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AA413.0 AND AA1050 JOINED WITH FRICTION-STIR WELDING

SPAJANJE ZLITINE AA413.0 IN AA1050 Z GNETENJEM

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Friction-stir-welding (FSW) technology has been growing since it was patented in 1991 at TWI. Since then the majority of research and industrial applications for joining aluminium alloys were made on wrought aluminium alloys. Lately several investigations have been done in FSW of dissimilar alloys. FSW also has a big potential in the casting industry – especially in high-pressure die casting (HPDC). In this article an investigation of a FSW dissimilar joint made from a casting aluminium alloy (AA413.0) and technically pure aluminium (AA1050) was done. This kind of joint can be used to make an assembled casting, joined with FSW with the aim to have a casting with different material properties or to join HPDC with FSW to assemble a casting with inner cavities.

In this article the temperature distribution of the FSW joint of a cast aluminum alloy and technically pure aluminum is investigated. In the experimental work several FSW parameters were tested: the tool speed, the tool rotation and the position of the tool regarding the joint center. During joining the temperature was measured with a thermocouple and the temperature distribution in steady state was calculated with the FEM program Sysweld. The microstructure and mechanical properties of the joint were investigated.

Keywords: friction-stir welding, AA413.0, AA1050, finite-element method

Spajanje z gnetenjem je tehnologija, ki se intenzivno razvija od patentiranja leta 1991 na Britanskem inštitutu za varjenje. V industrijski praksi je najbolj razširjena uporaba FSW-tehnologije za spajanje gnetnih aluminijevih zlitin. V zadnjem času se raziskave osredinjajo tudi na spajanje dveh različnih zlitin. Spajanje z gnetenjem ima velik potencial tudi v livarski industriji, še posebej pri tlačnem litju. Ta članek opisuje izvedeno eksperimentalno spajanje dveh različnih zlitin. Spojeni sta bili gnetna zlitina AA1050 in livarska zlitina AA413.0. Taki spoji imajo svojo uporabno vrednost pri sestavljenih ulitkih, kjer lahko s spajanjem različnih zlitin z različnimi fizikalnimi lastnostmi dosežemo nehomogene lastnosti sklopa, kjer je to potrebno. S spajanjem tlačnih ulitih delov lahko izdelamo sklope z notranjimi votlimi deli. Lastnosti tako izdelanih sklopov so primerljive z lastnostmi tlačnih ulitkov.

V članku so navedene temperature, izmerjene med spajanjem dveh različnih zlitin. Za določitev optimalnih parametrov spajanja je bilo le-to izvedeno pri različnih vrtljajih orodja in pri različnih hitrostih spajanja. Spoji so bili mehansko analizirani. Stacionarno temperaturno polje med spajanjem dveh različnih zlitin je bilo izračunano s programom Sysweld z metodo končnih elementov.

Ključne besede: spajanje z gnetenjem, AA413.0, AA1050, metoda končnih elementov

1 INTODUCTION

Aluminum die casting alloys are made with a rapid injection of a molten metal into metal molds under high pressure. Such an alloy has a dense and fine grain surface, resulting in excellent wear and fatigue properties. Approximately 85 % of aluminum die casting alloys are based on Al-Si-Cu. These alloys provide a good combination of the cost, strength, and corrosion resistance, together with high fluidities that are required for easy casting. In recent years, aluminum die casting alloys have been widely used in the automotive, electronics, machine and building industries because they are light and recyclable. However, these castings have their limitations arising from the casting-process limitations. This problem can be solved by joining several cast parts into one complex product. The welding of aluminum and its alloys has always represented a great challenge for designers and technologists. Fusion welding of aluminum die casting alloys is difficult due to the formation of welding defects, such as blowholes, and the welding deformation as a result of a high coefficient of thermal expansion of aluminum alloys. As welding defects result in decreased mechanical properties, this problem must be solved for the use in practical applications.[1,2]

From this point of view, friction-stir welding (FSW) was developed as a new joining process by The Welding Institute (TWI) in 1991.[3] The basic concept of FSW is remarkably simple. A non-consumable rotating tool with a specially designed pin and shoulder is inserted into the matching edges of the sheets or plates to be joined and traversed along the line of the joint (**Figure 1**). The tool serves two primary functions, the heating of a workpiece, and the movement of a material to produce the joint. The heating is accomplished by the friction between the tool and the workpiece, creating a plastic deformation of the workpiece. The localized heating softens the material around the pin and a combination of the tool rotation and translation leads to a movement of the material from the

Table 1: Chemical composition of AA1050 and AA413.0 in mass fractions, *w*/%[9]
Tabela 1: Kemijska sestava zlitine AA1050 in AA413.0 v masnih deležih, *w*/%[9]

	Al	Si	Fe	Cu	Mn	Mg	Zn	V
AA1050	99.5	max 0.25	max 0.4	max 0.05	max 0.05	max 0.05	max 0.05	max 0.05
AA413.0	rest	11–13	1.3	1.0	0.35	0.1	0.5	

Table 2: AA1050 and AA413.0 properties[9]
Tabela 2: Fizikalne lastnosti zlitine AA1050 in AA413.0[9]

	Liquidus temp.	Density	Tensile strength	Yield strength	Specific heat	Thermal conductivity	Electrical resistivity
	°C	g/cm^3	MPa	MPa	J/(kg K)	W/(m K)	nΩ m
AA1050	657	2.705	76	28	900	234	27.9
AA413.0	575–585	2.657	290	130	963	121	55.6

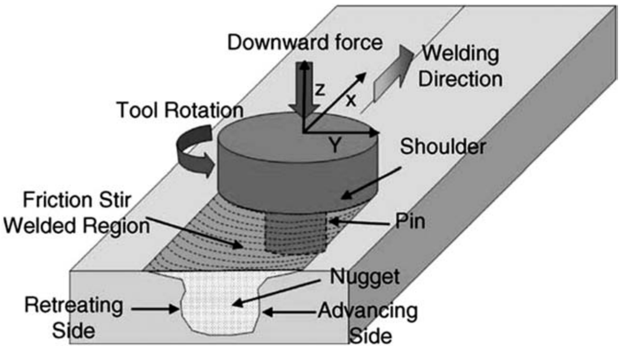

Figure 1: Schematic drawing of friction-stir welding[4]
Slika 1: Shematski prikaz spajanja z gnetenjem[4]

front of the pin to the back of the pin. As a result of this process a joint is produced in solid state. Because of the various geometrical features of the tool, the material movement around the pin can be quite complex. During a FSW process, the material undergoes an intense plastic deformation at an elevated temperature, resulting in a generation of fine and equiaxed recrystallized grains. The fine microstructure of the friction-stir welds produces good mechanical properties.[4,5]

FSW is effective in joining a number of different materials. Until now it has been aluminum alloys that FSW has been most successfully applied to. The reason for this is a combination of the process simplicity and a wide use of aluminum alloys in the mayor industries. FSW can be used for joining aluminum alloys that are difficult to fusion weld. FSW dominates in the fabrication of aluminum components and panels. Now even friction-stir spot welding (FSSW) is being intensively studied.[6,7]

Only a limited number of FSW-joint studies have been done on cast aluminum alloys, although they have been intensively studied.[4,8]

2 EXPERIMENTAL WORK

In this work an investigation of the temperature field of a FSW joint made from two different aluminum alloys has been done. The first alloy is a common cast alloy AA413.0 (AlSi12Cu), the other is made from pure aluminum AA1050 (Al 99.5 %). Such a joint is very interesting because it is made of alloys with different properties. The chemical compositions of AA1050 and AA413.0 are presented in **Tables 1**[9] and **2**[9].

In the experimental work two plates were joined. The joint was made on a milling machine Prvomajska ALG 2008. For this experiment the optimal feeding speed was 235 mm/min and the rotational speed of the tool was 475 min^{-1}. The tool was inclined at an angle of 3° as presented in **Figure 2**. The tool presented in **Figure 3** was made of hot-work tool steel H13. The dimensions of the used tool can be seen in **Figure 4**. The AA1050 alloy was on the retreating side and the AA413.0 alloy was on the advancing side. These parameters were selected on the basis of several tests involving the selected tool, plate thickness and milling-machine gear ratio.

The dimensions of the plates were 380 mm × 60 mm × 6 mm. To each plate a K-type thermocouple was mounted. Thermocouples were connected with the National Instrument CompactDAQ NI 9213 analog digital converter which was connected to the Labview software. The sampling rate was 10 Hz.

During FSW the model temperature distribution was numerically calculated with the Sysweld finite-element modeling software. The FSW module in Sysweld

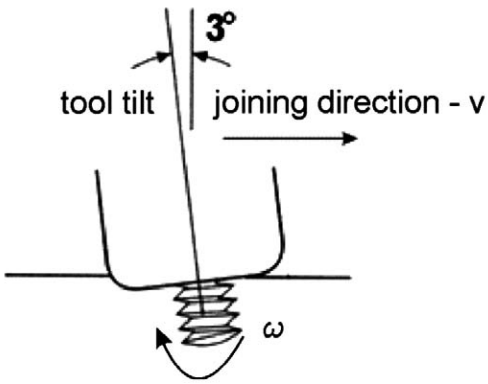

Figure 2: Tool tilt
Slika 2: Nagib orodja

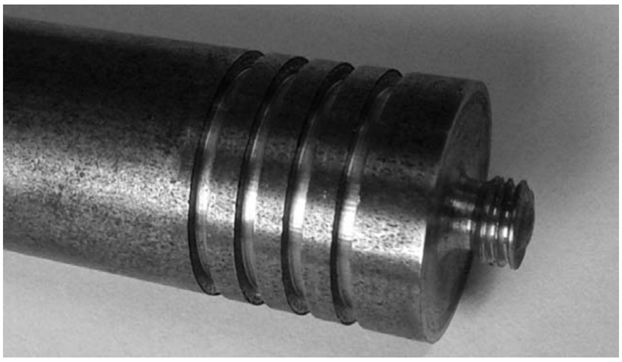

Figure 3: Tool used in the experiment
Slika 3: Orodje, uporabljeno za eksperiment

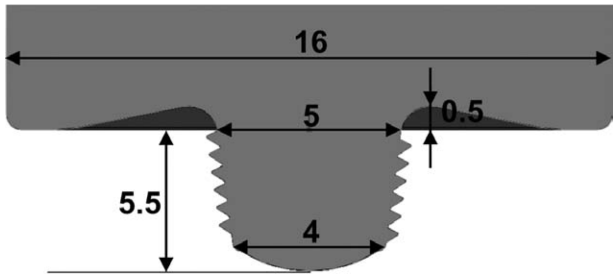

Figure 4: Tool dimensions
Slika 4: Dimenzije orodja

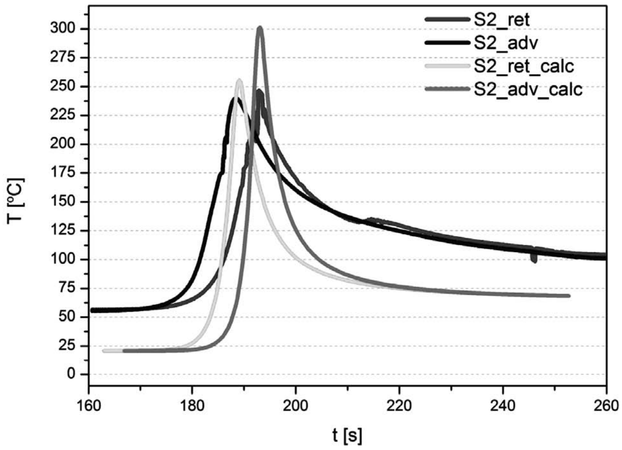

Figure 6: Measured and calculated temperatures in the joint
Slika 6: Izmerjene in izračunane temperature v spoju

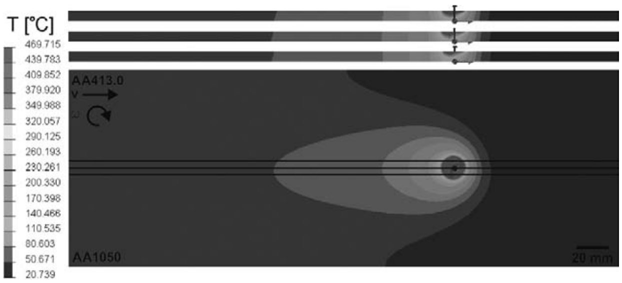

Figure 7: Temperature distribution calculated with the FSW module
Slika 7: Razporeditev temperature, izračunane s FSW-modulom

enables a calculation of the steady-state temperature field based on the custom FSW joining parameters for joining the parts of the same alloy[10]. For this experiment the model was upgraded so that the temperature field was calculated on the basis of joining two different alloys. The investigated model had 19277 nodes and the CPU time was two hours.

3 RESULTS AND DISCUSSION

The joint plate is shown in **Figure 5**. Some of the material was extruded during the joining because the plates were not in perfect alignment. The alignment of the plates had a big influence on the joint quality during the testing of the FSW joining parameters; in addition, the slot on the contact surface between the plates must be minimum.

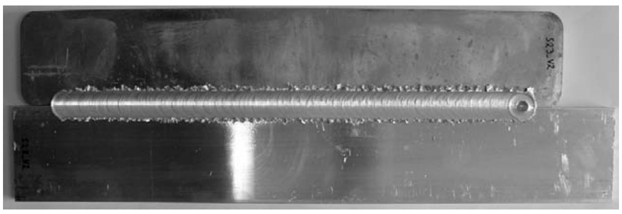

Figure 5: Plates joint with FSW (upper plate of AA413.0 alloy, lower plate of AA1050 alloy)
Slika 5: Plošči, spojeni s FSW-spojem (zgoraj zlitina AA413.0, spodaj zlitina AA1050)

The temperatures measured with the thermocouples and numerically calculated are presented in **Figure 6**. The maximum temperature measured on the advancing side was 250 °C and on the retreading side of the joint it was 240 °C. Similar temperatures at the thermocouple places were calculated with the FEM software. The maximum calculated temperature in the joint was 470 °C. This temperature and calculated stationary temperature field are presented in **Figure 7**. In the upper part of

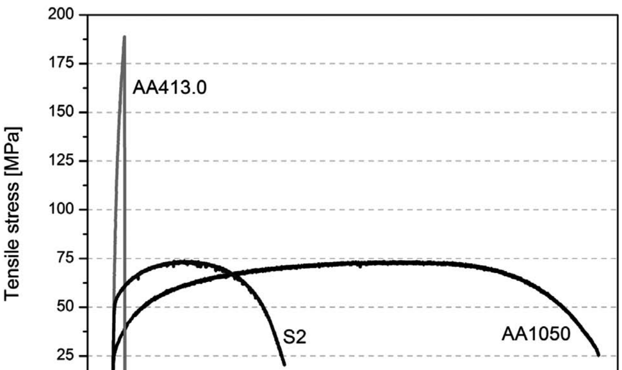

Figure 8: Tensile tests of the alloys and the FSW joint
Slika 8: Natezni preizkusi zlitin in FSW-spoja

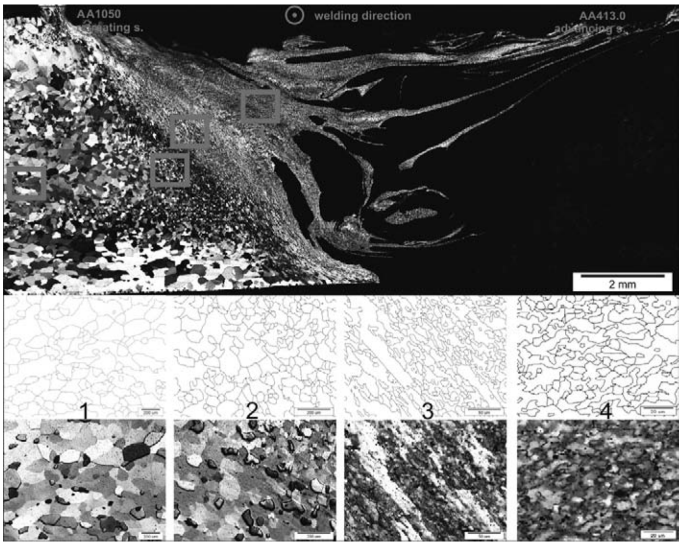

Figure 9: FSW cross-section in the polarolized light and grain size
Slika 9: Prerez FSW-spoja v polarizirani svetlobi in velikost zrn

Figure 7 the temperature field of the joint cross-section can be seen. These measurements show that FSW is a process joining different parts without melting the material. It can be seen that the heat input into the joint is very low. Due to a proper support and good clamping of the plates during FSW, no deformation was found after unclamping.

For a mechanical investigation of the joint, tensile tests were done. The results of the tensile tests of the joined alloys and the FSW joint can be seen in **Figure 8**. A contraction and defect of the joint appeared on the AA1050 alloy. The ultimate tensile stress of the joint was 74 MPa and it was the same as the ultimate tensile stress of the AA1050 alloy. Through the cross-section of the joint the Vickers hardness was measured. The hardness in the AA1050 alloy was 35 HV, 80 HV in the joint and 100 HV in the AA413.0 alloy. Good mechanical properties of the joint can also be seen from the microstructure investigation of the joint presented in **Figure 9**. According to standard ASTM E112 the mean intercept distance in the area marked with 1 was 92.37 μm, in area 2 the mean intercept distance was 44.86 μm, in area 3 the distance was 8.15 μm and in area 4 the distance was 5.56 μm. From the microstructure of the cross-section a good mixing of the used alloys can be seen. The stirring of the pin causes the grain size in the joint to be more than ten times smaller than the grain size in the base AA1050 alloy.

4 CONCLUSION

FSW has a big potential in joining a casting with other castings and/or extruded or rolled parts. In this article it was shown that the heat input for joining two different alloys with FSW is lower than for the joints made with other conventional welding processes. With the experiment we exactly determined the temperature in the stirring zone and calculated the established temperature field during the FSW process. A lower heat input leads to a small deformation of the workpiece and good mechanical properties of the joint.

The mechanical properties of the joint are better than those of the weaker alloy (AA1050) that was friction-stir welded. The good mechanical properties of the joint can be confirmed with the mean intercept distance between the grains in the joint. In these experiments the optimum FSW parameters for joining the AA413.0 and AA1050 alloys were used. Alloy AA413.0 must be on the advancing side, the tool rotational speed should be 475 min^{-1}, the joining speed should be 235 mm/min and the tool angle is 3°.

5 REFERENCES

[1] M. Ericsson, R. Sandstrom, International Journal of Fatigue, 25 (**2003**), 1379–1387

[2] Y. G. Kim, H. Fujii, T. Tsumura, T. Komazaki, K. Nakata, Materials Letters, 60 (**2006**), 3830–3837

[3] W. M. Thomas, Friction Stir Butt Welding International Patent Application, No. PCT/GB92 Patent Application No. 9125978.8, 1991

[4] R. S. Mishra, Z. Y. Ma, Materials Science and Engineering R, 50 (**2005**), 1–78

[5] S. R. Mishra, M. W. Mahoney, Friction Stir Welding and Processing, ASM International, 2007, 7–35

[6] S. Hirasawa, H. Badarinarayan, K. Okamoto, T. Tomimura, T. Kawanami, Journal of Materials Processing Technology, 210 (**2010**), 1455–1463

[7] M. K. Kulekci, U. Esme, O. Er, Mater. Tehnol., 45 (**2011**) 5, 395–399

[8] Y. G. Kim, H. Fujii, T. Tsumura, T. Komazaki, K. Nakata, Materials Letters, 60 (**2006**), 3830–3837

[9] ASM International: Volume 2, Properties and selection: Nonferous alloys and special-purpose materials, Metals Park, Ohio, 1990

[10] E. Feulvarch, Y. Gooroochurn, F. Boitout, 3D Modelling of Thermofluid Flow in Friction Stir Welding. In: Proceedings of the 7^{th} international conference on trends in welding research, Callaway Gardens resort, Pine Mountain, Georgia, USA, 2005