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Potential of error for arc welding processes - where can I make mistakes and how they affect the component?

Potencijal greške kod elektrolučnih postupaka zavarivanja - gde se mogu napraviti greške i kako one utiču na komponentu?

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Abstract

For example in vehicle or crane production and in the steel construction area - in many areas the weight reduction has a decisive influence on the development of new products. So modern, temperature-sensitive high-performance materials replace more and more unalloyed structural steels. The processing window by welding these materials is much smaller, so that the exact determination and compliance of the $t_{8/5}$ -value (cooling rate) is important. This is why the welding parameters and the exact determination of specific parameters have a great impact on the calculation and determination of the $t_{8/5}$ -value as well on the resulting mechanical and technological characteristics.

Depending on the welding process, a variety of welding parameters, welding seam geometry, the welding position and the layer structure changes the heat input into the component. On the one hand, the efficiency is changed and on the other hand they affect the cooling behavior by more than 60%.

Various welding processes and parameters are analyzed as well different error potentials discussed and following their impact will be illustrated.

The summation of the possible errors shows that the compliance with the mechanical and technological characteristics, as well as the theoretical determination of these values, and the calculation and simulation of the resulting sizes like arrears, microstructure or internal stresses is practically insufficiently possible. Knowing the sources of error and the use of this knowledge gained at the TU Chemnitz has a large contribution to improve the quality of welded joints.

At the end recommendations of necessary adaptations of actual standards are visualised.

Rezime

Na primer, u proizvodnji vozila ili dizalica i području čeličnih konstrukcija - u mnogim područjima smanjenje težine ima odlučujući uticaj na razvoj novih proizvoda. Tako moderni, temperaturno-osetljivi materijali visokih performansi zamenjuju sve više i više nelegirane konstrukcione čelike. Okvir obrade zavarivanjem ovih materijala je mnogo manji, tako da je tačno određivanje i usklađenost vrednosti $t_{8/5}$ (brzina hlađenja) vrlo važno. To je razlog zašto parametri zavarivanja i tačno određivanje specifičnih parametara imaju veliki uticaj na proračun i određivanje vrednosti $t_{8/5}$, kao i na rezultat mehaničkih i tehnoloških karakteristika.

Zavisno od postupka zavarivanja, različitosti parametara zavarivanja, geometrije šava, položaja zavarivanja i strukture sloja menja se unos toplote u komponentu. S jedne strane efikasnost se menja, a sa druge strane, oni utiču na vreme hlađenje za više od 60%.

Analizirani su različiti postupci zavarivanja i parametri i diskutovane različite mogućnosti greške a njihov prateći uticaj će biti ilustrovan.

Sabiranje mogućih grešaka pokazuje da je u skladu sa mehaničkim i tehnološkim karakteristikama kao i teorijskim određivanjem tih vrednosti a izračunavanje i simulacija rezultujućih veličina kao zaostataka mikrostrukture ili unutrašnjih napona je praktično nedovoljno moguće. Znajući izvore grešaka i korišćenje tog znanja stečenog na „TU Chemnitz“ ima veliki doprinos za poboljšanje kvaliteta zavarenih spojeva.

Na kraju preporuke potrebne adaptacije stvarnih standarda postaju vidljive.

1. Introduction and state of the art

Modern high-performance materials have an enormous potential for lightweight construction. During production there specific material properties can be adjusted by special temperature-time regimes. But it is hard to simulate that during welding. A welding process thus always represents a degradation of the material properties. As a consequence, these materials can be welded only in a very narrow parameter window. In practice this is realized by a defined $t_{8/5}$ -value [1; 2]. A distinction is made depending on the welded sheet thickness in 2 dimensional (Equation 1) and 3 dimensional (Equation 2) heat dissipation [3].

$$t_{8/5} = (4300 - 4,3T_0) * 10^5 * \frac{(E * \eta)^2}{d^2} * \left[\left(\frac{1}{500 - T_0} \right)^2 - \left(\frac{1}{800 - T_0} \right)^2 \right] * F_2 \quad (1)$$

$$t_{8/5} = (6700 - 5T_0) * E * \eta * \left[\frac{1}{(500 - T_0)^2} - \frac{1}{(800 - T_0)^2} \right] * F_3 \quad (2)$$

To calculate the $t_{8/5}$ -value the efficiency of the process, the form factors with respect to the weld geometry (F_2 , F_3), plate thickness, preheat temperature T_0 and welding performance and welding energy E is required. In particular, the efficiency, form factor and welding power have a high potential for error in their use, which are analyzed in more detail below.

a) Influence of the efficiency

Efficiency specifications for welding procedures are used among other things as an input variable in the calculation of the introduced energy per unit length. For this purpose values published in standards [1, 2, 5] as well as in literature are used. But there are a fixed and by welding parameter unchangeable efficiencies for each welding process defined. A classification into different power ranges or subgroups of the respective welding process does not take place. Recent research [4] has shown that the heat input into the component as a function of the welding parameter settings and conditions vary greatly [4]. Thus, for example, TIG welding has a span in the absolute values of about 15% between different setting values. The in the standard described efficiency of $\eta = 0,60$ is with an average value of $\eta = 0,75$ constantly exceeded.

b) Influence of the part geometry

The part geometry in the form of sheet thickness, welding seam geometry and partially buildup sequence are considered by correction factors according to DIN EN 1011-2 [5]. Just like

1.Uvod i pregled stanja

Moderni materijali visokih performansi imaju ogroman potencijal za lake konstrukcije. Tokom proizvodnje, ova specifična svojstva materijala mogu se prilagoditi posebnim režimima temperature i vremena. Ali, to je teško simulirati tokom zavarivanja. Tako proces zavarivanja uvek predstavlja degradaciju svojstava materijala. Kao posledica toga, ovi materijali mogu biti zavareni samo u vrlo uskom okviru parametara. U praksi, to se ostvaruje definisanom vrednošću $t_{8/5}$ [1; 2]. Napravljena je razlika u zavisnosti od debljine zavarenih limova za 2-dimenziono (jednačina 1) i 3-dimenziono (jednačina 2) odvođenje toplote [3].

Da bi izračunali vrednost $t_{8/5}$ potrebno je znati efikasnost postupka, faktor oblika u odnosu na geometriju šava (F_2 , F_3), debljinu ploče, temperaturu predgrevanja T_0 , performanse i energiju zavarivanja E . Konkretno, efikasnost, faktor oblika i snaga zavarivanja imaju visok potencijal za pogrešno korišćenje, što se detaljnije analizira u nastavku.

a) Uticaj efikasnosti

U specifikacijama zavarivanja, efikasnost se koristi među ostalim stvarima kao ulazna promenljiva u izračunavanju uvedene energije po jedinici dužine. U tu svrhu, koriste se vrednosti objavljene u standardima [1, 2, 5] kao i u literaturi. Ali postoje definisane fiksne i od parametara zavarivanja nepromjenjivi parametric za svaki proces zavarivanja. Klasifikacija u različite opsege snage ili podgrupe odgovarajućih procesa zavarivanja se ne dešava. Nedavna istraživanja [4] su pokazala da unos toplote u komponentu kao funkcija podešavanja parametara zavarivanja i uslova variraju [4]. Tako, na primer, TIG zavarivanje ima raspon u apsolutnim vrednostima od oko 15% između različitih vrednosti podešavanja. U standardu opisana efikasnost od $\eta = 0,60$ je s prosečnom vrednošću od $\eta = 0,75$ je konstantno premašena.

b) Uticaj geometrije dela

Geometrija dela u obliku debljine lima, geometrija šava i delimično nagomilavanje razmatra korekcija faktora u skladu sa DIN EN 1011-2 [5]. Baš kao i izračunavanje vrednosti vremena $t_{8/5}$ čak i sa

calculating the $t_{8/5}$ -values even with the correction factors F2 and F3 are separated by the welded sheet thickness in 2- or 3-dimensional heat dissipation (table 1).

The correction factors for all types of seam geometries are indicated relatively for bead on plate welds, for which a value of 1,0 is set.

Especially by joining of fillet welds, the details are very vague. A differentiation after opening angle, gap width or other geometric parameters are not done. Also not considered is a possible influence of the welding position on the heat input into the component.

korekcionim faktorima F2 i F3 su odvojeni za debljine zavarenih limova kod 2- ili 3-dimenzionalnog odvođenja toplote (tabela 1).

Faktori korekcije za sve tipove geometrije šava su označeni relativno u odnosu na navar na limu, za koji se postavi vrednost od 1,0.

Posebno kod ugaonih zavarenih spojeva, detalji su vrlo nejasni. Razlikovanja u zavisnosti od otvora žljeba, širine zazora ili drugih geometrijskih parametara nisu urađena. Takođe se ne razmatra mogući uticaj položaja zavarivanja na unos toplote u komponentu.



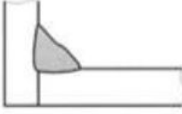
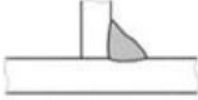
Geometrija šava		F2	F3
navar na limu		1,0	1,0
međusloj		0,9	0,9
ugoni šav-ivični		0,67...0,9	0,67
ugaoni šav-T spoj		0,45...0,67	0,67

Table 1. Correction factors in relation to the seam geometry [5]

Tabela 1. Korekcionni faktori vezani za geometriju šava [5]

Own studies [4, 6] to measure levels of emissions, heat conduction and convection energy of the arc have shown that up to 15% of the welding power are transferred by the welding arc to the environment. If the arc is capsuled through the weld geometry or by the welding position parts of this energy is absorbed by the component. The proportion and the influencing factors for the additional heat input into the component is unknown until now.

c) Influence of the welding power

For the determination and calculation of welding power are several methods to choose from. Thereby various values for the welding power can be determined for the same welding process, which has a high potential for error or high imprecision result. The physically correct method of calculation is shown in the formula 3.

$$P_S = \frac{1}{t_s} * \int_0^{t_s} U(t) * I(t) dt \quad (3)$$

Vlastite studije [4, 6] za merenje nivoa emisija, provođenje toplote i konvekciona energija luka su pokazale da se do 15% snage zavarivanja prenose u okolinu. Ako je luk kapsuliran unutar geometrije šava ili položaja zavarivanja delova, ova energije se apsorbuje u komponentu. Udeo i faktori za dodatni unos toplote u komponentu su nepoznati do sada.

c) Uticaj snage zavarivanja

Za utvrđivanje i obračun snage zavarivanje postoji nekoliko metoda koje se mogu izabrati. Na taj način, različite vrednosti za snagu zavarivanja mogu se odrediti za isti postupak zavarivanja, koji ima veliki potencijal za greške ili visok rezultat nepreciznosti. Fizički ispravan način izračunavanja je prikazan jednačinom 3.

In summary it can be stated that the calculation of the $t_{8/5}$ -values with the equations 1 and 2 is affected by three significant uncertainties. On the one hand, the efficiency is fixed depending on the welding process, without taking into account the different process states. Secondly, there are undefined variations in the selection of a correction factor for the weld shape to the user. Parallel the fact of the welding position is completely disregarded. Additionally the measurement and calculation of welding power has a high potential for error, whereby deviations of up to 70% were determined. These sources of error counteract the exact predetermination of welding-related heat input into the component. Consequently in industrial practice the heat input is usually determined experimentally by thermocouple-based measurements of the real $t_{8/5}$ values.

2. Measurement Technology

a) Determination of the heat input- calorimetry

The aim was to develop a calorimeter, to realise comparative studies on various welding processes and process conditions in defined welding positions and different joint geometries. For this purpose a difference-temperature calorimeter with water as calorimeter medium is used, see figure 1.

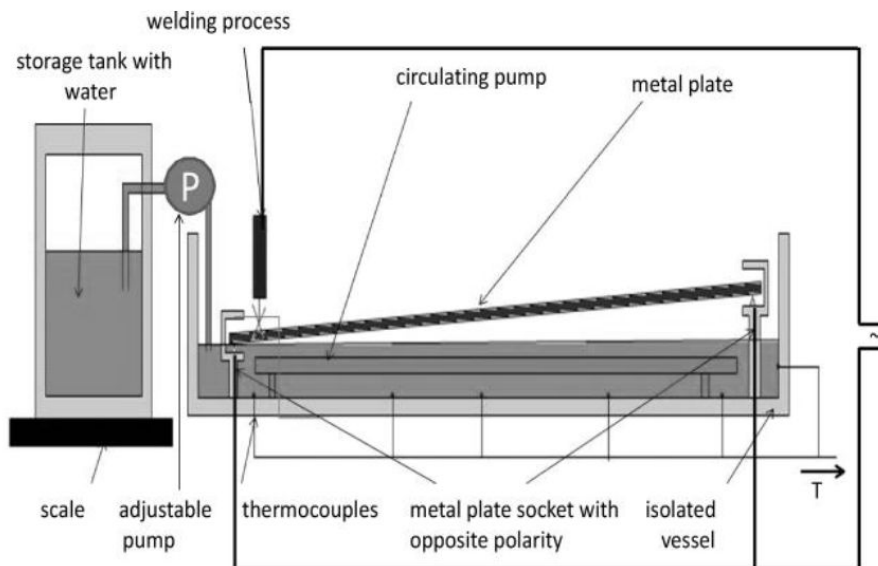


Figure 1. Calorimeter method at TU Chemnitz

Slika 1. Kalorimetarska metoda u TU Chemnitz

In an upwardly open, thermally insulated vessel, the welding sample is clamped at an angle. The welding torch is moved mechanized parallel to the sample surface and the water level raises simultaneous with the welding torch position. Afterwards the resulting temperature difference ΔT before and after welding is analysed. Since all parts in the calorimeter vessel (1 ... n) absorb heat, their

Ukratko se može reći da izračunavanja vrednosti $t_{8/5}$ prema jednačinama 1 i 2 ugrožavaju tri značajne neizvesnosti. S jedne strane, efikasnost je fiksna zavisno od postupka zavarivanja, ne uzimajući u obzir različita stanja postupka. Drugo, postoje nedefinisane varijacije u izboru faktora korekcije za oblik šava prema korisniku. Paralelno sa tim, položaj zavarivanja je potpuno zanemaren. Pored toga, merenje i izračunavanje snage zavarivanja ima veliki potencijal za greške, pri čemu su utvrđena odstupanja do 70%. Ovi izvori grešaka se suprotstavljaju tačnom predodređivanju ulazne toplote zavarivanja u komponentu. Zbog toga se u industrijskoj praksi ulazna toplota obično određuje eksperimentalno merenjem realne vrednosti $t_{8/5}$ zasnovane na merenjima termoparom.

2. Tehnologije merenja

a) Određivanje unete toplote- kalorimetrija

Cilj je bio da se razvije kalorimetar, da bi se uradile komparativne studije o raznim postupcima zavarivanja i uslovima postupka u određenim položajima zavarivanja i različite geometrije šava. U tu svrhu se koristi kalorimetar na bazi razlike temperatura sa vodom kao medijumom kalorimetra, vidi sliku 1.

U na gore otvorenoj, toplotno izolovanoj posudi, uzorak za zavarivanje je stegnut pod uglom. Pištolj za zavarivanje se pomera mehanizovano, paralelno sa površinom uzorka i nivo vode se simultano podiže sa položajem pištolja za zavarivanje. Nakon toga se analizira rezultujuća temperaturna razlika Δt pre i posle zavarivanja. Budući da svi delovi u kalorimetarskoj posudi (1 ... n) apsorbuju toplotu,

warming must be taken into account (equation 4). From the ratio of introduced amount of heat and it expended electrical work, the efficiency of the welding process is finally calculated (equation 5).

$$Q_{Cal} = \sum_1^n (m * c * \Delta T) \quad (4)$$

$$\eta_{eff} = \frac{Q_{BM} + Q_{Cal}}{P_W * t_W} = \frac{Q_{BM} + Q_{Cal}}{t_W * \frac{1}{t_E} * \int_0^{t_E} U_W * I_W * dt} \quad (5)$$

To examine various welding positions, the device is rotatable mounted (Figure 2). The rotation from position PA to PC takes place along the longitudinal axis of the weld. Basically a rotation of 360° is possible, which is reproducibly by an integrated scaling to 2° accuracy. Due to the measuring principle with a continuously rising water level the welding positions PD and PE are not feasible because the water would impede the welding process.

Radi ispitivanja različitih položaja zavarivanja, uređaj je postavljen tako da može da rotira (slika 2). Rotacija sa položaja PA na PC odvija se duž uzdužne ose šava. U osnovi je moguća rotacija 360°, što je ponovljivo integrisanom skalom do 2° preciznosti. Zbog princip merenja sa stalnim rastom nivoa vode, položaji zavarivanja PD i PE nisu mogući jer bi voda ometala proces zavarivanja

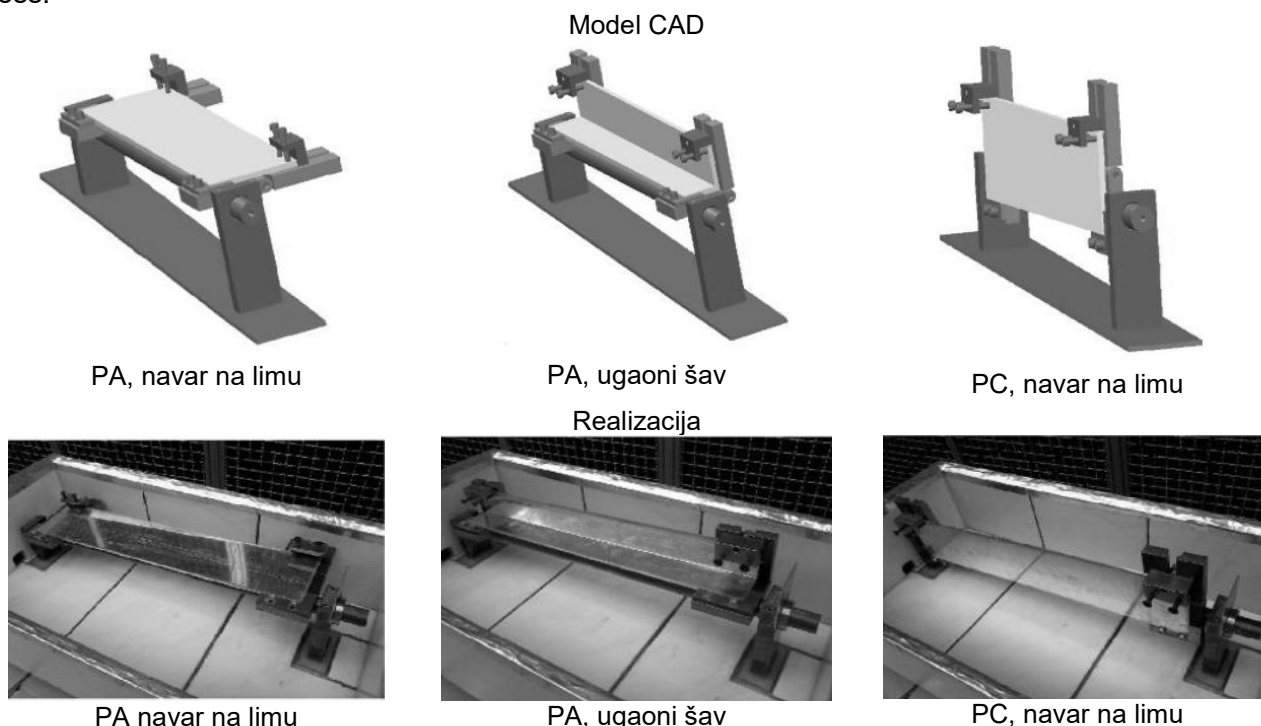


Figure 2. Principle of the turning and tilting function
Slika 2. Princip funkcije okretanja i označavanja

b) Measurement of the cooling rate - $t_{8/5}$ -value

The measurement of the real cooling rate was carried out by thermocouples. For the welding tests K-type thermocouples ($T = -200 \dots 1250 \text{ } ^\circ\text{C}$, wire diameter $2 \times 0,6 \text{ mm}$) were used.

Measuring the cooling rate was performed by immersing the thermocouple in the still liquid melt

b) Merenje brzine hlađenja- vrednosti $t_{8/5}$

Merenje realne brzine hlađenja je sprovedeno termoelementima. Kod testova za zavarivanje korišćen je K-tip termopar ($T = -200 \dots 1250 \text{ } ^\circ\text{C}$, prečnik žice $2 \times 0,6 \text{ mm}$).

Merenje brzine hlađenja je izvedeno potapanjem termoelementa u još tečnu zavarivačku kupku,

immediately after the welding process. Since the measurement position in relation to the weld varied by the manual immersion of the thermocouples, multiple thermocouple measurements were performed per weld, as shown in Figure 3.

odmah nakon procesa zavarivanja. S obzirom da položaj merenja u odnosu na šav varira zbog ručnog uranjanje termoparova, korišćeno je više termoelemenata po šavu, kao što je prikazano na slici 3.

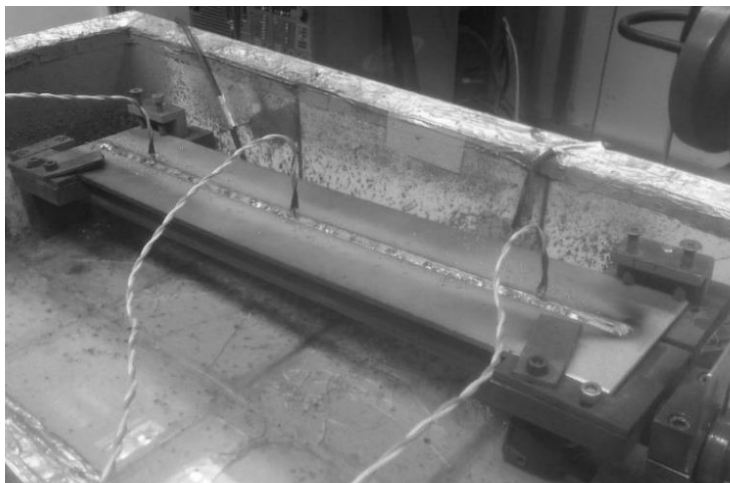


Figure 3. Positioning of the thermocouples in the weld seam
Slika 3. Pozicioniranje termoparova u šav

3. Discussion of potentials for errors

a) Deviations because of the efficiency

The efficiency of welding processes is dependent on a number of process parameter and it can't be defined as a static value. For this reason adaptations of the standards are necessary.

The comparison between the actual performed work, and already published results [4] to the efficiency of for example the GTAW process gave identical statements. The average arc efficiency of the GTAW process varies around $\eta_{\text{eff}} = 0,75$. The arc efficiency decreases with increasing welding current, increasing electrode distance and increasing positive polarity of the electrode. By increasing the amount of inert gas or the helium content in the shielding gas, the arc efficiency of the GTAW welding process increases. Also a dependence on the base material was detected. A dependence of the absolute heat input into the component by the component thickness was not determined.

Also, the effective efficiency of the GMAW process is not a global average of $\eta_{\text{th}} = 0,80$, as specified in DIN EN 1011-1 [1]. Rather, a classification according to the type of arc is advisable:

- Short arc $\eta_{\text{eff}} = 0,85$
- Pulsed arc $\eta_{\text{eff}} = 0,77$
- Spray arc $\eta_{\text{eff}} = 0,70$

Factors that reduce the effective efficiency are:

- Increasing the welding current
- Increasing the welding voltage

3. Diskusija o potencijalima za greške

a) Odstupanja zbog efikasnosti

Efikasnost procesa zavarivanja zavisi od broja parametara procesa i ne može se definisati kao statička vrednost. Iz tog razloga su neophodne adaptacije standarda.

Poređenje između stvarno izvedenih radova i već objavljenih rezultata [4] o efikasnosti za na primer proces TIG, dalo je identičan rezultat. Prosečna efikasnost luka kod postupka TIG je oko $\eta_{\text{eff}} = 0,75$. Efikasnost luka smanjuje se sa povećanjem struje zavarivanja, povećanjem rastojanja elektrode i povećanjem pozitivnog polariteta elektrode. Povećanjem količine inertnog gasa ili sadržaja helijuma u zaštitnom gasu, efikasnost luka TIG postupka zavarivanja se povećava. Takođe je otkrivena i zavisnost od osnovnog materijala. Zavisnost apsolutne količine unete toplote u komponentu za debljinu komponenta nije utvrđena.

Takođe, efektivna efikasnost postupka MIG/MAG nije globalni prosek od $\eta_{\text{th}} = 0,80$, kao što je navedeno u DIN EN 1011-1 [1]. Umesto toga, klasifikacija prema vrsti luka je u prednosti:

- kratak luk $\eta_{\text{eff}} = 0,85$
- impulsni luk $\eta_{\text{eff}} = 0,77$
- raspršeni luk $\eta_{\text{eff}} = 0,70$

Faktori koji smanjuju efektivnu efikasnosti su:

- Povećanje struje zavarivanja
- Povećanje napona zavarivanja

Factors that increase the effective efficiency are:

- Increasing the amount of shielding gas
- Increase in the helium or CO₂ content in the shielding gas
- Increase in the contact tube spacing

It was further noted that the modern heat reduced GMAW short arc processes have a slightly higher effective efficiency than classic GMAW process. However, the more decisive parameter is the required welding power, which is considerably lower in heat reduced GMAW processes. Thus the absolute heat input into the component decreases.

b) Influence of the welding seam geometry

Within the investigations the influence of different welding seam geometries (Figure 4) the heat input of GTAW and GMAW process was analysed.

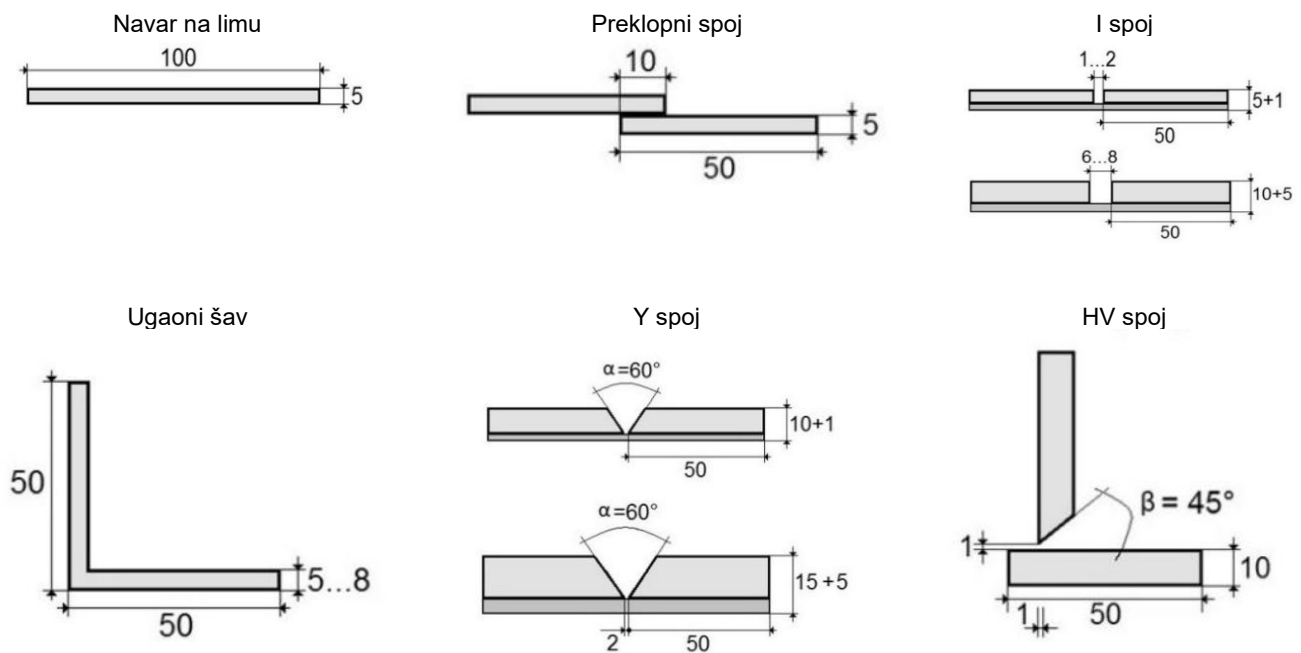


Figure 4. Analysed welding seam geometries

Slika 4. Analizirane geometrije šava

In contrast to the GTAW process is the energy transport of the GMAW process on the one hand by the welding arc as well partly direct by the short circuit and on the other hand by the molten filler material. This is why the influence of the welding seam geometry has a greater influence on the GMAW process. Figure 5 shows that the real heat input into the component can be increased up to 25% when the welding seam geometry is adjusted.

Faktori koji povećavaju efektivnu efikasnost su:

- Povećanje udela zaštitnog gasa
- Povećanje sadržaja helijuma ili CO₂ u zaštitnom gasu
- Povećanje razmaka kontaktne cevi

Dalje je navedeno da moderni toplotno smanjeni postupci MAG kratkim lukom imaju nešto veću efektivnu efikasnost od klasičnog MAG postupka. Međutim, parametar koji više utiče je potrebna snaga za zavarivanje, koja je znatno niža kod toplotno smanjenih MAG postupaka. Tako se smanjuje apsolutni unos toplote u komponentu.

b) Uticaj geometrije šava

U okviru istraživanja, analiziran je uticaj različitih geometrija šava (Slika 4) na unos toplote kod TIG i MAG postupaka.

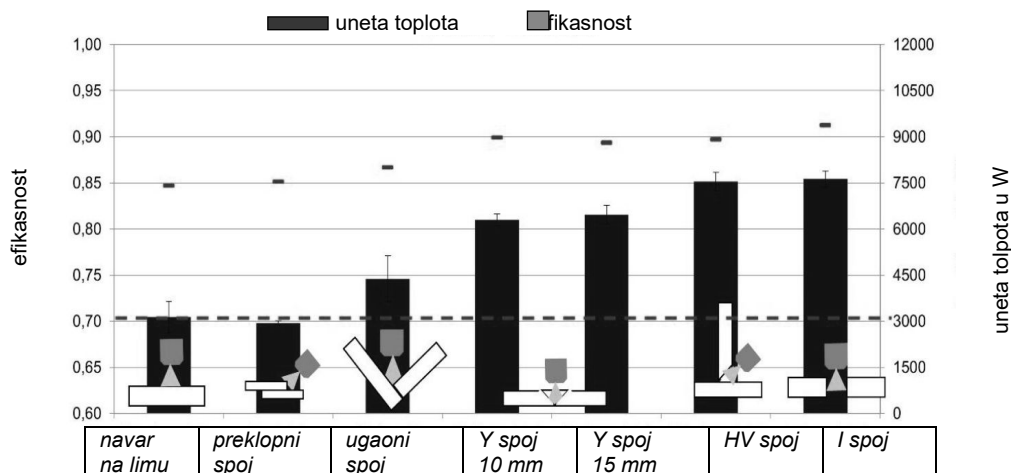


Figure 5. Influence of the welding seam geometry on the efficiency of GMAW

(Parameter: GMAW, $v_{wfs} = 10$ m/min-standard arc; 15 l/min 82 %Ar 18 % CO₂, distance of torch $s = 18$ mm; G3Si1 $d = 1,2$ mm; $vW = 70$ cm/min; BM: S235 $t = 5...15$ mm, PA-position)

Slika 5. Uticaj geometrije šava na efikasnost MAG

(Parametar: MAG, $v_{wfs} = 10$ m/min-standardni luk; 15 l/min 82 %Ar 18 % CO₂, razmak pištolja $s = 18$ mm; G3Si1 $d = 1,2$ mm; $vW = 70$ cm/min; OM: S235 $t = 5...15$ mm, PA-položaj)

Since the welding power remains extensive unchanged, this increase must be justified by the increase in efficiency. In comparison between a bead on plate weld and a V-seam weld the efficiency in GMAW increases about 15%. This shows that increasingly more energy of the welding arc is absorbed by the weld edges in the form of thermal conduction and thermal radiation. This increase is much higher than in GTAW (about 5%). When considering (figure 6) the cooling time of different welding seam geometries the period in which the cooling from $T = 800$ °C to $T = 500$ °C is carried out ($t_{8/5}$ value), reduced to less than half when the seam geometry changes from a bead on plate weld to a HV-seam.

Budući da snaga zavarivanja ostaje nepromenjeno velika, to povećanje mora biti opravdano povećanjem efikasnosti. U poređenju između navara na limu i V-šava, efikasnost kod MAG postupka se povećava za oko 15%. To pokazuje da se sve više energije od zavarivačkog luka apsorbiraju na ivicama šava u obliku toplotne provodljivosti i radijacije. Ovo povećanje je mnogo veće nego kod TIG (oko 5%).

Kada se razmatra (slika 6) vreme hlađenja različitih geometrija šava, period u kojem je završeno hlađenje od $T = 800$ °C do $T = 500$ °C ($t_{8/5}$ vrednosti), smanjen je na manje od pola kada se geometrija šava menja od navara na limu ka HV-šavu.

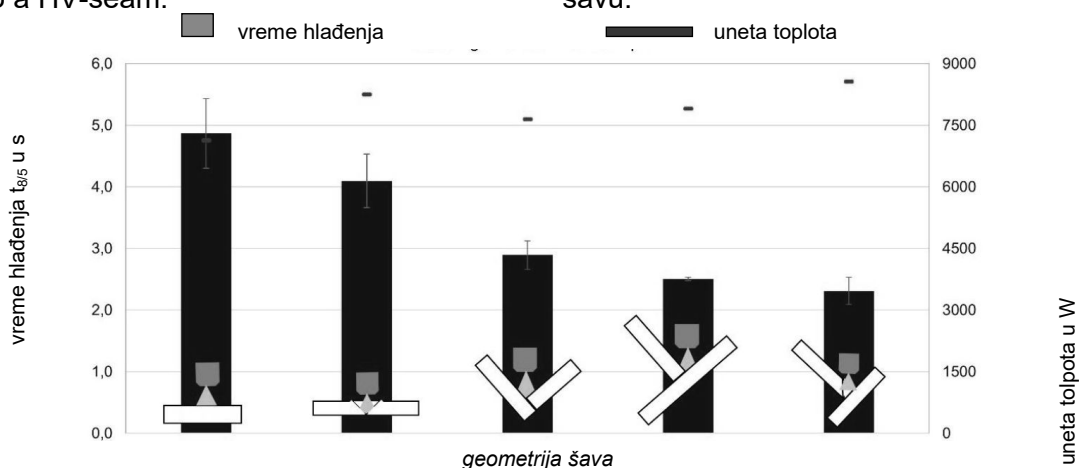


Figure 6. Influence of the welding seam geometry on the cooling rate $t_{8/5}$ of GMAW

(Parameter: GMAW, $v_{wfs} = 10$ m/min-standard arc; 15 l/min 82 %Ar 18 % CO₂, distance of torch $s = 18$ mm; G3Si1 $d = 1,2$ mm; $vW = 70$ cm/min; BM: S235 $t = 10$ mm, PA-position)

Slika 6. Uticaj geometrije šava na efikasnost MAG

(Parametar: MAG, $v_{wfs} = 10$ m/min-standardni luk; 15 l/min 82 %Ar 18 % CO₂, razmak pištolja $s = 18$ mm; G3Si1 $d = 1,2$ mm; $vW = 70$ cm/min; OM: S235 $t = 5...15$ mm, PA-položaj)

Since the plate thickness and the sheet metal volume were kept constant, the different heat dissipation in the volume cannot be the cause for the faster cooling. As the results of the increased efficiency show, the change of the thermal affected surface by the different welding seam geometry is a main influence coefficient. On one hand the heat dissipation in the component can take place into several directions, on the other hand linking of the welding process toward component inside is better. This causes a reduction of the $t_{8/5}$ -value. So for example with the Y-seam the energy can distribute better into the component inside in the comparison to the bead on plate weld, why the $t_{8/5}$ -value is smaller.

The actual information in the standards [5] indicate for example a potential bandwidth of the form factor F2 of $F2 = 0,67 \dots 0,90$. As a result nobody is able to calculate the exact $t_{8/5}$ -value. For this reason, table 2 describes a proposal for a necessary adaption of valid regulations [5] in order to achieve a simplification and systematization.

Budući da su debljine ploča i limova konstantne, različito rasipanje toplote u zapremini, ne može biti razlog za brže hlađenje. Kako rezultat povećanja efikasnosti pokazuje, promena termički pogođene površine zbog različitih geometrija šava je glavni uticajni koeficijent. S jedne strane, odvođenje toplote u komponenti može se odvijati u nekoliko pravaca, s druge strane, povezivanje procesa zavarivanja sa unutrašnjošću komponente je bolje. To uzrokuje smanjenje vrednosti $t_{8/5}$. Tako na primer sa Y-šavom, energija se može distribuirati bolje u unutrašnjost komponente u odnosu na navar, zbog čega je vrednost $t_{8/5}$ manja.

Postojeće informacije u standardima [5] ukazuju na primer potencijalne propusnosti faktora oblika F2 od $F2 = 0,67 \dots 0,90$. Kao rezultat toga je da niko nije u stanju da izračuna tačne vrednosti $t_{8/5}$. Iz tog razloga, u tabeli 2 je dat predlog za potrebno prilagođavanje važećim propisima [5] kako bi se postiglo pojednostavljenje i sistematizacija.



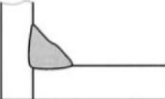
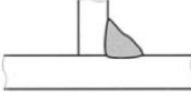
Geometrija šava		Faktor oblika F2 i F3
<i>navar na limu</i>		1,00
<i>međusloj</i>		0,85
<i>ugaoni šav-ivica</i>		0,60
<i>ugaoni šav- T-spoj</i>		0,50

Table 2. Proposal for the adaption of form factors in the standard [5]

Tabela 2. Predlog za adaptaciju faktora oblika u standardu [5]

c) Influence of the welding position

By changing the welding position the efficiency respectively the percentage of welding power, which is converted into real heat in the component, increases by changing the welding position from PA- to PC-position. In this specific case, the relative difference of the efficiency between the PA and PB (60°) position is more than 12%, as shown in figure 7. In GTAW this difference is about 5%.

c) Uticaj položaja zavarivanja

Promenom položaja zavarivanja, efikasnost odnosno procenat snage zavarivanja koja se pretvara u stvarnu toplotu u komponenti, povećava se sa promenom položaja zavarivanja od PA- na PC. U ovom konkretnom slučaju, relativna razlika u efikasnosti između PA i PB (60°) položaja je više od 12%, kao što je prikazano na slici 7. Kod TIG, ova razlika je oko 5%.

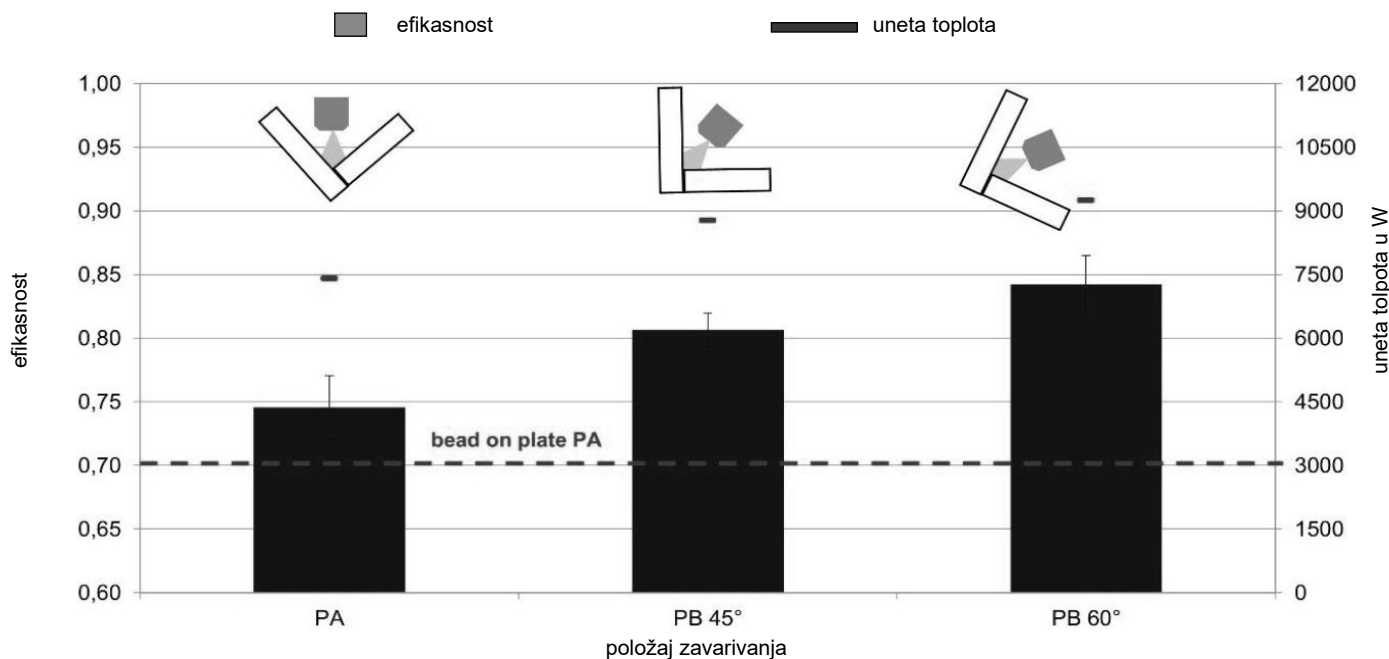


Figure 7. Influence of the welding position on the efficiency of GMAW

(Parameter: GMAW, $v_{wfs} = 10$ m/min-standard arc; 15 l/min 82 %Ar 18 % CO₂, distance of torch $s = 18$ mm; G3Si1 $d = 1,2$ mm; $vW = 70$ cm/min; BM: S235 $t = 10$ mm, fillet weld- edge)

Slika 7. Uticaj položaja zavarivanja na efikasnost MAG

(Parametar: MAG, $v_{wfs} = 10$ m/min-standardni luk; 15 l/min 82 %Ar 18 % CO₂, razmak pištolja $s = 18$ mm; G3Si1 $d = 1,2$ mm; $vW = 70$ cm/min; OM: S235 $t = 5...15$ mm, ugaoni spoj-ivica)

The investigations show that the ascending heat is increasingly absorbed by the component and weld flanks. In this case, the heat input in the component increases by 25%. A justification of this fact can provide the analysis of heat flow behavior on the part in various welding positions. Naturally a warm medium is moving upwards. Due to the additional gas flow of the welding process, the arc energy is transported not only in the form of radiant energy, but also bounded by the material respectively gas. Compared to the PA position the contact area between the component and heated gas increases, so more energy can be absorbed by the entire component.

Despite the unchanged component geometry and constant welding parameter, the heat input increases. Parallel the cooling time increases from $t_{8/5} = 2,9$ s to $t_{8/5} = 4,4$ s when the welding position changes from PA to PC-position (see figure 8). Since the heat input in the component increases by 15% parallel the cooling time increases more than 50%, it seems that the warming was locally improved. The effect is a better warming or "reheating" of the joining zone by the encapsulation of the welding process by the changed welding position.

Istraživanja pokazuju da rastuću toplotu sve više apsorbuju komponente i stranice šava. U ovom slučaju, unos toplote u komponenti povećava se za 25%. A opravdanje ove činjenice može pružiti analiza ponašanja protoka toplote kroz deo u različitim položajima zavarivanja. Naravno topli medijum se kreće uzlaznom putanjom. Zbog dodatnog protoka gasa tokom procesa zavarivanja, energija luka se prenosi ne samo u obliku zračenja, već je vezan i materijal, odnosno gas.

U poređenju sa položajem PA kontaktna površina između komponente i zagrejanog gasa se povećava, tako da više energije može se apsorbirati u celu komponentu.

Uprkos nepromijenjenoj geometriji komponente i stalnim parametrima zavarivanja, unos toplote se povećava. Paralelno se vreme hlađenja povećava od $t_{8/5} = 2,9$ s do $t_{8/5} = 4,4$ s, kada se položaj zavarivanja promeni od PA na PC-položaj (vidi sliku 8). S obzirom da se unos toplote u komponenti povećava za 15% paralelno se vreme hlađenja povećava više od 50%, što ukazuje da se lokalno zagrevanje poboljšalo. Efekat je bolje zagrevanje ili "dogrevanje" od zone spajanja zbog inkapsulacije zavarivanja, promenjenim položajem zavarivanja.

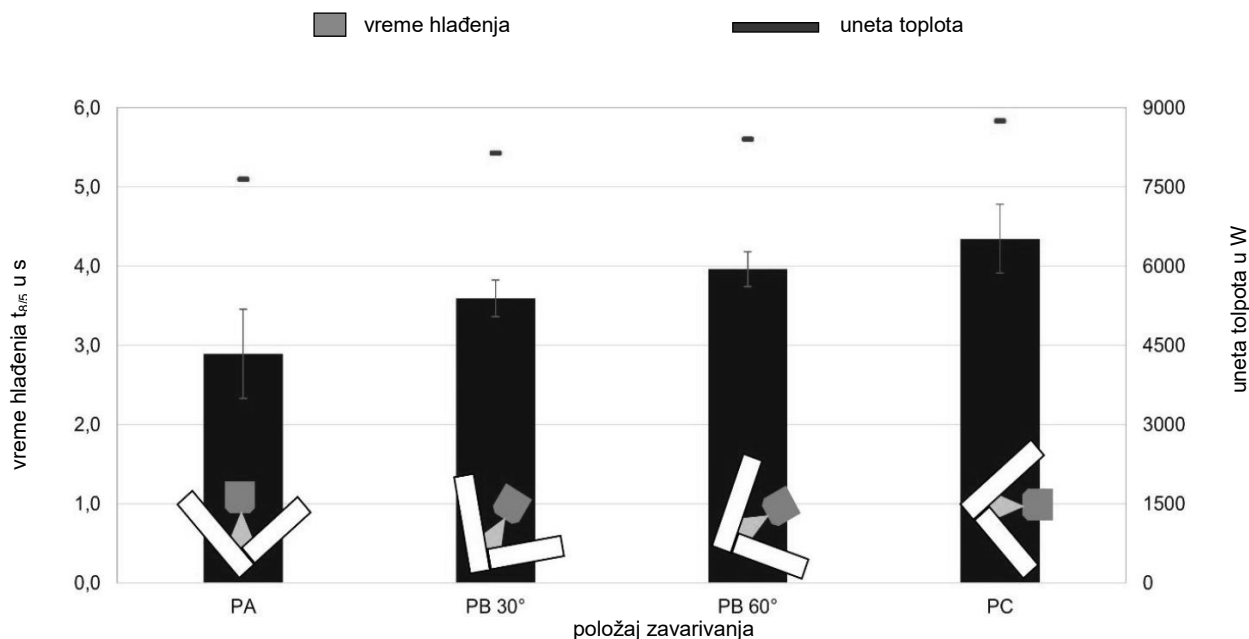


Figure 8. Influence of the welding position on the cooling rate $t_{8/5}$ of GMAW

(Parameter: GMAW, $v_{wfs} = 10$ m/min-standard arc; 15 l/min 82 %Ar 18 % CO₂, distance of torch $s = 18$ mm; G3Si1 $d = 1,2$ mm; $vW = 70$ cm/min; BM: S235 $t = 10$ mm, fillet weld-edge)

Slika 8. Uticaj položaja zavarivanja na brzinu hlađenja $t_{8/5}$ kod MAG

(Parametar: MAG, $v_{wfs} = 10$ m/min-standardni luk; 15 l/min 82 %Ar 18 % CO₂, razmak pištolja $s = 18$ mm; G3Si1 $d = 1,2$ mm; $vW = 70$ cm/min; OM: S235 $t = 5...15$ mm, ugaoni spoj- ivice)

Both in the literature and in the actual standards [5] no correction factors exist with respect to the welding position. However figure 8 illustrates that the welding position has a significant influence on the cooling time of the component. For this reason it is recommended to introduce and correction factors with respect to the welding position in addition to the correction factors with respect to the welding seam geometry. A first proposal for the necessary adaption or integration of a position factor can be seen in table 3.

I u literaturi i u važećim standardima [5] ne postoje faktori korekcije u odnosu na položaj zavarivanja. Međutim, slika 8 pokazuje da položaj zavarivanja ima značajan uticaj na vreme hlađenja komponente. Iz tog razloga se preporučuje da se uvede i korekcionni faktor u odnosu na položaj zavarivanja pored faktora korekcije u odnosu na geometriju šava. Prvi predlog za potrebnu adaptaciju ili integraciju faktora položaja se može videti u tabeli 3.

Položaj zavarivanja	Faktor položaja
PA	1,0
PB	1,3
PC	1,5

Table 3. Proposal for the adaption of the position factor in the standard [5]

Tabela 3. Predlog za adaptaciju faktora položaja u standardu [5]

d) Influence of Interlayers

The investigations in relation to the layer structure were carried out exclusively with the GMAW process, since hereby continuously filler material is introduced into the weld.

Figure 9 clearly shows that with increasing layer structure, in the predetermined V welding seam geometry, the efficiency and thus the proportion of welding power, which is converted into heat in the

d) Uticaj međuslojeva

Istraživanja u odnosu na strukturu sloja obavljena su isključivo sa postupkom MAG, jer je ovde primenjeno kontinuirano dodavanje dodatnog materijala u šav.

Slika 9 jasno pokazuje da se sa povećanjem slojeva, u prethodno određen V šav, smanjuje efikasnost, a time i udeo snage zavarivanja koji se pretvara u toplotu u komponenti. U poređenju

component decreases. Compared between root and top layer, the efficiency of $\eta = 0,82$ (root pass) drops to $\eta = 0,70$ (top layer).

This confirms the results of previous work that the thermal conduction and thermal radiation from the arc can be better absorbed by the weld edges, if this is "encapsulated" by the component or welding seam geometry. In direct comparison to the results shown in Figure 4 the root layer has the same level like the Y-shape joint ($t = 15 \text{ mm}$ and $\alpha = 60^\circ$), and the top layer provides identical results as the bead on plate weld.

između korena i završnog sloja, efikasnost $\eta = 0,82$ (koreni prolaz) padne na $\eta = 0,70$ (završni sloj).

To potvrđuje rezultate dosadašnjeg rada na tome da termička provodljivost i radijacija iz luka mogu bolje da se apsorbiraju kroz stranice šava, ako je "inkapsulirana" od strane komponente ili geometrije šava. U direktnom poređenju rezultata prikazanih na slici 4, koreni sloj ima isti nivo kao i Y-oblik spoja ($t = 15 \text{ mm}$ i $\alpha = 60^\circ$), a završni sloj daje identične rezultate kao navar.

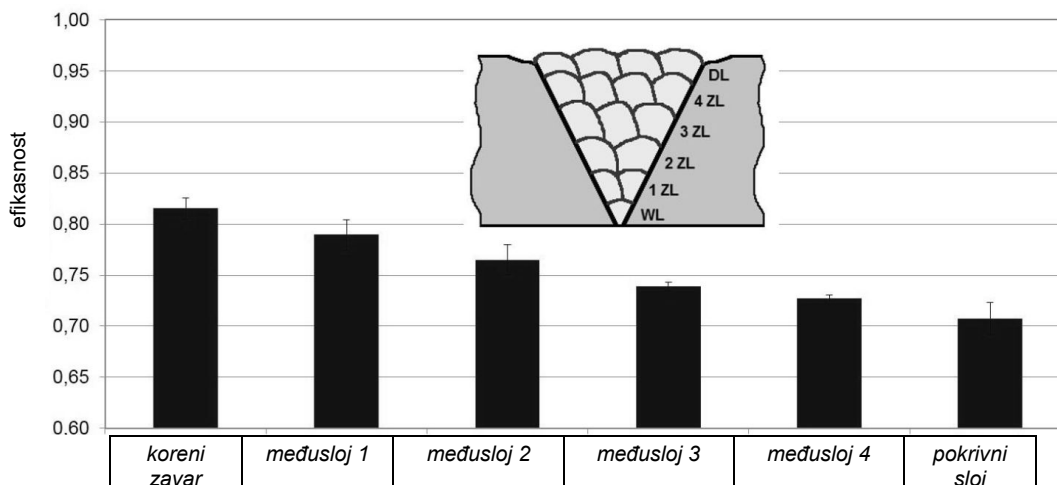


Figure 9. Influence of the interlayer on the efficiency of GMAW

(Parameter: GMAW, $v_{wfs} = 10 \text{ m/min}$ -standard arc; 15 l/min 82 %Ar 18 % CO₂, distance of torch $s = 18 \text{ mm}$; G3Si1 $d = 1,2 \text{ mm}$; $vW = 70 \text{ cm/min}$; BM: S235 $t = 15 \text{ mm}$, Y-shape joint $\alpha = 60^\circ$, PA-position)

Slika 9. Uticaj međusloja na efikasnost kod MAG

(Parametar: MAG, $v_{wfs} = 10 \text{ m/min}$ -standardni luk; 15 l/min 82 %Ar 18 % CO₂, razmak pištolja $s = 18 \text{ mm}$; G3Si1 $d = 1,2 \text{ mm}$; $vW = 70 \text{ cm/min}$; OM: S235 $t = 5...15 \text{ mm}$, Y-spoj $\alpha = 60^\circ$, PA-položaj)

4. Summary

The results show that the energy input into the component depends on a number of parameter and can be calculated only inadequately with the details of the actual standards.

Within this project practically used determination and calculation methods of welding performance were analyzed and their potential for errors determined. Deviations of up to 70% were determined. Depending on the set parameter of the welding process, deviations in efficiency of up to 20% can occur. In addition, the welding processes with non-consumable electrode have an average of 25% higher efficiency than described in the actual standards [1, 2]. Welding processes with consumable electrodes should be divided depending on the type of arc. The static value of $\eta = 0,80$ [1, 2] should therefore be adjusted.

The welding seam geometry has a serious influence on the energy input into the component. For example when GMAW in comparison of the

4. Sažeti prikaz

Rezultati pokazuju da unos energije u komponentu zavisi od većeg broja parametara i može se izračunati samo neadekvatno prema detaljima važećeg standarda.

U okviru ovog projekta praktično su korišćene metode za utvrđivanje i izračunavanje a performanse zavarivanja su analizirane i utvrđen njihov potencijal za greške. Ustanovljeno je da su odstupanja do 70%. Zavisno od seta parametara postupka zavarivanja, može doći do odstupanja u efikasnosti i do 20%. Osim toga, postupci zavarivanja sa netopivim elektrodama imaju u proseku 25% veću efikasnost nego što je opisano u važećem standardu [1, 2]. Postupci zavarivanja sa topivim elektrodama treba da budu podeljeni u zavisnosti od vrste luka. Statička vrednost $\eta = 0,80$ [1, 2] stoga treba da bude prilagođena.

Geometrija šava ima ozbiljan uticaj na unos energije u komponentu. Na primer, kod MAG postupka u poređenju efikasnosti između navara

efficiency between a bead on plate weld $\eta_{\text{eff}} = 0,70$ and an HV-seam $\eta_{\text{eff}} = 0,85$, the relative proportion of the heat input into the component increases by more than 20%. However the period in which the cooling from $T = 800 \dots 500 \text{ } ^\circ\text{C}$ is performed ($t_{8/5}$ -value) decreases to less than half.

Regarding to the absolute heat input respectively efficiency the sheet thickness has no influence. But the sheet thickness has a significant influence on the cooling rate ($\Delta t_{8/5} = 50\%$) in the considered range from $t = 5 \dots 15 \text{ mm}$. Then there is the factor of the welding position. By GMAW the efficiency increases about 12% when changing the welding position from PA to PC-position. In this case, the heat input in the component increases by 25%. At the same time the cooling time ($t_{8/5}$ -value) increases by more than 50%. For this reason it is recommended to introduce and correction factors in the valid regulations [5] with respect to the welding position in addition to the correction factors with respect to the welding seam geometry.

The analysis of the layer structure in the predetermined V-shape geometry showed that the efficiency and thus the proportion of welding power, which is converted into the component, decreases.

Acknowledgement

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na limu $\eta_{\text{eff}} = 0,70$ i HV-šava $\eta_{\text{eff}} = 0,85$, relativni udeo unete toplote u komponentu se povećava za više od 20%. Međutim, period hlađenja od $T = 800 \dots 500 \text{ } ^\circ\text{C}$ ($t_{8/5}$ -vrednosti) smanjuje se na manje od pola.

Što se tiče apsolutnog unosa toplote, debljina lima nema uticaja na efikasnost. Ali debljina lima ima značajan uticaj na brzinu hlađenja (vrednost $\Delta t_{8/5} = 50\%$) u razmatranom rasponu od $t = 5 \dots 15 \text{ mm}$.

Zatim, tu je i faktor položaja zavarivanja. Kod MAG, efikasnost raste za oko 12% kada se menja položaj zavarivanja od PA ka PC. U ovom slučaju, unos toplote u komponenti se povećava za 25%. U isto vreme, vremena hlađenja ($t_{8/5}$ -vrednosti) se povećavaju za više od 50%. Iz tog razloga se preporučuje da se uvede i korektivni faktor u važećim propisima [5] vezano za položaj zavarivanja pored faktora korekcije vezanih za geometriju šava.

Analiza strukture sloja u prethodno određenoj geometriji V-oblika pokazala je da se efikasnost, a time i udeo energije za zavarivanje, koji se uvodi u komponente, smanjuje.

Zahvalnost

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