Krohn, H.; Hanke, S.; Beyer, M.; dos Santos, J.F.:

Influence of external cooling configuration on friction surfacing of AA6082 T6 over AA2024 T351

In: Manufacturing Letters (2015) Elsevier

DOI: 10.1016/j.mfglet.2015.04.004

Influence of external cooling configuration on friction surfacing of AA6082 T6 over AA2024 T351

H. Krohn [a], S. Hanke [a], M. Beyer[b], J.F. dos Santos [a]

[a] Helmholtz-Zentrum Geesthacht GmbH
Institute of Materials Research
Materials Mechanics
Solid State Joining Processes (WMP)

[a] Ilsenburger Grobblech GmbH
Erzeugnisentwicklung / Technologie

Abstract

Friction surfacing is a solid-state surface engineering technology. Previous studies have shown that underwater friction surfacing has some advantages in efficiency and homogeneity of the deposited material. To use these advantagesa water spray cooling system was implemented to achieve a more flexible process. This concept has been investigated by depositing Al alloy AA6082 T6 on AA2024 T351 substrate. The efficiency of the process was increased from 19% to 31% without influencing the properties of the deposited material. Temperature measurements revealed that the intensity and chosen location of cooling also affect the process characteristics and allow modifying the coating geometry.

1. Introduction

Friction surfacing is a solid-phase process whereby a metallic layer is deposited on a substrate material. To deposit the layer, a rotating consumable rod made of the coating material is brought in contact with the substrate under an axial force whereby friction and shear stresses lead to plastification of the material at the rod tip. Combined with a movement of the rod relative to the substrate, a layer is deposited onto the substrate. Further information can be found in a recently published review [1].

Friction surfacing was first described and patented in 1941 by Klopstock and Neelands [2]. After that for a long period of time only a few activities regarding the process have been published [3], until recently renewed interest in the process arose [4-9]. Underwater friction surfacing of stainless steel on low carbon steel has been shown to increase the deposition efficiency and to produce more homogeneous coatings [10]. The objective of this study is to investigate if this behaviour also occurs during the friction surfacing of aluminium and to use a spray cooling system instead of a water bath, since water spray is easier to adopt in an industrial environment.

2. Materials and methods

A hydraulic stud welding machine combined with an electric driven linear axle was deployed for the present study. An axial force of 5 kN, rotational speed of 2500 min^{-1} and a traverse speed of 2 m/min have been applied. To gain information about the effect of the external cooling, the process parameters were kept constant, and only the cooling conditions were varied.

Aluminium AA6082 T6 rods with a diameter of 20 mm were used to produce the layers. Plates of AA2024 T351 measuring 300 mm x 100 mm x 10 mm serve as substrate.

Temperature measurements were performed with 20 type K thermocouples aligned perpendicularly to the welding direction in a special holder (see Figure 1a). The holder is introduced into a cut-out on the bottom of the substrate, the remaining thickness of the substrate at this position is 2 mm. During the process a close contact between the substrate and the thermocouples was provided though the axial process force. The temperature values were recorded with a frequency of 80 Hz.

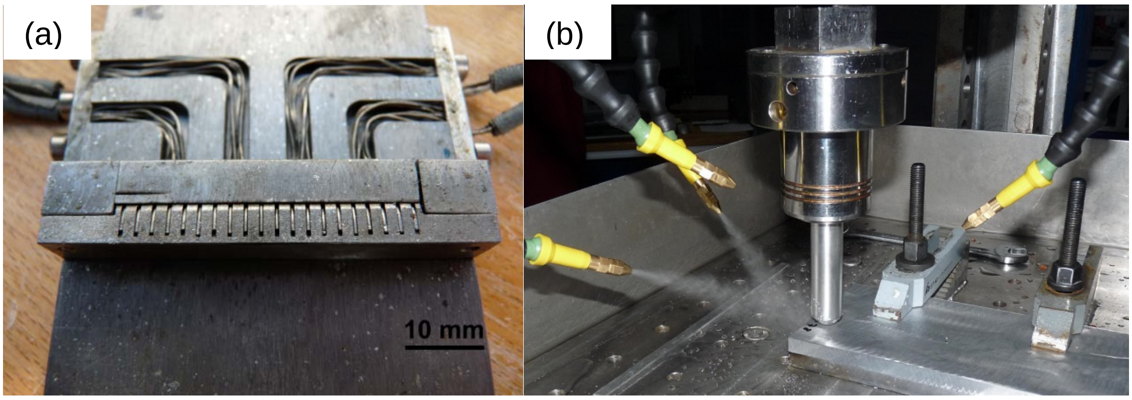

Figure 1: (a) Holder equipped with 20 thermocouples, (b) Arrangement of the nozzles

Cooling has been achieved by using a commercially available minimum quantity lubrication system. The cooling fluid applied was distilled water. Two nozzles are aligned to cool the layer behind the rod, and three to cool the flash (Figure 1b). The air pressure was kept constant at 3.8 bars. Experiments were carried out in three configurations: cooling the flash, the layer and both flash and layer concurrently. The water flow through the nozzles was varied in 6 steps (0, 0.2, 1.3, 18.3, 28.3, 31.3 ml/min per nozzle).

To investigate the properties of the deposited material, tensile tests were carried out. Six micro flat specimens were prepared out of each deposited layer. The micro flat tensile samples have a tested material volume of 2mm x 0.5mm x 13mm (see Figure 4).

3. Results and Discussion

The introduction of external cooling into the friction surfacing process has a significant effect on the efficiency of the process. The deposition efficiency *E* is the ratio of the deposited material volume to the consumed volume of the rod. For the deposited volume, the traverse speed and the cross-section area of the layer were multiplied. The cross-section was calculated from the width *W* and height *H* of the layer. Only the bonded width (see Figure 2a) was considered. For the height, the average from three measurements was used. The consumed rod volume was determined by multiplying the shortening rate of the rod (speed of the Z-axis) by the cross-section area of the rod (equation in Figure 2b).

For all cooling configurations, the efficiency increases (Figure 2b). Cooling of the flash shows an effect of the amount of sprayed water on the achieved process efficiency, while for cooling of only the layer the increase in efficiency is less pronounced and seems not to be affected by the amount of sprayed water. Possibly, the efficiency increase in the latter case may be attributed to a slight cooling effect on the flash occurring also in this configuration.

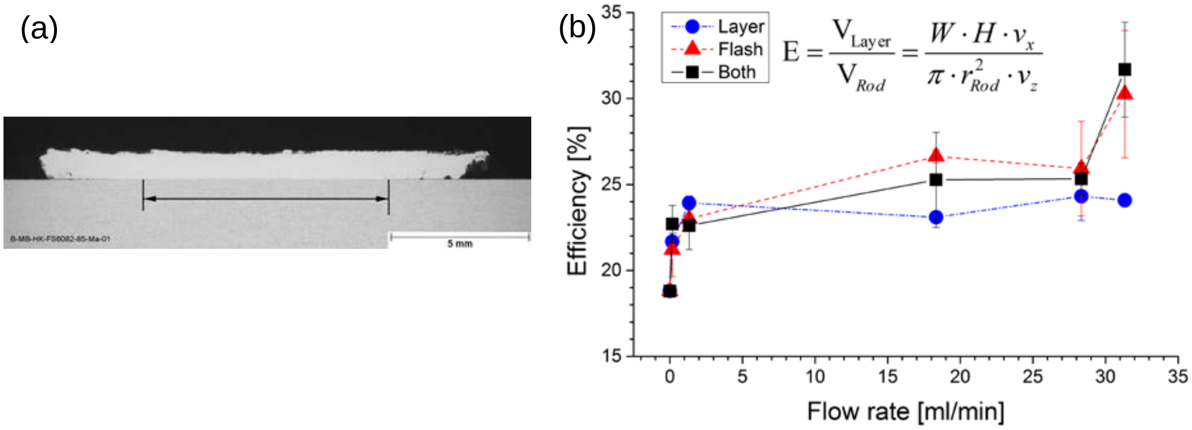

Figure 2: (a) Bonded width of the layer, (b) Efficiency of the process with external cooling

As a result of cooling the flash temperature is obviously reduced. This can be assumed to lead to an increase in the strength of the material, which changes the pressure field between the rod and the layer and results in a smaller flash. Additionally, a change in the bonded width of the layer is observed when cooling the flash, increasing from 9 mm to 12 mm. The temperature measurements are consistent with this finding. The region subjected to the highest temperatures during the deposition increases in width with increasing cooling intensity on the flash (Figure 3a). For each layer the time frame with the highest measured peak temperature is presented, the two vertical lines represent the total width of the deposited layer.

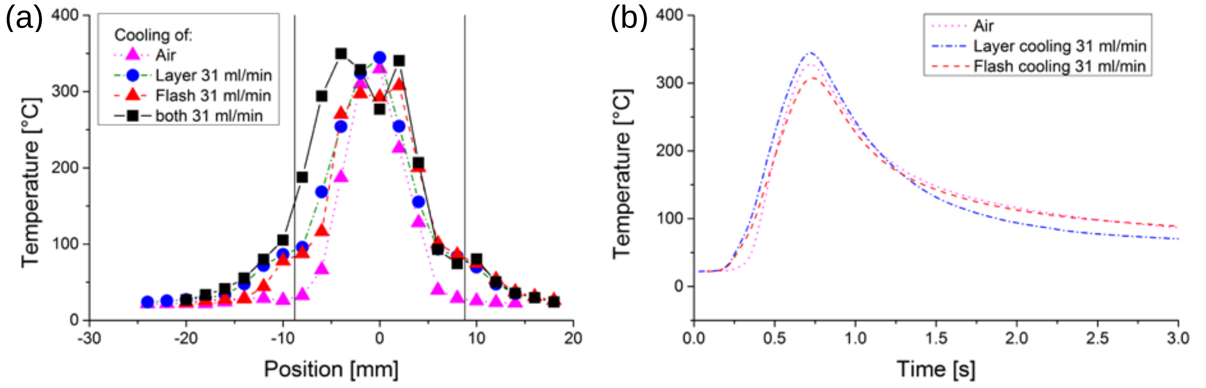

Figure 3: (a) Process peak temperature across the layer, (b) Temperature below the layer centre for different cooling intensities

The temperature measured in the process without any cooling shows a clear peak in the middle of the layer. A higher intensity of cooling of the flash results in a wider region at peak temperatures. In addition, there is a drop of temperature in the middle of the layer for experiments with high cooling intensity of the flash. This indicates a shift of the pressure at the interface towards the outer regions of the rod (i.e. the flash), due to the strengthening of the material as a result of cooling. A higher pressure in the outer regions of the rod, combined with the high circumferential speed, leads to an increased heat generation and this to a higher measured temperature at this location. The wider peak temperature region also indicates that cooling the flash results in a higher overall amount of heat generated in the process. The depositions with cooling of the layer did not show this phenomenon. For a better understanding, torque measurements during the experiment will be carried out in the future, since from the measured torque and the rotational speed the energy input into the process can be estimated.

The measured temperatures also show a slight increase in cooling rate with increasing cooling intensity (see Figure 3b). The highest cooling rate of approximately 260 K/s was measured for the highest intensity of layer cooling. Without external cooling it is in the range of 240 K/s. Hence an effect of cooling is recognisable, but small. For a deeper investigation of the cooling rate, temperature measurements closer to the process zone need to be performed.

The results of the tensile tests did not show a clear tendency for the influence of the cooling on the properties of the deposited material.

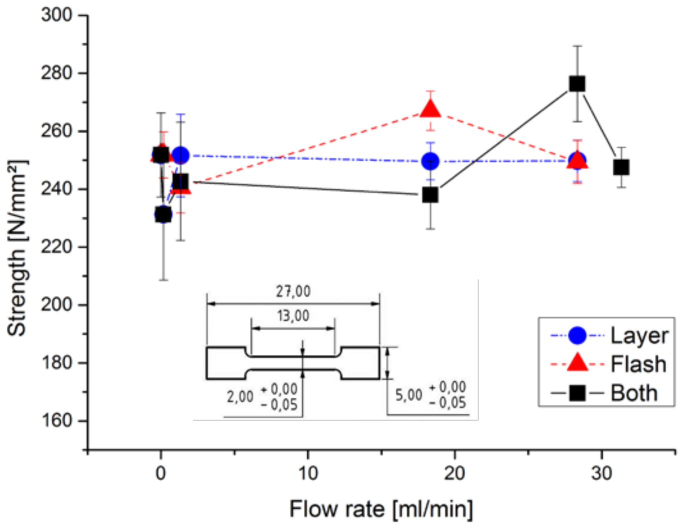

Figure 4: Ultimate tensile strength of the deposited material with different cooling conditions

The mean values for all cooling conditions lie between 231 MPa and 276 MPa (see Figure 4). The change of the strength with different cooling conditions is +/- 20 MPa from the mean value of 250 MPa, which is comparable to +/-8%. The scatter in the tensile tests of the six specimens of one layer lies between 2% and 10%. So, the change of strength is in the range of the test scatter and no clear conclusion can be drawn. Still, the results imply that there may be an effect of the cooling, as seen by the rather constant average strength of the layer cooling, compared to the variations for the flash cooling. Microstructural investigations are needed to clarify these observations.

Microhardness measurements have been performed on a polished cross section of each, 0.2 mm and 0.6 mm above the substrate. The lower regions showed values of 80-86 HV0.2 and the upper ones of 82-89 HV0.2. No correlation to the cooling methods was identified.

4. Conclusions

The deposition efficiency of bonded material was increased from 19% to 31% by applying external cooling on the flash, while cooling of the layer directly behind the rod had no clear effect on the efficiency. This is attributed to the following mechanisms:

1. A cooled flash has a higher mechanical strength.
2. This leads to an increase in the load carrying diameter of the rod tip.
3. As a result, a higher circumferential speed takes effect on generating more heat.

These factors lead both to an increase in the bonded width, as well as a decrease of the flash volume.

The mechanical properties of the coatings are not greatly affected, since they are mainly determined by the cooling rate, which does not change significantly with the applied cooling measures.

Applying a well-defined cooling method therefore may be used not only to increase the coating efficiency, but as a specific process parameter to control overall heat input, temperature distribution and bonding width.

5. References

1. Gandra J, Krohn H, Miranda RM, Vilaça P, Quintino L, dos Santos JF. Friction surfacing - a review. J of Mater Process Technol 2014;214/5:1062-1093.

2. Klopstock H, Neelands AR. An improved method of joining or welding metals. British Patent specification 572789; 1941.

3. Thomas WM. An introduction to friction surfacing. In: First International Conference on Surface Engineering. Brighton;1985:25-28.

4. Chandrasekaran M, Batchelor AW, Sukumar J. Friction surfacing of metal coatings on steel and aluminum substrate. J of Mater Process Technol 1997;72/3:446-452.

5. Vitanov VI, Voutchkov II, Bedford GM. Decision support system to optimise the Frictec (friction surfacing) process. J of Mater Process Technol 2000;107/1-3:236-242.

6. Yamashita Y, Fujita K. Newly developed repairs on welded area of LWR stainless steel by friction surfacing. J of Nucl Sci and Technol 2001;38/10:896-900.

7. Rafi HK, Ram GD, Phanikumar G, Rao KP. Friction surfaced tool steel (H13) coatings on low carbon steel: A study on the effects of process parameters on coating characteristics and integrity. Surf and Coat Technol 2010;205/1:232-242.

8. Vitanov VI, Javaid N, Stephenson DJ. Application of response surface methodology for the optimisation of micro friction surfacing process. Surf and Coat Technol 2010;204/21-22:3501-3508.

9. Shinoda T. Deposition of hard coating layer by friction surfacing. Q J of Jpn Weld Soc 1995;13:432-437.

10. Li JQ, Shinoda T. Underwater friction surfacing. Surf Eng 2000;16/1:31-35.