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Spajanje zlitin AA1170 in AA6060

Bonding of AA1170 and AA6060 alloys

Izvleček

Interakcija med dvema materialoma na osnovi aluminija za posebne namene, kot je delo pri povišanih temperaturah in tlakih, pospešuje spajanje v trdnem. Zaradi povišane temperature na fazni meji tam poteka difuzija. Tako imenovano »difuzijsko spajanje« poteka pri temperaturah, ki predstavljajo 50 - 70 % temperature tališča osnovnega materiala. Pred spajanjem je potrebno trdni površini ustrezno očistiti. Vse nečistoče na površini (okside, prah, vlago …) je potrebno odstraniti.

Preiskovali smo interakcije med dvema enakima (AA1170) in dvema različnima (AA1170 in AA6060) materialoma. Preizkuse smo naredili s termomehanskim simulatorjem metalurških stanj Gleeble 1500D pri različnih temperaturah (400 – 600 °C), z različnimi silami (40 – 80 kN) in različnimi konstrukcijami orodji. Stisnjene vzorce smo preiskovali makroskopsko. Mikrostrukture smo analizirali s svetlobno mikroskopijo, spoje pa z DSC-analizo. Najboljše rezultate spajanja smo dosegli pri stiskanju z orodjem z negativom rebra s silo 35 kN pri temperaturi 450 ºC. Za čiščenje smo uporabili čistilno sredstvo Nubadur 152 (S).

Ključne besede: aluminijeve zlitine, spajanje, povišane temperature

Abstract

The interaction of the two materials based on aluminium for special conditions, such as elevated temperature and pressure, speeds up the bonding in the solid. Due to the elevated temperature at the interface, the process of diffusion occurs. The so-called "diffusion bonding" is carried out at high temperatures, of about 50-70 % of the melting temperature of the base material. Before bonding the solid surface must be properly cleaned. All the impurities (oxides, dust, moisture ...), which are present on the surface of metals must be removed.

The interaction between two identical (AA1170) and two different (AA1170 and AA6060) materials has been investigated. Tests were carried out by thermomechanical simulator of metallurgical states Gleeble 1500D at different temperatures (400–600 °C), forces (40–80 kN) and various tool constructions. Compressed samples were examined macroscopically. Furthermore, the microstructure was analyzed by optical microscope and the bond was tested using DSC analysis. The microhardness of the bonds was analysed. The best results show the bond that was compressed with the construction of the tool with negative rib at temperature of 450 °C and force of 35 kN, which was cleaned with cleaning media Nubadur 152 (S).

Key words: Aluminium alloys, bonding, elevated temperature

1. Uvod

Difuzijsko spajanje materialov v trdnem stanju je postopek za izdelavo monolitnih spojev, pri katerih nastanejo vezi na atomski ravni kot rezultat spajanja dveh površin zaradi lokalne plastične deformacije pri povišanih temperaturah, kar pospešuje medsebojno difuzijo v površinskih plasteh materialov, ki so v stiku [1].

Spajanje v trdnem stanju je skupna oznaka za postopke spajanja brez veziva. Material se segreje, da nastane luknjičasta površina, spoj pa se doseže s stiskanjem. Površini prideta v stik na ravni atomskih razdalj, zato na vez vplivajo adhezijske sile. Ker se v mejni plasti poviša temperatura, se sproži difuzijski proces. Zaradi pritiska se vez deformira, kombinacija pritiska ter visoke temperature pa spodbudi proces rekristalizacije [2].

Difuzijsko spajanje navadno poteka pri visokih temperaturah, ki predstavljajo 50–70 % temperature tališča osnovnega materiala. Daljši časi, ki se uporabljajo pri klasičnih postopkih spajanja s pritiski, npr. pri spajanju z valjanjem ali kovanjem, olajšajo lezenje, kar prispeva k boljšemu spajanju in pomeni, da je potreben manjši pritisk za tesen stik med očiščenima površinama. Zato difuzijsko spajanje za razliko od večine postopkov spajanja v trdnem navadno ni povezano z veliki deformacijami [3]. Postopki difuzijskega spajanja se delijo na difuzijsko spajanje brez dodajanja materiala in na difuzijsko spajanje z dodajanjem materiala. V našem primeru je bilo uporabljeno difuzijsko spajanje brez dodajanja materiala.

Spajanje v trdnem stanju je postopek, pri katerem povišana temperatura in tlak omogočata nastanek vezi, ko razmere na stični površini omogočijo difuzijo. Pred spajanjem morata biti stični površini ustrezno očiščeni. Vse nečistoče, kot so

1. Introduction

Diffusion bonding of materials in the solid state is a process for making a monolithic joint with the formation of bonds at an atomic level as a result of joining the opposite surfaces due to local plastic deformation at elevated temperatures, which increases the interdiffusion at the surface layer of the materials, which are brought together [1].

Joining in solid state is a joint mark for proceedings in which there is no bonding material, but the material is heated only to the pitting state and the joint is achieved by pressing. Here the surface is brought to the atomic level distance (distance between the atoms), therefore the adhesion forces influence on the bond. Due to the increase in temperature at the boundary layer the process of diffusion occurs. Because the bond is deformed due to the pressure, a combination with the high temperature processes of recrystallization occurs [2].

Diffusion bonding in the solid state is normally carried out at high temperatures, approximately 50 – 70 % of the melting temperature of the base material. Longer times used in conventional joining by pressure, for example roll or forge bonding, are used to facilitate the process of creep to contribute to the bonding and that there is a reduction of pressure required to achieve close contact between the cleaned surfaces. Therefore, in opposite to most processes of the solid state joining, diffusion bonding is not normally associated with high deformations [3]. The diffusion bonding procedures are divided into diffusion bonding without added material, and the diffusion bonding with the addition of material. In our case, the method used is the diffusion bonding without added material.

Joining the solid state is a process where elevated temperature and pressure allow the formation of the bond, whereas dušik, absorbirani ioni (ioni žvepla, fosforja in kisika), delci prahu, maščoba in vlaga, je potrebno odstraniti [4]. Površina se lahko očisti kemično ali mehansko [5].

Cilj tega prispevka je bil preiskati interakcijo med dvema materialoma na osnovi aluminija in tudi ugotoviti optimalne razmere za stiskanje, ki omogočajo dobro spajanje. Narejene so bile tri različne serije spajanja pri različnih pogojih in določili najboljše razmere za stiskanje zlitin AA1170 in AA6060.

2. Raziskovalni del

Raziskali smo interakcijo med dvema enakima (AA1170) in dvema različnima (AA1170 in AA6060) materialoma. Kemične sestave uporabljenih zlitin so prikazane v razpredelnici 1. Razpredelnica 2 prikazuje tri različne serije poskusov pri različnih eksperimentalnih pogojih. Vezi smo preskušali s termomehanskim simulatorjem metalurških stanj Gleeble 1500D z različnimi silami (40–80 kN) pri različnih temperaturah (400 – 600 °C), pri čemer smo orodje za stiskanje vsakokrat prilagodili dobljenim predhodnim rezultatom.

Naredili smo tri različne serije poskusov stiskanja. Prva serija vzorcev je bila stisnjena pri enaki, konstantni temperaturi (400 °C), medtem ko se je sila stiskanja spreminjala. Uporabili smo čistilo Ridolin 241 (5 %). Vse vzorce smo metalografsko pripravili in preiskali s svetlobnim mikroskopom Olympus BX61. Poleg tega smo merili tudi debelino vezi.

V drugi seriji se je spremenila geometrija stiskalnega orodja. Vzorce smo stiskali pri različnih temperaturah in z različnimi pomiki orodja. Uporabili smo čistilo Nabudur 152 (5 %). Vse vzorce smo preiskali s svetlobnim mikroskopom Olympus BX61 in izmerili debelino vezi. Pri vzorcih 2/2 in

these conditions on the contact surface lead to diffusion. Very important is also the preparation of the surface. Before joining the solid surface must be provided by properly cleaning. All contaminants must be eliminated, which may consist of nitrogen, absorbed ions (ions of sulphur, phosphorus and oxygen), the dust particles, grease and moisture [4]. The surface can be cleaned chemically or mechanically [5]. The purpose of this work was to investigate the interaction between the two materials based on aluminium and also to determine optimal conditions of compression that would provide a good bond. Three different series of compression at different conditions were examined and the best conditions of pressing aluminium alloy AA1170 and AA6060 were determined.

2. Experimental Work

The interaction between two identical (AA1170) and two different (AA1170 and AA6060) materials was investigated. Chemical composition of used alloys is presented in Table 1. With this aim, three different series were made at various experimental conditions, presented in Table 2. Tests of bonding were carried out by thermomechanical simulator of metallurgical states Gleeble 1500D at different temperatures (400 – 600 °C) and forces (40 – 80 kN), whereas the bonding tool was adjusted every time regarding the previous results.

Three different series of compression tests were made. The first series of samples were compressed at the same, constant temperature (400 °C), where the force of compression varied. Cleaning agent Ridolin 241 (5 %) was used. All samples were metallographic prepared and analyzed using an optical microscope Olympus BX61.

Razpredelnica 1. Kemična sestava uporabljenih zlitin / mas. %

Table 1. Chemical composition of used alloys / mass fraction, %

		Element									
		Al	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti
Zlitina / Alloy	AA1170	ostanek / alloy	0,0423	0,1030	0,0027	0,0032	0,0204		0,0037	0,0133	0,0050
	AA6060	ostanek / alloy	0,5188	0,3124	0,0121	0,0211	0,6407	0,0040	0,0032	0,0459	0,0118

Razpredelnica 2. Vzorci za poskuse

Table 2. Experimental samples

vzorec / sample	zgornji vzorec / upper sample	spodnji vzorec / lower sample	temperatura / temperature [°C]	sila / force [kN]
1/1	AA1170 (očiščen) / (cleaned)	6060 (očiščen) / (cleaned)	400	80
1/2	AA1170 (očiščen) / (cleaned)	AA1170 (očiščen) / (cleaned)	400	27
1/3	AA1170 (očiščen) / (cleaned)	AA1170 (očiščen) / (cleaned)	400	40
1/4	AA1170 (očiščen) / (cleaned)	AA6060 (očiščen) / (cleaned)	400	40
1/5	AA1170 (očiščen) / (cleaned)	AA1170	400	40
1/6	AA1170 (očiščen) / (cleaned)	AA6060	400	40
1/7	AA1170 (očiščen) / (cleaned)	AA1170 (očiščen) / (cleaned)	400	60
1/8	AA1170 (očiščen) / (cleaned)	AA6060 (očiščen) / (cleaned)	400	60
1/9	AA1170 (očiščen) / (cleaned)	AA1170	400	60
1/10	AA1170 (očiščen) / (cleaned)	AA6060	400	60
2/1	AA1170 (očiščen) / (cleaned)	AA1170 (očiščen) / (cleaned)	400	1,5
2/2	AA1170 (očiščen) / (cleaned)	AA1170 (očiščen) / (cleaned)	500	2,5
2/3	AA1170 (očiščen) / (cleaned)	AA1170 (očiščen) / (cleaned)	500	3
2/4	AA1170 (očiščen) / (cleaned)	AA1170 (očiščen) / (cleaned)	600	3
2/5	AA1170 (očiščen) / (cleaned)	AA1170 (očiščen) / (cleaned)	550	3
2/6	AA1170 (očiščen) / (cleaned)	AA6060 (očiščen) / (cleaned)	500	3
2/7	AA1170 (očiščen) / (cleaned)	AA6060 (očiščen) / (cleaned)	550	3
2/8	AA1170 (očiščen) / (cleaned)	AA6060 (očiščen) / (cleaned)	450	3
3/1	AA1170	AA6060	450	3
3/2	AA1170	AA6060	500	3
3/3	AA1170	AA6060	550	3
3/4	AA1170	AA1170	550	3
3/5	AA1170	AA1170	500	3
3/6	AA1170	AA1170	450	3

2/7 smo merili še trdoto. Poleg tega smo vzorce elektrolizno jedkali in mikrostrukturo preiskali v polarizirani svetlobi.

V tretji seriji poskusov se je geometrija orodja zopet spremenila. Napravili smo

Furthermore, the thickness of the bond was measured.

In the second series the squeezing tool geometry was changed. Samples were pressed at different temperatures negativ orodja, ki je bilo uporabljeno v drugi seriji. Uporabili smo čistilo Nabudur 152 (5 %). Pri vzorcih 3/1, 3/3, 3/4 in 3/6 smo merili debelino vezi, vzorca 3/3 in 3/4 smo elektrolizno jedkali in mikrostrukturo analizirali v polarizirani svetlobi.

Z diferenčno vrstično kalorimetrijo (DSC) smo analizirali dva vzorca druge serije (2/5 in 2/7) in dva vzorca (3/3 in 3/4) tretje serije poskusov stiskanja. Vsi vzorci so bili stisnjeni pri 550 ºC, pomik orodja je bil 3 mm. Edina razlika med njimi je bila geometrija orodja. Z DSC analizo smo analizirali tudi nedeformirano zlitino AA1170. Trdoto smo merili z merilnikom Vickers - Instron Tukon 2100B. Obremenitev je bila 0,02 kg.

Vzorce smo vložili v hladno polimerno maso in jih pripravili po standardnem metalografskem postopku za mikroskopske preiskave. Nekatere smo tudi elektrolizno jedkali. Vzorce smo preiskali s stere-mikroskopom Olympus SZ61 in svetlobnim mikroskopom Olympus BX61, s katerim smo tudi merili debelino vezi.

3. Rezultati in razprava

Rezultate meritev pri poskusih stiskanja vzorcev 1/3 in 1/8 kaže slika 1. Merili smo temperaturo, silo in pomik orodja. Pri prvi seriji poskusov stiskanja se je temperatura znižala za 70–100 ºC. Uporabljeni sili sta bili 40 in 60 kN.

Slika 2 grafično prikazuje časovno spreminjanje sile, temperature in pomika orodja glede na čas pri drugi seriji poskusov stiskanja. Vidi se, da se je temperatura pri vseh stiskanjih znižala za 50 do 100 ºC. Pri stiskanju pri 500 ºC in pomiku orodja za 3 mm (slika 2.a) je bila dosežena sila 75 kN. Ko se je temperatura stiskanja zvišala za 50 ºC (slika 2.b), se je sila zmanjšala za okrog 10 kN.

and different movements of the tool. Cleaning agent Nabudur 152 (5 %) was used. All samples were examined with an optical microscope Olympus BX61 and the thickness of the bond was measured. At the samples 2/5 and 2/7 the hardness was measured. Moreover, these samples were electrolytic etchant and the microstructure was analyzed in polarized light.

In the third series the geometry of the tool has been changed, namely, a negative tool used in the second series has been created. Cleaning agent Nabudur 152 (5 %) was used. In the samples 3/1, 3/3, 3/4 and 3/6 the thickness of the bond was measured, samples 3/3 and 3/4 were electrolytic etched and microstructurelly analyzed in the polarized light.

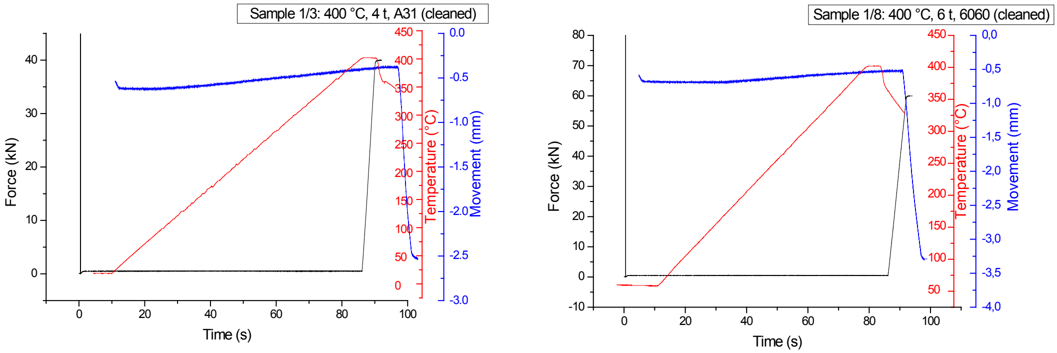
DSC analysis was made from two samples of the second (2/5 and 2/7) and from two samples from the third (3/3 and 3/4) series of compression tests. All these samples were pressed at temperature 550 °C, and the movement of the tool was 3 mm. The only difference between them was the tool geometry. DSC analysis was done on the undeformed alloy AA1170 also.

Hardness measurements were carried out on Vickers - Instron Tukon 2100B. Load was 0.02 kg.

Samples were submitted into the polymer cold mass and microscopic prepared by standard metallographic procedure, some were also electrolytic etched. The samples were examined with a stereo-microscope Olympus SZ61 and an optical microscope Olympus BX61, where the thickness was also measured.

3 Results and Discussion

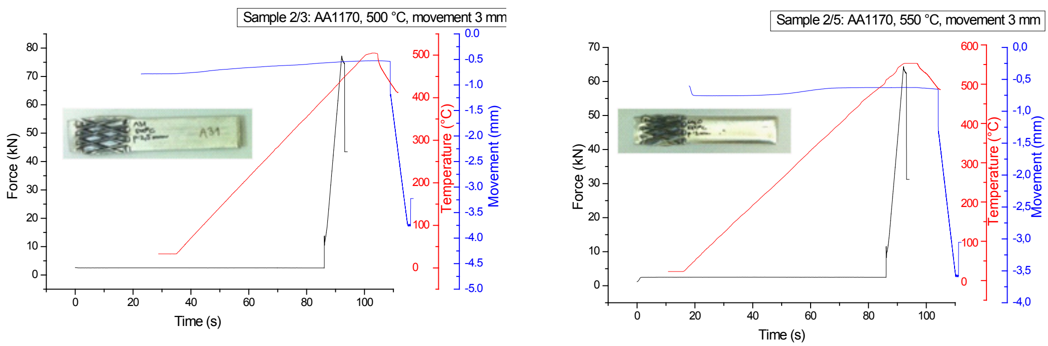
The measurements of compression test of samples 1/3 and 1/8 are presented in Figure 1. The temperature, force and the



a) b)

Slika 1. Grafični prikaz časovnega spreminjanja sile, temperature in pomika orodja za vzorca 1/3 (a) in 1/8 (b)

Figure 1. Graphic show of force, temperature and tool movement of sample 1/3 (a) and 1/8 (b)



a) b)

Slika 2. Grafični prikaz časovnega spreminjanja sile, temperature in pomika orodja pri vzorcih 2/3 (a) in 2/5 (b)

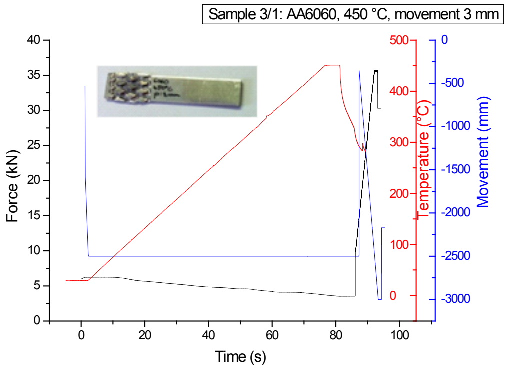
Figure 2. Graphic show of force, temperature and tool movement of sample 2/3 (a) and 2/5 (b)

Diagram na sliki 3 kaže časovno spreminjanje sile, temperature in pomika orodja pri tretji seriji poskusov stiskanja. Vidi se, da se je temperatura pri vseh poskusih stiskanja znižala za 80 - 150 °C. Dosežene sile so bile med 35 in 70 kN.

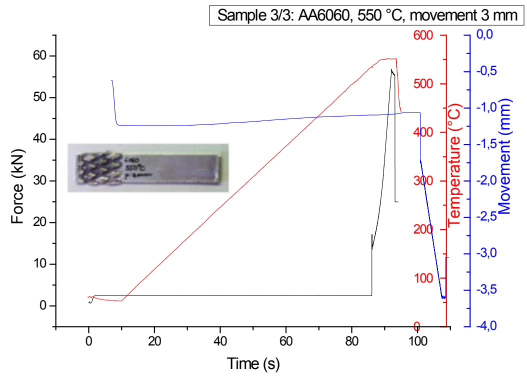
Trdoto smo merili na vzorcih 2/5 in 2/7. Na nestisnjenem delu vzorca 2/5 je bila trdota zlitine AA1170 približno 28 HV, na stisnjenem pa približno 32 HV. Vidi se, da se trdota materiala s stiskanjem rahlo

movement of the tool were measured. At the first series of pressing tests the temperature was reduced namely by 70–100 °C. The tests were made with force of 40 and 60 kN.

Figure 2 shows a graphical representation of the force, temperature and the tool movement regarding the time of the second series of compression tests. It can be seen that the temperature in all cases of the compression is reduced from 50 to 100



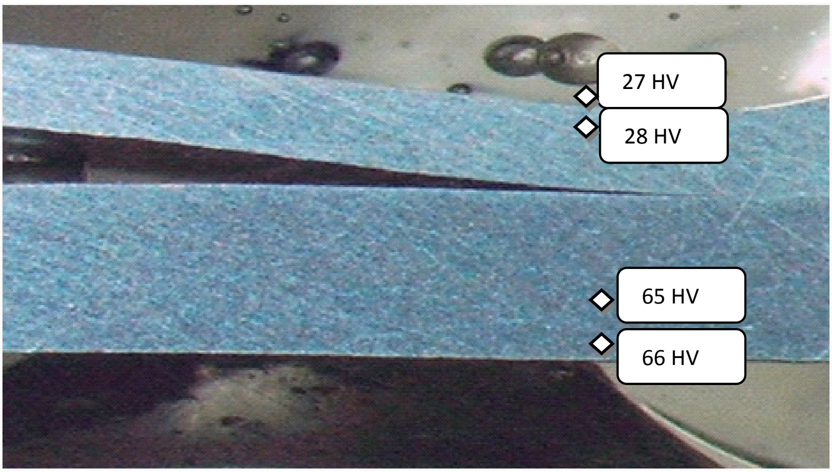
a)



b)

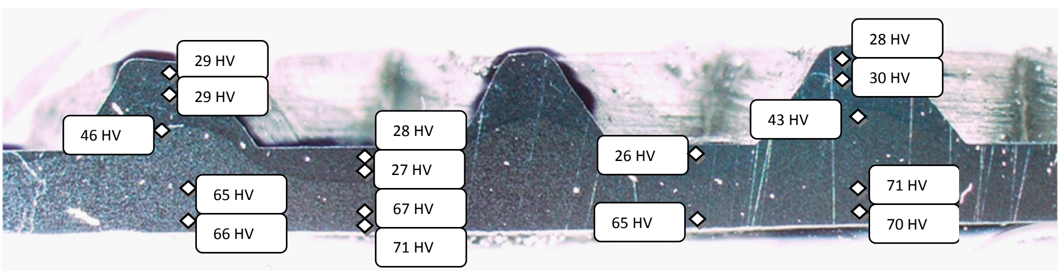
Slika 3. Grafični prikaz časovnega spreminjanja sile, temperature in pomika orodja pri vzorcih 3/1 (a) in 3/3 (b)

Figure 3. Graphic show of force, temperature and tool movement of sample 3/1 (a) and 3/3 (b)



Slika 4. Trdota vzorca 2/7, nespojeni vzorec

Figure 4. Hardness of sample 2/7, unbonded part



Slika 5. Trdota vzorca 2/7, spojeni vzorec

Figure 5. Hardness of sample 2/7, bonded part

spreminja. Pri stiskanju vzorca 2/7 je bila trdota nestisnjenega dela zlitine AA1170 (slika 4) okoli 27 HV, zlitine AA6060 pa 65 HV. Na stisnjenem delu zlitine AA1170 (slika 5) je bila trdota okoli 28 HV in zlitine AA6060 67 HV, trdota vezi pa je bila 44 HV. Vidi se, da je trdota zlitine AA6060 dvakrat višja od trdote zlitine AA1170. Trdota vezi je nekje vmes.

V prvi seriji poskusov stiskanja je spoj nastal vedno, kadar je bila površina obeh vzorcev očiščena. Vidi se, da smo najboljšo vez dosegli pri stiskanju enakih materialov. Najboljša vez je bila pri vzorcih 1/3 in 1/7, ko sta bila stisnjena enaka materiala s silo 40 kN in 60 kN. A pri stiskanju dveh različnih aluminijastih materialov se je na spoju vedno pojavilo nekaj oksida. Razpredelnica 3 prikazuje rezultate meritev spoja za vse tri serije poskusov stiskanja.

V drugi seriji poskusov stiskanja je bila vez dosežena vedno. Pri stiskanju enakih materialov meje niso bile vidne, pri stiskanju različnih pa so bile vidne. Pri stiskanju pri temperaturi 600 ºC (vzorec 2/4) je med poskusom prišlo do taljenja materiala. Na sliki 6 je prikazan makroskopski posnetek vezi vzorca 2/6. Razpredelnica 3 prikazuje tudi rezultate meritev debeline vezanih vzorcev v drugi seriji poskusov stiskanja.

Tudi pri tretji seriji poskusov stiskanja je vedno nastal spoj. Meje med enakimi materiali pri stiskanju niso bile vidne, medtem ko so bile vidne pri stiskanju

°C. In the case of compression at 500 °C and the displacement of 3 mm (Figure 2.a), a force of 75 kN was achieved. When the temperature of compression increased for 50 °C (Figure 2.b), the force is reduced by approximately 10 kN.

The graph in Figure 3 shows the dependence of force, temperature and displacement on the time of the third series of compression tests. It can be seen that the temperature in all cases of compression is reduced by 80–150 °C. The forces that were have achieved are between 35 and 70 kN.

Hardness was measured on a samples 2/5 and 2/7. In the uncompressed part of the sample 2/5, the hardness of the alloy AA1170 was approximately 28 HV and in the compressed part approximately 32 HV. It can be seen that the hardness of the material slightly changed by the pressing. In the case of the compression of the sample 2/7 hardness on an uncompressed part of AA1170 alloy (Figure 4) was approximately 27 HV and AA6060 alloy 65 HV. On the compressed part (Figure 5) of AA1170 alloy, hardness was approximately 28 HV, at AA6060 alloy 67 HV and on the bonded part 44 HV. It can be seen that the hardness of the alloy AA6060 is about twice as high as the hardness of the alloy AA1170. The hardness of the bond is somewhere in between.

In the first series of compression tests the joint was always achieved when the

Slika 6. Meritve debeline vezi na vzorcu 2/6

Figure 6. Thickness measured in sample 2/6

dveh različnih materialov. Razpredelnica 3 prikazuje tudi rezultate meritev debeline spoja pri tretji seriji poskusov stiskanja.

Razpredelnica 3. Rezultati meritev debeline vezi pri vseh treh serijah poskusov stiskanja

Table 3. Results of thickness measurement of all series of compression test

vzorec / sample	povprečna debelina (μm) / average thickness (μm)	
	na izboklini	v vdolbini
1/1	2639,3	1051,01
1/2	2582,64	1287,89
1/3	2598,52	1325,69
1/4	2788,74	1278,41
1/5	2752,98	1228,63
1/6	2676,63	1430,01
1/7	2766,94	1260,06
1/8	2757,39	1296,76
1/9	2798,01	1218,01
1/10	2730,13	1304,99
2/3	2307,21	957,12
2/5	2307,63	868,82
2/6	2118,85	1062,84
2/7	2465,60	1142,07
2/8	2633,67	1230,12
3/1	2504,88	1108,94
3/3	2504,88	1148,48
3/4	2465,99	1122,14
3/6	2326,75	970,34

Sliki 7 in 8 kažeta mikrostrukturo stisnjenega dela vzorcev 3/3 in 3/4. Na mikrostrukturnih posnetkih se lahko vidi, da so zrna na mestih spoja deformirana in razpotegnjena v smeri toka materiala ali deformacije. Zato je spoj boljši.

Na sliki 9 je prikazana primerjava DSC krivulj pri segrevanju vzorcev 2/5, 3/4 in nedeformirane zlitine AA1170. Vzorca 2/5 in 3/4 sta bila stisnjena pri 550 ºC in pomiku orodja za 3 mm. Edina razlika med njima je

surface of both samples were cleaned. It can be seen that the best bond was made in case of compression of two identical materials. The best bond has been made with a sample of 1/3 and 1/7, when two identical cleaned materials with force of 40 kN and 60 kN were compressed. In case of pressing of two different aluminium materials, in all cases there are some oxides at the junction. Table 3 presents the results of measurements of the thickness of the all three series of compression tests.

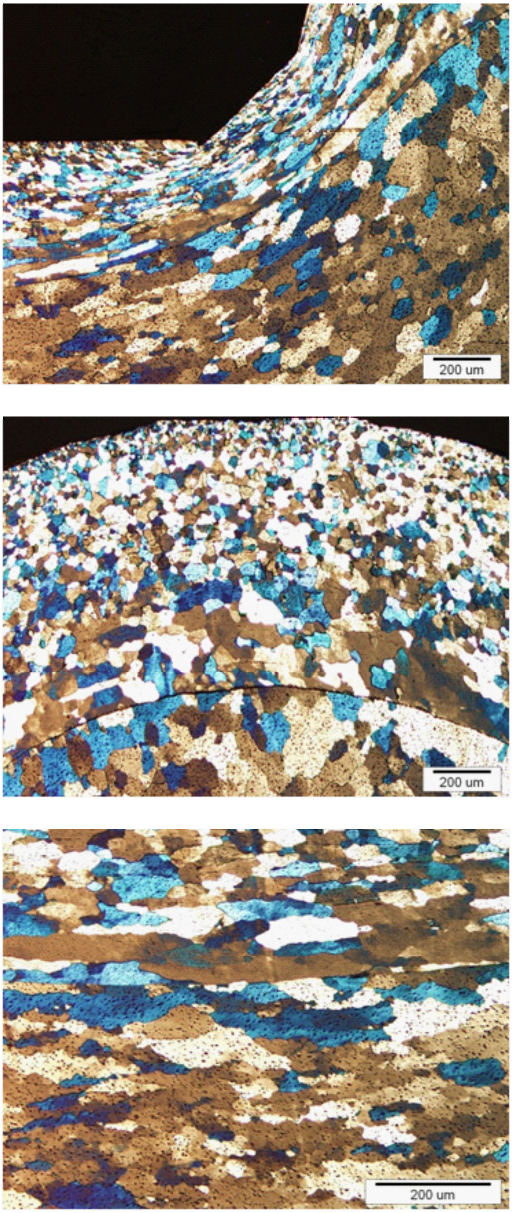
In the second series of compression tests the bond was always achieved. When compressing the same material, boundaries are not visible, while at compression of different materials, are visible. When compressing at 600 °C (sample 2/4) melting of the material occurred during the test. In Figure 6, the macroscopic bond of sample 2/6 is presented. Table 3 presents the results of measurements of the thickness of the bonded sample in second series of compression tests.

In the third series of compression tests the joint was also always achieved. The boundaries at pressing the same materials are not visible, while in the pressing of two different materials are visible. Table 3 presents the results of measurements of the thickness of the third series of compression tests.

Figures 7 and 8 show the microstructure of the compressed segment of sample 3/3 and 3/4. From the microstructural images can be seen that the grains on a bonded place deform and flow in the direction of the material flow or deformation. For this reason, the joint is better.

In Figure 9, a comparison of heating DSC curves of samples 2/5, 3/4 and undeformed alloy AA1170 is presented. Samples 2/5 and 3/4 were compressed at 550 °C and at the displacement of 3 mm. The only difference between them was in the geometry of the

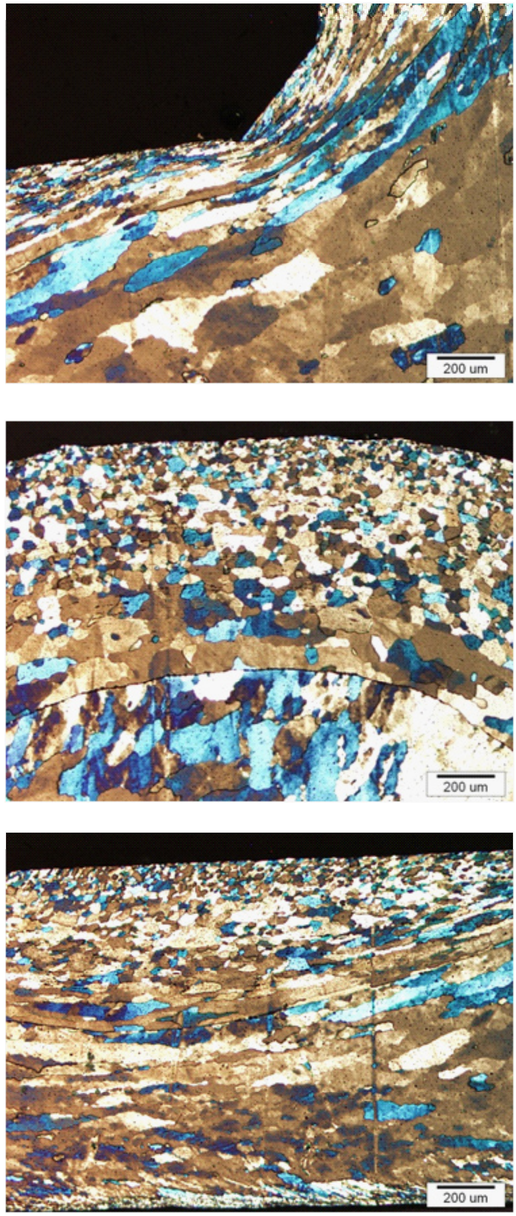
a)
b)
c)



Slika 7. Mikrostruktura vzorca 3/3: (a) prehod v rebro, (b) rebro vzorca in (c) spoj

Figure 7. Microstructure of sample 3/3: (a) transition into the rib, (b) the rib of the sample and (c) the bond

a)
b)
c)



Slika 8. Mikrostruktura vzorca 3/4: (a) prehod v rebro, (b) rebro vzorca in (c) spoj

Figure 8. Microstructure of sample 3/4: (a) transition into the rib, (b) the rib of the sample and (c) the bond

bila geometrija orodja. Zaradi spremenjene geometrije orodja je bila hitrost deformacije posameznih delov spajanih materialov različna. Zato lahko sklepamo, da je bila stopnja deformacije v vzorcu 3/4 večja kot v vzorcu 2/5. Za taljenje vzorca 2/5 je bila potrebna energija 229,3 J/g, vzorca 3/4 183,1 J/g in nedeformirane zlitine AA1170 283,9 J/g. Vidi se, da sta bila potek taljenja in talilna toplota odvisna od stopnje deformacije.

4. Sklepi

Glede na dobljene rezultate sklepamo, da:

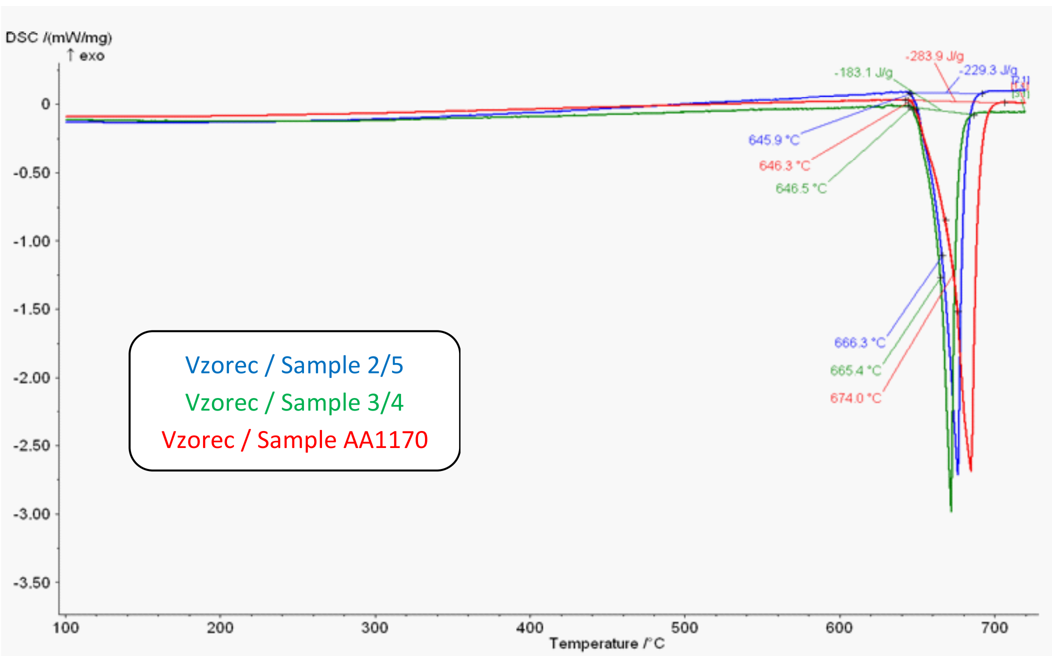
- ima priprava površine vzorcev pred stiskanjem velik vpliv pri doseganju dobrih spojev; spoj je boljši, če sta obe površini očiščeni pred stiskanjem; poleg tega je površina bolje pripravljena s

tools. Due to changes in the geometry of the tool, the rate of deformation in the individual parts of the bonded materials varies. It can be concluded that the degree of deformation in sample 3/4 is greater than in sample 2/5. For the melting of the sample 2/5 there was 229.3 J/g energy required, for sample 3/4 183.1 J/g, and for undeformed alloy AA1170 283.9 J/g. It can be seen that the course of melting and heat of fusion is associated with the degree of deformation.

4. Conclusions

According to the results it can be concluded:

- The surface preparation of the samples before compression has great influence on good bond achievement. The bond is better if both surfaces are cleaned



Slika 9. Primerjava segrevalnih DSC krivulj za vzorce 2/5, 3/4 in zlitine AA1170

Figure 9. The comparison of heating DSC curves of sample 2/5, 3/4 and AA1170

čistilom Nabudur 152 (S),
- se trdoti deformiranih in nedeformiranih delov stisnjenih delov le malo razlikujeta; trdota vezi je med trdotama obeh spojenih materialov,
- na spoj vpliva geometrija orodja; spoj je najboljši, kadar se uporabi negativ rebra (tretja serija poskusov stiskanja), pri čemer je za dober spoj potrebna manjša sila; v tretji seriji je bil dober spoj dosežen že s stiskanjem pri 450 ºC s silo 35 kN;
- iz segrevalnih DSC krivulj lahko sklepamo, da deformacija vpliva na potek taljenja in strjevanja materiala; stopnja deformacije vpliva na hitrost taljenja (naklon krivulje DSC), ki se veča s stopnjo deformacije, in na potrebno toploto taljenja, ki se s stopnjo deformacije zmanjšuje.

prior to compression. Furthermore, the surface is better prepared by cleaning with a cleaning agent Nabudur 152 (S).
- Hardness of the deformed and undeformed parts of the compressed materials are changed only slightly. The hardness of the bond was somewhere in between the both bonded materials.
- The geometry of the tool has influence on the joint. The junction is the best in the construction of a negative rib (third series of compression), which also required less force to achieve a good bond. In the third series of the compression test a good bond is obtained already at the pressing at a temperature of 450 °C and at force of 35 kN.
- From the heating DSC curves can be concluded that deformation effects on the course of melting and solidification of the material. The degree of deformation impacts on the melting rate (slope of the DSC curve), which with the degree of deformation is increased and on the necessary heat of fusion, which with the deformation rate is decreased.

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