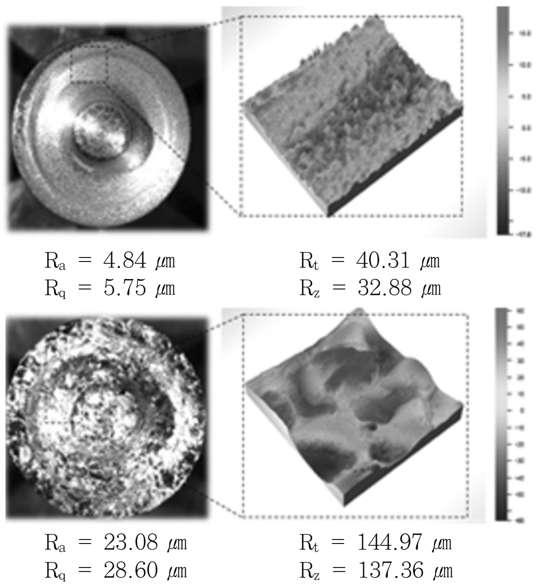


Fig. 13 White-light interferometer measurement tool VDI 24 (on top) and VDI 45(at the bottom) after a welding legth of 600 mm

measurement range (1×1 mm) of the white-light interferometer, an especially high altitude difference was measured on the surface profile which may be caused by the differently marked clogging behaviour of the tool surface. The measurement images in Fig. 13 exemplify a measurement of the loaded tools with the roughness VDI 24 and VDI 45.

5. Conclusion

This study dealt with the influence of different tool roughness on the welding process. By means of systematic examinations, it could be determined that the friction combination of the surface profiles of tool and joint partner has a significant influence on the temperature and, consequently, on the weld quality. In order to improve the results of the friction stir welding, the use of surface optimised tools is recommended to maximise the friction surface. Through this, the best result from the tool surface to the temperature generating active area is achieved. Turned tools already have a very good surface structure after their production. This structure can be improved by means of a finishing-treatment (for instance, eroding with VDI 12).

The most important findings of this study are:

1) The surface condition of the joint partners has an influence on the welding result; the finer/more even the surface the finer/more even the resulting weld surface

2) The active friction surface, altered by a modification of the tool surface, changes the inserted temperature; the rougher the surface the lesser the friction and the lesser the inserted temperature

3) A rougher tool surface consequently leads to an increased shearing of material particles which settle on the weld surface

4) The decreased temperature insertion in case of rough tools leads to an increased formation of defects in the surface interior and, consequently, to diminished mechanical qualities

5) Improvement of the surface structure of friction stir welding tools is recommendable (eroding, polishing, or the like)

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