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Dissimilar metal joining by ultrasonic welding
Spajanje raznorodnih metala ultrazvučnim zavarivanjem

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Ključne reči: Ultrazvučno zavarivanje, zavarivanje u čvrstom stanju, zona uticaja toplote

Abstract

The dissimilar metal welding always challenges. The different alloys have different physical and mechanical properties. In the case of the electronic component of the car, it needs to establish a joint between dissimilar metals. The useful metals are for this application are copper and aluminium. Even that has good conductivity, corrosion resistance and formability. By fusion welding technologies these thin metal workpiece joining is not a simple technology. To use a solid state welding technology can be a suitable solution to establish a cohesion joint in case of this task. It well-known much suitable technologies, even that all of them has advantages and disadvantages. The choice of solid-state technology is the ultrasonic welding process. In the case of this process, we use pressure and highfrequency vibration for welding. Besides this process, the friction and vibration generated heat is lower than the metal melting temperature. The base of this technology is the ultrasound-assisted high-level formability. The optimization of this dissimilar joining technology parameters needs many pre-welding and testing process. In this work, we wanted to introduce this empirical optimization process.

Rezime

Zavarivanje različitih metala uvek predstavlja izazov. Različite legure imaju različite fizičke i mehaničke osobine. U slučaju elektronskih komponenti za vozila, potrebno je uspostaviti spoj različitih metala. Metali koji se primenjuju su bakar i aluminijum. Čak i kada imaju dobru provodljivost, koprozionu otpornost i plastičnost, zavarivanje takvih metalnih komada nije jednostavna tehnologija. Upotreba tehnologija zavarivanja u čvrstom stanju može predstavljati prihvatljivo rešenje za dobijanje kohezionog spoja. Dobro su poznate mnoge takve tehnologije i one imaju svoje prednosti i nedostatke. Jedan od mogućih izbora tehnologija zavarivanja u čvrstom stanju je process ultrazvučnog zavarivanja. Kod tog postupka zavarivanja primenjuje se pritisak i vibracije viskih frekvencija. Osim toga kod ovog postupka trenje i vibracije generišu toplotu koja je niža od potrebne za topljenje metala. Osnova ove tehnologije je visok nivo plastičnosti metala potpomognut ultrazvukom. Optimizacija ove thnologije spajanja različitih metala zahteva puno probnih zavarivanja i ispitivanja. U ovom radu bila je želja da se prikaže proces empiričke optimizacije.

1. Introduction

Well known that the weldability of the materials is not a material property, depends on the material properties, the welding process and the process parameters too. In this article, we wanted to studies the weldability of some metals by ultrasonic welding process under different preparation and in case of different process parameters. The ultrasonic welding is a special quasi-solid-state process because the joint established by high-frequency ultrasound and clamping force. The high-frequency sound waves vibration cause friction and occurs

1. Uvod

Dobro je poznato da zavarljivost materijala nije osobina materijala i zavisi od više uticajnih faktora: pored osobina materijala i od postupka zavarivanja i procesnih parametara. U ovom radu izučavana je zavarljivost nekih metala zavarivanih ultrazvučnim zavarivanjem u zavisnosti od različitih priprema i u slučaju različitih različitih procesnih parametara.

Ultrazvučno zavarivanje je poseban process, u kvazi črstom stanju, zato što se spoj uspostavlja visokofrekventnim ultrazvukom i silom spajanja. Visokofrekventni zvučni talasi vibracijom izazivaju heat [2]. Between the joined surfaces, the introduced affects build strong cohesion bonding. This joint is a real welding joint without melting and fusion but with strong atomic bonding. The advantages of ultrasonic welding are that it: Permits joining of thin materials to thick materials, permits dissimilar metal joints provides joints with good thermal and electrical conductivity Joins metals without the heat of fusion, provides efficient energy use Typically requires no filler material, flux, or special atmosphere Typically requires no special cleaning processes Welds through most oxides [2] The high-frequency friction establishes heat could cause some changing in the microstructure and the mechanical properties of the joint and the heat affected zone. Even that the joining technologies established bonds quality and failures kinds depends on the process parameters. The parameters optimization on the base of the joining process physical and theoretical knowledge is very important to assure the quality by the way of the expected mechanical properties.

2. Theoretical background

The ultrasonic welding is a solid state welding. The joining process base is the plastic deformation. The plastic deformation and the plasticity depends on the temperature. Also the microstructure and the mechanical properties of the metal depends on the deformation leve and the temperature. The heat during the ultrasonic welding established from the process friction and vibration. Known the dislocation theory of the ultrasound energy influence in case of the metalworking [4]. The base of the ultrasonic welding technology the ultrasound effect for the metal formability because the joint made by pressing and vibration. The ultrasonic welding is a solid-state welding technology in which detectable the high-frequency vibration caused friction effected warming in the joint and the heat-affected zone [5- 7]. The established heat can cause changes in the joint microstructure as a function of the established heat and the heat transfer coefficient of the used metal. This changing of the microstructure determine the mechanical properties of the joint. The established heat level and the changing in the metal structure depends on the welding parameters. The expected mechanical properties need always to satisfy the industrial quality requirements. The relationship found between the experimented aluminium-aluminium and aluminium-copper thin sheets welded joint mechanical properties and the welding parameters.

trenje pri čemu se oslobađa toplota [1, 2]. Između površina koje se spajaju, nastaju efekti koji ostvaruju snažno koheziono spajanje. Ovaj spoj je stvarni zavareni spoj bez topljenja i stapanja, ali sa jakim atomskim vezama. Prednosti ultrazvučnog zavarivanja su da ono: omogućava spajanje tankih materijala sa debelim materijalima, omogućava spajanje raznorodnih metala obezbeđujući spoj sa dobrom toplotnom i električnom provodljivošću. Spojevi metala nastali bez utroška toplote za spajanje, obezbeđuju efikasnu upotrebu energije. Proces obično ne zahteva upotrebu dodatnog materijala, topitelja ili posebne atmosphere, zatim ne zahtva poseban proces pripreme čišćenjem i omogućava spajanje kroz većinu oksida [1, 2]. Visokofrekveno trenje stvara toplotu koja može da proizvede neke promene u mikrostrukturi i kod mehaničkih osobina spoja, kao i zonu pod uticajem toplote. Tehnolgija spajanja uslovljava nivo kvaliteta spoja, kao i pojavu grešaka koje zavise od procesnih parametara. Optimizacija parametara procesa spajanja, na osnovu fizičkih i teoretskih znanja, je vrlo značajna radi obezbeđenja potrenog kvaliteta spoja i očekivanih mehaničkih osobina.

2. Teoretske osnove

Ultrazvučno zavarivanje je proces zavarivanja u čvrstom stanju. Proces spajanja se zasniva na plastičnoj deformaciji. Plastična deformacija i plastičnost zavise od temperature. Takođe mikrostruktura i mehaničke osobine metala zavise od nivoa deformacija i temperature. Toplota nastala pri procesu ultrazvučnog zavarivanja nastaje od procesa trenja i vibracija. Poznato je iz dislokacione teorije uticaj energije ultrazvuka u slučajevima prerade metala [3, 4]. Osnova tehnologije ultrazvučnog zavarivanja je efekat ultrazvuka na plastičnost metala, obzirom da spoj nastaje pritiskom i vibracijama. Ultrazvučno zavarivanje je tehnologija zavarivanja u čvrstom stanju pri kojoj visokofrekventne vibracije izazivaju efekat trenja koji zagreva spoj i stvara zonu uticaja toplote [5-7]. Nastala toplota može izazvati promene u mikrostrukturi spoja u zavisnosti od količine nastale toplote i koeficijenta prenosa toplote korišćenog metala. Promene u mikrostrukturi određuju mehaničke osobine spoja.

Nivo nastale toplote i promene u strukturi metala zavise od parametara zavarivanja. Očekivane mehaničke osobine spoja trebalo bi uvek da zadovolje industrijske zahteve za kvalitet. U radu su prikazane eksperimentalne zavisnosti parametara zavarivanja na mehaničke osobine, za kombinacije zavarenih spojeva tankih traka metala u kombinaciji aluminijum – aluminijum i aluminijum – bakar.

In the case of the traditional ultrasonic welder machines used magnetostrictive inverter but nowadays the piezoelectric inverter is the applicated, the ultrasonic welding setup shown in Fig. 1. The ultrasonic welding standard sign MSZ EN ISO 4063, number 41 process [7, 8].

U slučaju tradicionalnih uređaja za ultrazvučno zavarivanje koristi se magnetostriktivni inverter, dok se danas koristi piezoelektrični inverter u opremi za visokofrekventno zavarivanje, a šematski prikaz procesa je prikazan na slici 1. Standard za ultrazvučno zavarivanje označava se MSZ EN ISO 4063, a broj procesa je 41 [7, 8].

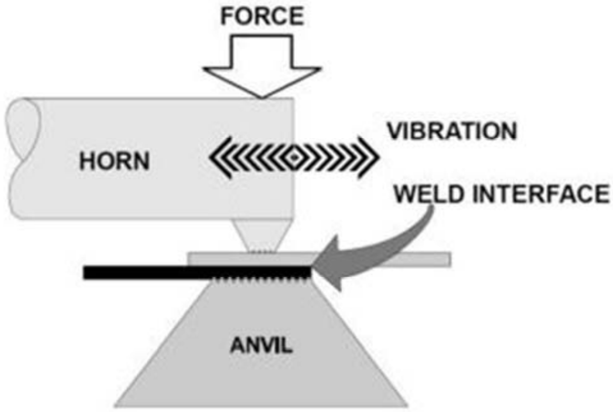

Figure 1. *Ultrasonic welding setup [7]*
Slika 1. *Šematski prikaz ultrazvučnog zavarivanja [7]*

The vibration if transmitted by sonotrode. The geometry of the sonotrode is a very important parameter in the setup. Also the material of them is a special alloy (f.ex. Ti base). Ultrasonic welded aluminum sampes shown in the Fig. 2. It can see that the joint tested by visual inspection is suitable.

Vibracije se prenose sonotrodom. Geometrija sonotroda je vrlo važan parameter pri podešavanju procesa. Takođe njihov material je od specijalnih legura, na primer titanovih legura. Ultrazvučno zavarivareni aluminijumski uzorci prikazani su na Slici 2. Može se primetiti da je moguće da se spoj vizuelno ispita.

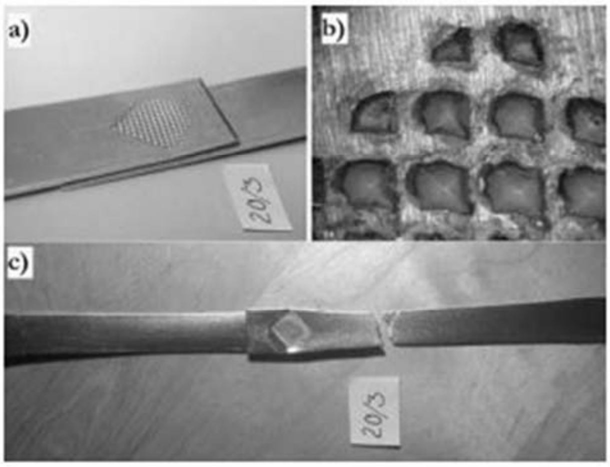

Figure 2. *The welded joint*
Slika 2. *Zavareni spoj*

3. Application for dissimilar joining

The variable parameters of the process are the next: time, T (s) the duration of applied ultrasonic vibration, amplitude, A (μm) the longitudinal displacement of the vibration, clamping force, F (N) the compressive force applied perpendicular (normal) to the direction of the vibration. The frequency f (Hz) was constant [9, 10]. The power and energy are calculable from the variable parameters by following equation (1-2), where

3. Primena za raznorodne spojeve

Promenljivi parametri procesa su sledći: vreme T (s), trajanje primenjenih ultrazvučnih vibracija, amplituda A (μm) uzdužnog pomeranja vibracija, sila pritiska F (N), pritisna sila primenjena poprečno (normalno) na pravac vibracija. Frekvencija f (Hz) je bila konstantna [9, 10]. Snaga i energija se mogu proračunati iz promenljivih parametara sledećim jednačinama (1-2), F force (N), A amplitude (μm), f frequency 20 000 Hz, T time (s):

$P = F * A * f$ [W] (1)

$E = P * T$ [J] (2)

gde je F sila (N), A amplituda (μm), f frekvencija 20 000 Hz, T (s) vreme:

$P = F * A * f$ [W] (1)

$E = P * T$ [J] (2)

3.1 Used materials

It was used aluminium (Al) and copper (Cu) metals sheets for the joining process. The experiments metal pairs were Al-Al and the Al-Cu. The used aluminium grade for the welding experiments was aluminium EN AW 1050A (EN 485-2:2016), chemical composition shown in the Tab. 1. The hardness of the used aluminium samples were 32 HV0,2.

3.1 Primenjeni materijali

Za process spajanja korišćene su metalne trake od aluminijuma (Al) i bakra (Cu). Eksperimentalni parovi metala su bili Al – Al i Al – Cu. Kvalitet aluminijuma za ekperimente zavarivanja je bio EN AW 1050A (EN 485-2:2016), a hemijski sastav je prikazan u Tabeli 1. Tvrdoća primenjenih uzoraka aluminijuma je bila 32 $HV_{0,2}$.

Table 1. *The experimented aluminium sheets chemical composition on mass percent (%)*
Tabela 1. *Hemijski sastav eksperimentalnih aluminijumskih traka u masenim (%)*

Si	Fe	Cu	Mn	Zn	Ti	Al
0.25	0.40	0.05	0.05	0.07	0.05	rest

The used copper CW008A (EN/TS 1172:2011) chemical composition shown in the Tab. 2. The hardness of the samples were 73 $HV_{0,2}$.

Hemijski sastav korišćenog bakra CW008A (EN/TS 1172:2011) prikazan je u Tabeli 2. Tvrdoća uzoraka je bila 73 $HV_{0,2}$.

Table 2. *The experimented copper sheets chemical composition on mass percent (%)*
Tabela 2. *Hemijski sastav eksperimentalnih bakarnih traka u masenim (%)*

Pb	Bi	Cu
Max. 0.005	Max. 0.001	rest

3.2 Experiments

The design of the test samples shown in Fig. 3. In the case of the Al-Cu joint used 0,5 mm thickness sheets. The width of the Al-Cu were 15 mm.

3.2 Eksperimenti

Oblik ispitnih uzoraka je prikazan na slici 3. U slučaju spojeva Al- Cu korišćene su trake debljine 0.5mm, a širine 15mm.

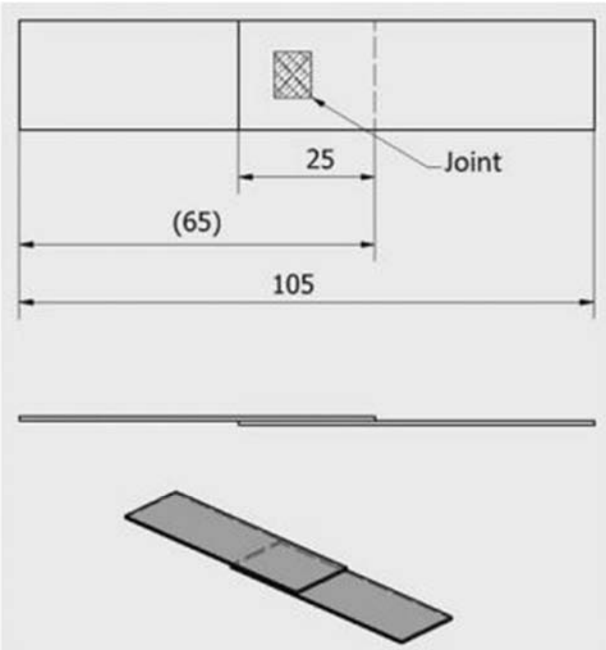

Figure 3. *The test samples design*
Slika 3. *Oblik i dimenzije uzoraka za ispitivanje*

The experiments were made by standard parameters as a function of the welding time and used a Branson L20 setup [11, 12]. The copper and the aluminium shows different formability and plastic deformation under the same loading. On the base of the Al-Al joining experiments results, it was used the same welding parameters.

Eksperimenti su vršeni sa standardnim parametrima u funkciji vremena zavarivanja na uređaju Branson L20 [11, 12]. Bakar i aluminijum pokazuju različitu obradljivost i plastičnu deformaciju pri istim opterećenjima. Na osnovu eksperimentalnih rezutata spojeva Al – Al, korišćeni su identični parametri zavarivanja.

Table 3. *Al-Cu joint suitable welding parameters*
Tabela 3. *Parametri zavarivanja za Al – Cu spoj*

Welding Energy	Energija zavarivanja	600 J
Trigger Pressure	Pritisak aktivacije	26 Psi
Welding Pressure	Pritisak zavarivanja	26 Psi
Amplitude	Amplituda	40 µm
Min. Welding Time	Min. vreme zavarivanja	0,5 s
Max. Welding Time	Max. vreme zavarivanja	1,26 s
Min. Welding Power	Min. snaga zavarivanja	690 W
Max. Welding Power	Max. snaga zavarivanja	4800 W

As function on the joint mechanical properties, the parameters were modified. Base on the empirical and literature results during the tests, it changed the amplitude and the welding energy [13-15]. The used parameters are shown in Tab. 3

U funkciji mehaničkih osobina, parametri zavarivanja su modifikovani. Na osnovu empirijskih rezultata ispitivanja i podataka iz literature, menjani su amplituda i energija zavarivanja [13-15]. Primenjeni parametri prikazani su u Tabeli 3.

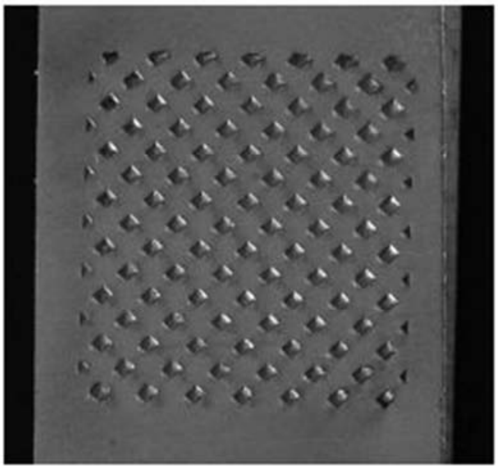

Figure 4. *The joint welded face side*
Slika 4. *Prednja strana zavarenog spoja*

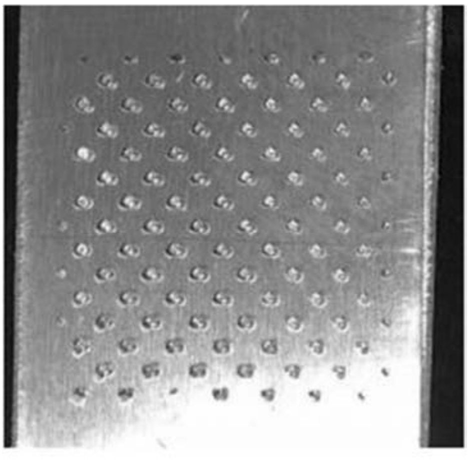

Figure 5. *Joint root side*
Slika 5. *Korena strana zavarenog spoja*

The Fig. 4-5. show the welded joint by the suitable parameters. The tensile test results reinforced the visual inspection results, about the used parameters. The strengthened samples are shown in Fig. 6., the tensile test measured maximal tensile forces summarized in the Tab. 4.

Slike 4 i 5 prikazuju zavarene spojeve dobijene odgovarajućim parametrima. Rezultati ispitivanja zatezanjem potvrdili su i dopunili rezultate vizuelnig ispitivanja za primenjene parametre zavarivanja. Na Slici 6 prikazan je izgled uzoraka ispitivanja zatezanjem, a u Tabeli 4 sumirani su rezultati zateznih ispitivanja sa merenim maksimalnim silama.

Table 4. *Maximal tensile forces under the suitable welding parameters*
Tabela 4. *Maksimalne zatezne sile sa odgovarajućim parametrima zavarivanja*

Sample sign Oznaka uzorka	Maximal tensile force Maksimalna zatezna sila
600/40/1	533,5 N
600/40/2	534 N
600/40/3	535,8 N
Average Srednja vrednost	534,43 N

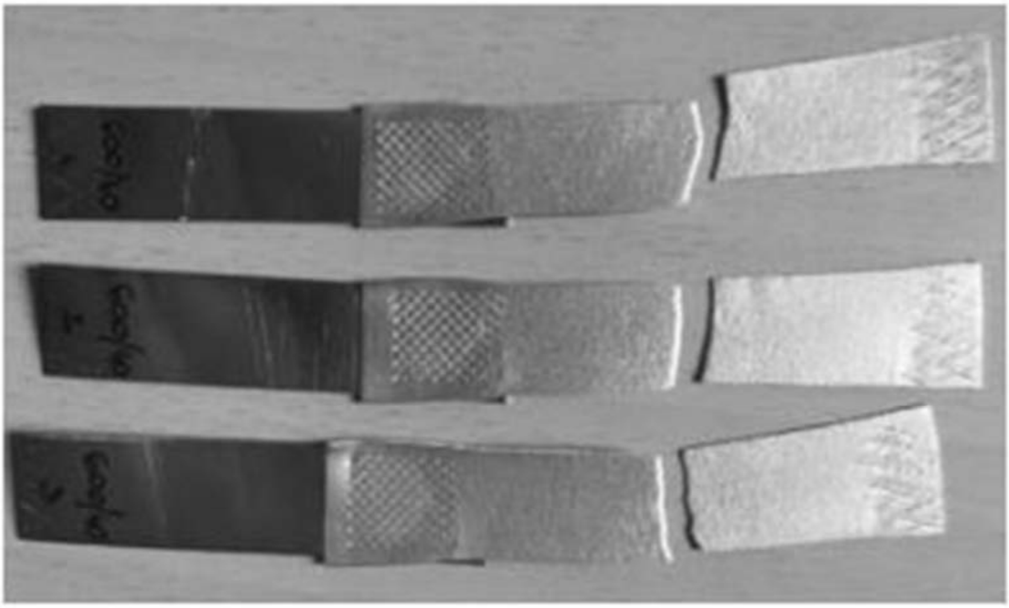

Figure 6. *The strengthened samples*
Slika 6. *Uzorci ispitani zatezanjem*

The welded joint is shown higher tensile strength than the lowest base material tensile strength. The unsuitable parameters affected failures in the joint and modified the mechanical properties [16-19].

Zavareni spojevi pokazuju višu zateznu čvrstoću u odnosu na zateznu čvrstoću osnovnog materijala. Neodgovarajući parametri uzrokuju lomove u spojevima i menjaju mehaničke osobine [16-19].

3.3 Failures

The unsuitable parameters cause cracking and failures. The optimization of the parameters in the case of this process is important like in the case of any metal working process. The parameters effects are different. The high level amplitude and long welding time effected heat can burn the joint surface and result unsuitable joint quality. The cacking in the joint shown in Fig. 7.

3.3 Prelomi

Neodgovarajući parametri prouzrokuju prsline i lomove uzoraka. Otimizacija parametara u slučaju ovog procesa su značajni, kao i u slučajevima bilo kog procesa obrade metala. Uticaj parametara je različit. Visok nivo amplitude i dugo vreme zavarivanja izazivaju toplotu koja može da ošteti površinu spoja i time rezultira neodgovarajućim kvalitetom spoja. Pucanje uzorka u spoju prikazano je na Slici 7.

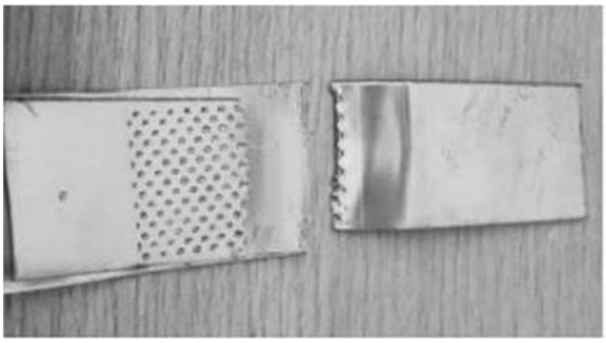

Figure 7. *Cracking in the joint border*
Slika 7. *Prelom na granici spoja*

As we use too short welding time, the joint cant establish.

Ako se primeni suviše kratko vreme zavarivanja, zavareni spoj ne može da se ostvari, što je prikazano na Slici 8.

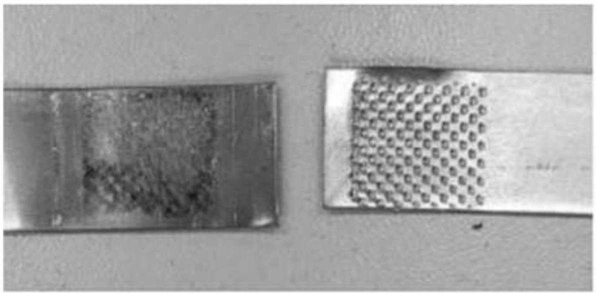

Figure 8. *Unjoined samples*
Slika 8. *Nespojeni uzorci*

4. Conclusion

It was optimized the ultrasonic welding parameters in case of the used Al-Cu grades joining by the experimental way. Under different parameters welded samples were visual inspected and tensile tested (maximal tensile force). Base on the experimental results is concluded:

I. The ultrasonic welding technology is suitable in case of similar aluminium and dissimilar aluminium-copper thin sheets under the determined welding parameters.
II. The suitable parameters determination is the key to the ultrasonic welding process joint quality.
III. On the base of the experimental results, it can conclude that between the parameters the time, amplitude and power is the most important.
IV. The ultrasonic welding joints welded under optimal parameters show the required joint strength.

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4. Zaključak

Na osnovu eksperimentalnih ispitivanja optimizovani su parametri ultrazvučnog zavarivanja za spajanje materijala kvaliteta Al – Cu. Uzorci su zavarivani različitim parametrima zavarivanja i ispitivani su vizuelno i zatezanjem sa određivanjem maksimalne zatezne sile. Na osnovu eksperimentalnih rezultata, može se zaključiti:
I. Tehnologija ultrazvučnog zavarivanja je primenljiva za slučajeve spajanja sličnih aluminijumskih i različitih aluminijum – bakar tankih traka primenom odgovarajućih parametara zavarivanja.
II. Određivanje odgovarajućih parametara procesa ultrazvučnog zavarivanja je najznačajnij za postizanje kvalitetnog spoja.
III. Na osnovu eksperimentalnih rezultata može se zaključiti da su najznačajniji parametri: vreme, amplituda i snaga.
IV. Ultrazvučno zavareni spojevi, zavareni optimalnim parametrima pokazuju zahtevanu čvrstoću spoja.

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