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The influence of the tranverse inclination of the MAG welding torch on the geometry of the root seam

Uticaj poprečnog nagiba gorionika za zavarivanje MAG na geometriju korenog šava

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Ključne reči: zavarivanje, MAG gorionik za zavarivanje, bočni nagib, šav

Key words: welding, MAG welding torch, side slope, seam

Abstract

When the welding torch is manually guiding, the influ-ence on the quality of the welded joint has a welder or welding operator in automatic or robotized welding. In both cases, due to negligence, ignorance or other objective reasons, there may be deviations from symmetry or source of heat – welding torch or deviations of the axis groove. That is the cause of unevenly heating of the groove side, the asymmetry of the heat impact zone and the welding seam cross-sectional have different mechanical, structu-ral and chemical properties. The asymmetricity of the amount of heat input leads to problems in the formation of welding seam and the occurrence of welding errors.

Through the work, is analiyzed the influence of the transverse inclination of the MAG welding torch on the geometry of the root seam, represented by the proportion of the melted material of the groove edges.

Rezime

Kada se gorionik za zavarivanje ručno vodi, uticaj na kvalitet zavarenog spoja ima zavarivač ili zavarivač u automatskom ili robotizovanom zavarivanju. U oba slučaja, zbog nepažnje, neznanja ili drugih objektivnih razloga, može doći do odstupanja od simetrije ili izvora toplote za zavarivanje-gorionika ili odstupanja od ose žljeba.To je uzrok neravnomernog zagrevanja strane žljeba, asimetrije zone uticaja toplote i preseka šava koji imaju različita mehanička, strukturna i hemijska svojstva. Asimetričnost količine unesene toplote dovodi do problema u formiranju šava i do pojave grešaka u zavarivanju. Kroz rad se analizira uticaj poprečnog nagiba MAG gorionika za zavarivanje na geometriju korenog šava, predstavljen proporcijom rastopljenog metala ivica žljeba.

1. Introduction

When designing welding technology, such as welding position, burner position, electrical arc dynamics and electric arc control, seam parameters, input parameters and heat dissipation from welding zones are essential parameters to be chosen in optimum values so that a precisely defined welded joint meets the set requirements.

1. Uvod

Pri projektovanju tehnologije zavarivanja, parametri kao što su položaj zavarivanja, položaj gorionika, dinamika električnog luka i kontrola električnog luka, parametri šava, ulazni parametri i rasipanje toplote iz zona zavarivanja su bitni parametri koji se biraju u optimalnim vrednostima tako da precizno definisan zavareni spoj ispunjava postavljene zahteve.

2. The position of the burner in relation to the straight joint and welding direction

The geometrical characteristics of the seam and the penetration are influenced by the welding torch position relative to the straight joint, and are determined by the following factors:

- welding direction,
- the angle of the longitudinal slope (angle of movement) is the angle that the part of the burner closes with the reference line perpendicular to the seam, (Fig. 1). It is also the corner of the burner tip relative to the welding direction. The influence of

2. Položaj gorionika u odnosu na ravnost spoja i smer zavarivanja

Na geometrijske karakteristike šava i uvarivanje utiče položaj gorionika za zavarivanje u odnosu na ravnost spoj, a određuju ih sledeći faktori:

- smer zavarivanja,
- ugao podužnog nagiba (ugao kretanja) je ugao koji deo gorionika zatvara sa referentnom linijom normalnom na šav (Sl. 1). To je takođe ugao vrha gorionika u odnosu na smer zavarivanja. Uticaj ovog ugla na geometrijske karakteristike šava prikazan je na slici 2.

this angle on the geometrical characteristics of the seam is shown in Figure 2.

- transversal inclination - angle of displacement between the burner and the reference line vertical to the seam of the seam, (Fig. 1). For this angle in the literature there is no specific data for the MAG welding process.

- poprečni nagib - ugao pomeranja između gorionika i referentne linije vertikalno na šav, (Sl. 1). Za ovaj ugao u literaturi ne postoje konkretni podaci za MAG postupak zavarivanja

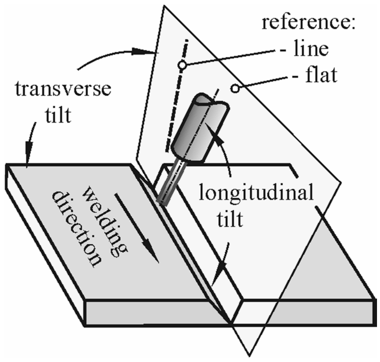

Figure 1. *The slope of the burner in relation to the reference line and flat*
Slika 1. *Nagib gorionika u odnosu na referentnu liniju i rava*

The gravity of the burner in the direction of welding can influence the geometrical characteristics of the weld. The forehand technique formed by the seam remains behind the burner, and the protective gas covers only the bath and base material that is heated in front of the burner tip, Figure 2a. Penetration is the smallest and the largest stitch width, with a low gloss and a nice face look. In the backhand technique of torch control, the formed seam remains in front of the burner tip so that the protective gas covers the bath and formed the seam, Figure 2c. This technique provides a convex and narrower seam, with greater overhang and penetration, more rugged face seams, more stable arc and less spreading of additional material. In this technique, the tendency for porosity to appear is lower than in the technique left.

Gravitacija gorionika u smeru zavarivanja može uticati na geometrijske karakteristike zavarenog spoja. Tehnika unapred znači da šav ostaje iza gorionika, a zaštitni gas pokriva samo kupku i osnovni materijal koji se zagreva ispred vrha gorionika, slika 2a. Uvarivanje je najmanje i najveća širina šava, malog sjaja i lepog izgleda lica. U tehnici unazad za kontrolu gorionika, formirani šav ostaje ispred vrha gorionika tako da zaštitni gas prekriva kupku i formirani šav, slika 2c. Ova tehnika obezbeđuje konveksni i uži šav, sa većim pregibom i uvarivanjem, hrapavijim licem šava, stabilnijim lukom i manjim razbrizgavanjem odatnog materijala. U ovoj tehnici, tendencija pojave poroznosti je niža nego kod tehnike u levo.

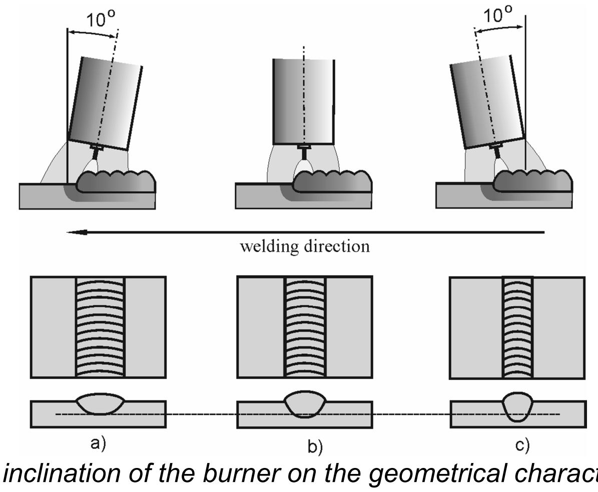

Figure 2. *Impact of longitudinal inclination of the burner on the geometrical characteristics of the seam: a) forehand technique - electrode directed in front of the bath b) vertical - electrode is perpendicular to seam c) backhand technique - the electrode is directed to the bath*
Slika 2. *Uticaj uzdužnog nagiba plamenika na geometrijske karakteristike šava: a) tehnika unapred - elektroda usmerena ispred kupke b) vertikalna - elektroda je normalna na šav c) tehnika unazad - elektroda je usmerena na kupku*

The maximum penetration depth is achieved in the horizontal position of welding backhand technique, at a longitudinal angle of about 25° from the vertical or.

The side inclination of the burner leads to: uneven heating of the groove side, sewing problems, welding errors and the unbalance of the heat impact zone (Fig. 3):

Maksimalna dubina prodiranja postiže se u vodoravnom položaju tehnikom zavarivanja unazad, pri podužnom uglu od oko 25° od vertikale.

Bočni nagib gorionika dovodi do: neravnomernog zagrevanja stranice žljeba, problema sa slaganjem, grešaka u zavarivanju i neravnotežne zone uticaja toplote (Sl. 3):

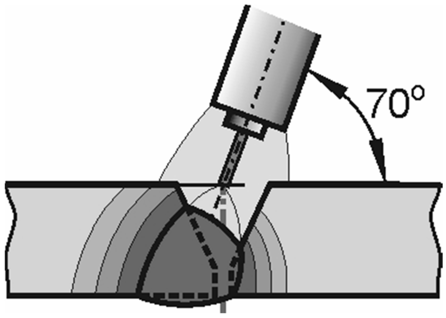

Figure 3. *Asymmetry seam and HAZ for skewing axis groove and burners*
Slika 3. *Asimetrični šav i ZUT u za kosu osu žljeba i gorionika*

a) In the lateral inclination of the burner, the electric arc is shifted to a greater extent on one of the side edges of the groove, whereby it is more melted than the other - less heated edge. In this way an asymmetric seam with different mechanical, structural and chemical properties per section is obtained.

b) Between the formed seam and the less heated side of the groove a sharp transition is formed which represents the voltage concentration, while this shape of the seam prevents the proper cleaning of the frame and makes it difficult to form the next passage in the multi-threaded welding.

c) At higher volumes of deposits, the melting excess of excess material may appear, which fades into the side of the groove which is less heated.

d) Due to the increased amount of heat on the side of the heated overflow it may be possible to appear in the joint.

A large number of influencing parameters in the MAG welding process, requires prior testing and selection of influencing parameters. The process was limited in terms of performing the experimental part of the work and sample numbers that would give the qualifying values needed to evaluate the set problem. Repeatability of the set welding parameters required that the experimental part of the work be performed automated or robotically.

All experimental samples were prepared by assembling two plates (length 300 mm, width 150 mm and thickness 8 mm). The panels are welded to the profiles assembled and tightened at both ends, and a gap between the plate is formed. In the center a "V" groove is formed. During the welding of the sample series probes, in the position of the

a) Kod bočnog nagiba gorionika, električni luk se pomera u većoj meri na jednu od bočnih ivica žljeba, pri čemu se topi više od druge - manje zagrejane ivice. Na ovaj način se dobija asimetrični šav različitih mehaničkih, strukturnih i hemijskih svojstava po preseku.

b) Između formiranog šava i manje zagrejane strane žjeba formira se oštar prelaz koji predstavlja koncentraciju napona, dok ovaj oblik šava sprečava pravilno čišćenje i otežava formiranje sledećeg prolaza kod višelojnih šavova.

c) Pri većim količinama depozita, može se pojaviti višak rastopljenog materijala koji upada na stranu žljeba koja je manje zagrejana.

d) Zbog povećane količine toplote sa strane pregrejanog dela, može se pojaviti preliv u spoju.

Veliki broj uticajnih parametara u MAG postupku zavarivanja, zahteva prethodno testiranje i izbor uticajnih parametara. Proces je bio ograničen u pogledu izvođenja eksperimentalnog dela rada i broja uzoraka koji bi dali kvalifikovane vrednosti potrebne za procenu postavljenog problema.

Ponovljivost zadatih parametara zavarivanja zahtevala je da se eksperimentalni deo rada izvodi automatizovano ili robotski

Svi eksperimentalni uzorci pripremljeni su postavljanjem dve ploče (dužine 300 mm, širine 150 mm i debljine 8 mm). Ploče su zavarene u profile postavljene i zategnute na oba kraja, a između ploče se formira zazor. U sredini je formiran "V" žljeb.

burner in favor of the axis of the groove, the problem was the value of the gap between the slab of the experimental samples
- at a gap greater than the diameter of the wire, regardless of the welding speed, there was excessive melting of the edges of the groove, after which the electric arc was poured and the electrode wire passed through the gap,
- in a small gap, the influence of the temperature introduced by the mobile heat source was so high that the temperature tensions caused the deformations that had accumulated the groove and further reduced the gap, so that it was not possible to fully recover the root.

The smallest number of errors was achieved with the value of the gap between the plates equal to the diameter of the electrode wire, so all the samples were prepared with this gap.

Through the experimental part of the work, besides the many variable and influencing parameters set as constant values, three variable parameters have been selected, which can be linearly altered from the bottom to the upper level. In the selected three-stage level, values have been changed:
- transversal inclination of the burner,
- longitudinal inclination of the burner,
- welding current strengths.

An experiment with three variable sizes in three levels, ie type 3^3 experiment, was formed.

The paper analyzes the obtained values of the geometrical characteristics of seams and holes, formed in the "V" rod at MAG welding of the root passage in the horizontal position (Fig. 4). An analysis of the errors and the homogeneity of the seam was made.

Tokom zavarivanja serije uzoraka, u položaju gorionika u osi šava, problem je bila vrednost zazaora između ploče eksperimentalnih uzoraka
- pri zazoru većem od prečnika žice, bez obzira na brzinu zavarivanja, došlo je do prekomernog topljenja ivica žljeba, nakon čega je električni luk bio slab i žica prolazi kroz zazor,
- pri malom zazoru, uticaj temperature koju je uneo mobilni izvor toplote bio je toliko visok da su temperaturna zatezanja izazivala deformacije koje su se nagomilale na žljebu i dodatno smanjile zazor tako da nije bilo moguće potpuno oporaviti koren.

Najmanji broj grešaka postignut je pri vrednosti zazora između ploča jednakog prečniku žice, tako da su svi uzorci pripremljeni sa ovim zazorom.

Kroz eksperimentalni deo rada, pored mnogih promenljivih i uticajnih parametara postavljenih kao konstantne vrednosti, odabrana su tri promenljiva parametra, koja se mogu linearno menjati od dna do gornjeg nivoa. U odabranom nivou od tri faze, vrednosti su promenjene:
- poprečni nagib gorionika,
- uzdužni nagib gorionika,
- jačine struje zavarivanja

Formiran je eksperiment sa tri promenljive veličine u tri nivoa, tj. eksperiment tipa 3^3.

U radu su analizirane dobijene vrednosti geometrijskih karakteristika šavova i rupa, formiranih u šipki "V" pri MAG zavarivanju korenog prolaza u vodoravnom položaju (slika 4). Izvršena je analiza grešaka i homogenosti šava.

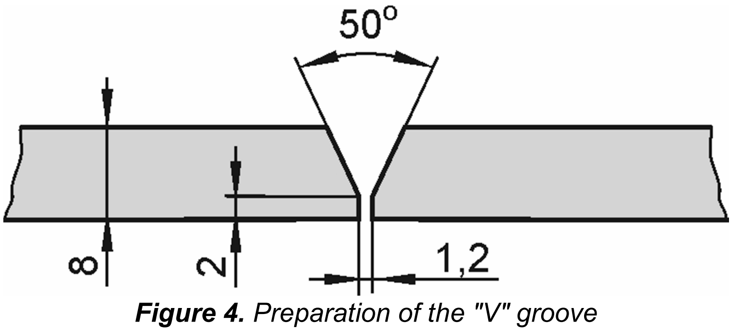

Figure 4. *Preparation of the "V" groove*
Slika 4. *Priprema "V" žljeba*

3. Experimental part of the work

In addition to the selected influencing parameters of welding that change through experimental operation, the welding parameters adopted as constant values are:
- basic material of quality S 235 JR thickness 8 mm,
- prepared "V" groove with a gap of 1.2 mm and a 2 mm root canopy,

3. Eksperimentalni deo rada

Pored odabranih uticajnih parametara zavarivanja koji se menjaju u eksperimentu, parametri zavarivanja koji su prihvaćeni kao konstantne vrednosti su:
- osnovni materijal kvaliteta S 235 JR debljine 8 mm,
- pripremljeni "V" žljeb sa zazorom od 1,2 mm i visinom od 2 mm,

- additional material - electrode wire, quality G 42 2 C G3Si1, diameter 1,2 mm,
- a protective gas composition of 82% Ar and 18% CO2,
- a 12-liter turbine flow rate,
- welding speed - burner movement: 50 cm per minute,
- the top of the burner nozzle with the tip of the leader of the electrode wire,
- positioning of the burner tip at a distance of 6 mm from the upper surface of the experimental sample,
- the length of the free end of the electrode wire is 6 mm,
- device operation mode: no pulse current, with synchronous connection, with start and end current,
- wire electrodes at the plus (+) pole.

The variable parameters were changed in three levels:
- transverse inclination of the burner: 90°, 80° and 70° (Fig. 5)

- dodatni materijal - elektrodna žica, kvaliteta G 42 2 C G3Si1, prečnik 1,2 mm,
- zaštitni sastav gasa od 82% Ar i 18% CO_2,
- protok gasa u turbini od 12 litara,
- brzina zavarivanja - kretanje gorionika: 50 cm u minuti,
- vrh mlaznice gorionika sa vrhom vođice žice ,
- postavljanje vrha gorionika na udaljenosti od 6 mm od gornje površine eksperimentalnog uzorka,
- dužina slobodnog kraja žice je 6 mm,
- režim rada uređaja: bez impulsne struje, sa sinhronom vezom, sa početnom i krajnjom strujom,
- žičane elektrode na plus (+) polu

Promenljivi parametri su promenjeni u tri nivoa:
- poprečni nagib gorionika: 90°, 80° i 70° (Sl. 5)

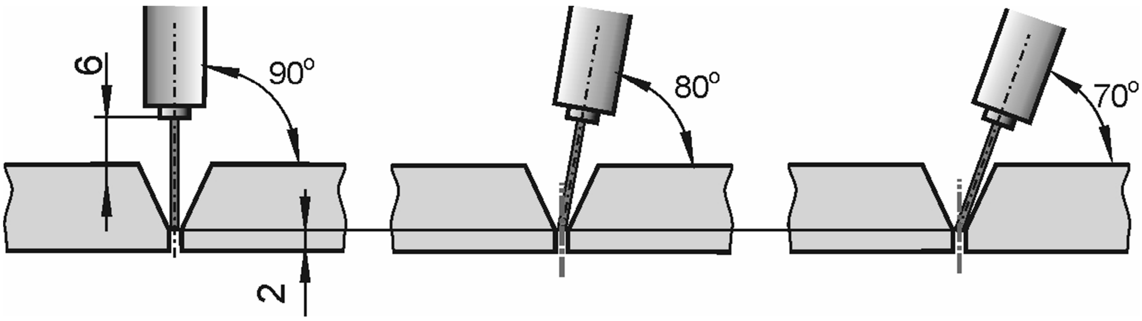

Figure 5. *Levels transverse inclination of the burner*
Slika 5. *Nivoi poprečnog nagiba plamenika*

- the longitudinal inclination of the burner; 100°, 90° and 80° (Fig. 6)

- uzdužni nagib gorionika; 100°, 90° i 80° (Sl. 6)

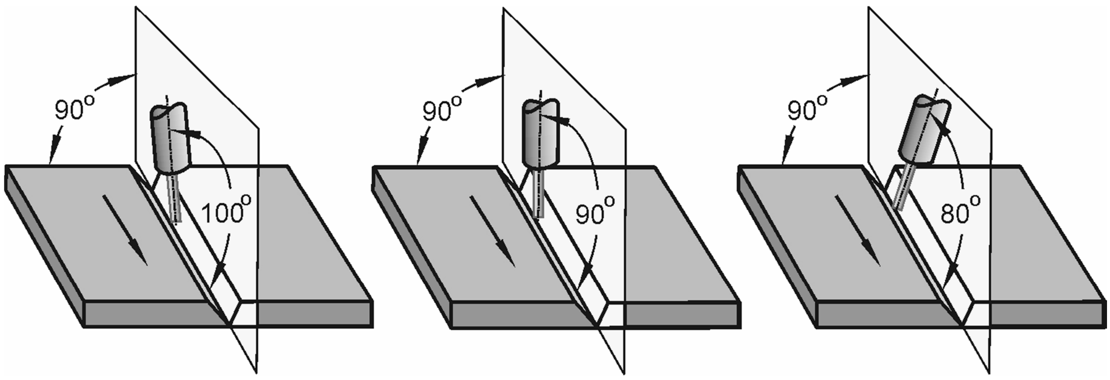

Figure 6. *Levels longitudinal inclination of the burner*
Slika 6. *Nivoi uzdužnog nagiba plamenika*

- welding current: 240 A, 230 A and 220 A.

Based on the selected variable parameters, an experiment matrix was created (Table 1).

- struja zavarivanja: 240 A, 230 A i 220 A.

Na osnovu izabranih parametara promenljivih, kreirana je eksperimentalna matrica (Tabela 1).

Sample mark	Variation level								
	1. parameter (°)			2. paremater (°)			3. paremater (A)		
	1	2	3	1	2	3	1	2	3
K 111	90			100			240		
K 112	90			100				230	
K 113	90			100					220
K 121	90				90		240		
K 122	90				90			230	
K 123	90				90				220
K 131	90					80	240		
K 132	90					80		230	
K 133	90					80			220
K 211		80		100			240		
K 212		80		100				230	
K 213		80		100					220
K 221		80			90		240		
K 222		80			90			230	
K 223		80			90				220
K 231		80				80	240		
K 232		80				80		230	
K 233		80				80			220
K 311			70	100			240		
K 312			70	100				230	
K 313			70	100					220
K 321			70		90		240		
K 322			70		90			230	
K 323			70		90				220
K 331			70			80	240		
K 332			70			80		230	
K 333			70			80			220

Table 1. *Sample marks, depending on the level of variable parameters*
Tabela 1. *Oznake uzoraka, zavisno od nivoa promenljivih parametara*

Samples was welding on robot type AX-V4L, with control type AX-C manufacturers OTC - Daihen and power source type VPS 400 digits.
After welding, the crop made metallographic sample preparation for analysis of the geometry of the weld and the HAZ.
For each sample, a mesh was made over the cross-sectional screen (Figure 7), after which a characteristic surface was measured:
- the transverse side of the groove to which the electric arc is directed (left side - 1),
- HAZ on the side of the groove to which the electric arc (zl) is directed,
- Deposits (3),
- the transverse side of the groove to which the burner is inclined (right side - 2),
- HAZ on the side of the slit to which the burner is inclined (zd),
- indentation on the left edge (4l) and right (4d) fit groove.

Uzorci su zavarivani na robotu tipa AKS-V4L, sa kontrolnim tipom AKS-C proizvođača OTC - Daihen i izvorom snage VPS 400 .
Posle zavarivanja, isečen je metalografski uzorak za analizu geometrije zavara i ZUT
Za svaki uzorak napravljena je mreža preko ekrana poprečnog preseka (slika 7), nakon čega je izmerena karakteristična površina:
- poprečna strana žljeba na koji je usmeren električni luk (leva strana - 1),
- ZUT sa strane žljeba na koji je usmeren električni luk (zl),
- depoziti (3),
- poprečna strana žljeba do koje je gorionik nagnut (desna strana - 2),
- ZUT sa bočne strane na koji je gorionik nagnut (zd),
- žljeb na levoj ivici (4l) i žljeb na desnoj (4d) .

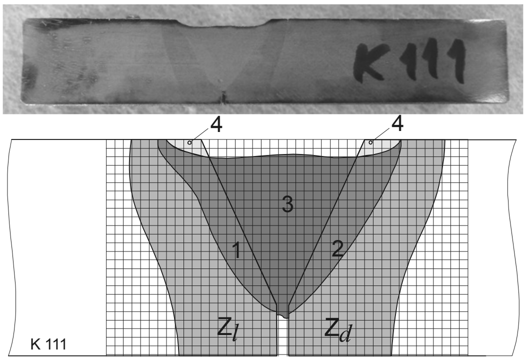

Figure 7. *Surfaces obtained by covering seam borders*
Slika 7. *Površine dobijene prekrivanjem obruba šava*

Measured values of individual surfaces are shown in Table 2 and used in mathematical analysis and modeling the impact of the selected variable parameters.

Izmerene vrednosti pojedinih površina prikazane su u Tabeli 2 i koriste se u matematičkoj analizi i modeliranju uticaja odabranih promenljivih parametara.

Sample mark	*4l*	*Zl*	1	3	2	*Zd*	*4d*
	Surface (mm²)						
K111	0,61	20,88	6,76	16,50	7,17	21,39	0,65
K112	0,42	21,01	6,50	14,22	6,37	20,50	0,55
K113	0	17,67	4,96	14,39	4,08	18,13	0
K121	0	20,48	12,38	19,80	13,88	21,07	0
K122	0	20,73	9,64	15,41	12,16	22,18	0,18
K123	0	20,46	6,46	14,22	5,40	20,49	0
K131	0,39	27,97	7,96	17,35	5,61	23,40	0,25
K132	0	21,29	7,77	13,34	6,20	20,26	0
K133	0	17,21	4,27	12,87	3,10	16,95	0
K211	0	21,43	11,05	16,87	12,38	16,27	0
K212	0	21,33	8,76	14,91	8,13	16,26	0
K213	0	18,18	3,75	14,59	6,15	19,08	0
K221	0	21,20	4,12	17,07	7,17	20,82	0
K222	0	19,79	7,35	14,78	10,23	18,51	0
K223	0	18,99	4,26	14,88	5,87	16,10	0
K231	0,23	23,49	7,66	19,03	6,95	19,07	0,20
K232	0	21,57	5,20	15,51	7,84	20,64	0
K233	0	13,48	5,30	12,11	8,46	15,10	0
K311	0	19,85	10,09	16,75	9,32	19,43	0
K312	0	19,56	3,64	17,33	8,70	20,35	0,26
K313	0	16,97	3,74	14,44	6,26	18,77	0
K321	0,15	23,63	5,13	18,78	7,13	22,28	0,10
K322	0	18,97	6,14	13,36	9,83	17,75	0
K323	0	13,76	1,87	14,85	6,58	19,70	0,33
K331	0,43	24,14	5,30	14,92	7,13	20,62	0,39
K332	0	22,61	4,51	16,78	8,33	21,40	0
K333	0	17,98	5,48	13,76	7,19	17,81	0

Table 2. *Measured surface values*
Tabela 2. *Izmerene površinske vrednosti*

4. Mathematical analysis of experiments

Through the previous planning of the experiment, model 3^3 was selected, ie three independently variable factors at three levels.

However, by analyzing the results of the visual inspection as well as the interruption of intervals between the previously selected variables of

4. Matematički model emksperienata

Kroz prethodno planiranje eksperimenta, odabran je model 3^3, odnosno tri nezavisno promenljiva faktora na tri nivoa.

Međutim, analizom rezultata vizuelnog pregleda kao i prekida intervala između prethodno izabranih varijabli nezavisno promenljivih varijabli, utvrđeno

independently variable variables, it has been found that the analysis on model 2^3 or three independent variable factors on two levels is sufficient to obtain the solution with the required accuracy.
In this sense, from the previously planned three levels, a mathematical analysis will eliminate the middle level at all three influencing parameters.
Table 3 shows the samples used for mathematical analysis.

je da je analiza na modelu 2^3 ili tri nezavisna promenljiva faktora na dva nivoa dovoljna da se dobije rešenje sa potrebnom tačnošću.
U tom smislu, iz prethodno planiranih tri nivoa, matematička analiza će eliminisati srednji nivo na sva tri uticajna parametra.
Tabela 3 prikazuje uzorke korišćene za matematičku analizu.

Number of samples	Sample mark	Variation level					
		1. parameter		2. paremater		3. paremater	
		1	2	1	2	1	2
1	K 111	90		100		240	
2	K 113	90		100			220
3	K 131	90			80	240	
4	K 133	90			80		220
5	K 311		70	100		240	
6	K 313		70	100			220
7	K 331		70		80	240	
8	K 333		70		80		220

Table 3. *Experimental samples used in mathematical processing of results*
Tabela 3. *Eksperimentalni uzorci korišćeni u matematičkoj obradi rezultata*

Output sizes represent the function of the response, also called the regression equation:
Y = f (x1, x2, x3) (1)
where: x1 - transverse inclination of the burner, x2 - longitudinal burner inclination and x3 - welding current strength.
For simpler writing of the experimental conditions, for the further mathematical processing of experimental results, the encoded factor level values are used: minus one (- 1) for the first level and plus one (+ 1) for the second level. With this interception interval marking system, all three influencing factors having a continuous domain of definition have been translated into the interval, Table 4.

Izlazne veličine predstavljaju funkciju odgovora, koja se naziva i regresijska jednačina:
Y = f (x1, x2, x3) (1)
gde je: x1 - poprečni nagib gorionika, x2 - uzdužni nagib gorionika i x3 - jačina struje zavarivanja.
Radi jednostavnijeg pisanja eksperimentalnih uslova, za dalju matematičku obradu eksperimentalnih rezultata koriste se kodirane vrednosti nivoa faktora: minus jedan (-1) za prvi nivo i plus jedan (+1) za drugi nivo. Pomoću ovog sistema obeležavanja intervala presretanja, sva tri faktora koji utiču na kontinuirani domen definicije prevedeni su u interval, Tabela 4.

Number experiment	Encoded values			
	influencing factors			dependent variable
	x_1	x_2	x_3	Y
1	– 1	– 1	– 1	Y_1
2	– 1	– 1	+ 1	Y_2
3	– 1	+ 1	– 1	Y_3
4	– 1	+ 1	+ 1	Y_4
5	+ 1	– 1	– 1	Y_5
6	+ 1	– 1	+ 1	Y_6
7	+ 1	+ 1	– 1	Y_7
8	+ 1	+ 1	+ 1	Y_8

Table 4. *Mathematics model matrix*
Tabela 4. *Matrica matematičkog modela*

Adequacy of the model is verified by experiment results. For the analysis of the mutual effect of individual factors, a three-factor experiment uses a regression model of the following form:

$$Y = b_o + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + + b_{23}x_2x_3 + b_{123}x_1x_2x_3 \quad (2)$$

To define this regression model, it is necessary to determine the numerical values of the unknown coefficients b_0, b_1, b_2, b_3, b_{12}, b_{13}, b_{23} and b_{123}.

Coefficients of regression equations are determined on the basis of the test results of the selected experimental samples.

For regression analysis requires two repetitions, but for obtaining the mean value of the results from measurements of a selected surface with two series of metallographic specimens cut from welded plates.

To assess the quality of the weld, as revantan taken the attitude the size of penetration on the left and right side of the joint, and are repeated in a series of samples measured only these values (Table 5).

Adekvatnost modela se potvrđuje rezultatima eksperimenta. Za analizu međusobnog dejstva pojedinih faktora, trofaktorni eksperiment koristi regresijski model sledećeg oblika:

$$Y = b_o + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + + b_{23}x_2x_3 + b_{123}x_1x_2x_3 \quad (2)$$

Da bi se definisao ovaj regresijski model, potrebno je odrediti numeričke vrednosti nepoznatih koeficijenata b0, b1, b2, b3, b12, b13, b23 i b123.

Koeficijenti regresijske jednačine određuju se na osnovu rezultata ispitivanja odabranih eksperimentalnih uzoraka.

Za regresijsku analizu potrebna su dva ponavljanja, ali za dobijanje srednje vrednosti rezultata merenja odabrane površine sa dve serije metalografskih uzoraka isečenih iz zavarenih ploča.

Da bi se procenio kvalitet zavara, kao relevantan je zauzet stav o veličini prodiranja na levoj i desnoj strani spoja, i ponavljaju se u nizu uzoraka merenih samo ovim vrednostima (Tabela 5).

Sample mark	Surface (mm^2)					
	1			2		
	1_1	1_2	1_3	2_1	2_2	2_3
K111	6,758	6,614	6,464	7,168	7,015	6,843
K113	4,956	4,830	4,721	4,076	3,958	3,894
K131	7,956	7,767	7,593	5,612	5,452	5,354
K133	4,270	4,129	4,088	3,103	3,006	3,008
K311	10,086	9,831	9,579	9,318	9,120	8,917
K313	3,738	3,618	3,611	6,257	6,143	6,016
K331	5,304	5,161	5,081	7,127	7,015	6,795
K333	5,478	5,382	5,266	7,188	7,025	6,834

Table 5. *The surface penetration values for all three measurements*
Tabela 5. *Vrednosti površinskog uvarivanja za sva tri merenja*

Values of proportional surface relationships for all three measurements of characteristic surfaces:

$$Y_i^{I} = 1_1 : 2_1 \cdot 100\ (\%),$$
$$Y_i^{II} = 1_2 : 2_2 \cdot 100\ (\%), \quad (3)$$
$$Y_i^{III} = 1_3 : 2_3 \cdot 100\ (\%),$$

and their mean value ($\overline{Y}_i$) for the selected series of experimental samples are shown in Table 6.

Vrednosti proporcionalnih odnosa površine za sva tri merenja karakterističnih površina

$$Y_i^{I} = 1_1 : 2_1 \cdot 100\ (\%),$$
$$Y_i^{II} = 1_2 : 2_2 \cdot 100\ (\%), \quad (3)$$
$$Y_i^{III} = 1_3 : 2_3 \cdot 100\ (\%),$$

i njihova srednja vrednost ($\overline{Y}_i$) za odabrani niz eksperimentalnih uzoraka prikazani su u tabeli 6.

Sample mark	Proporcionalni odnos površina			
	Y_i^{I}	Y_i^{II}	Y_i^{III}	$\overline{Y}_i$
K111	94,38	94,28	94,46	94,37
K113	121,59	122,03	121,24	121,62
K131	141,77	142,46	141,82	142,02
K133	137,61	137,36	135,91	136,96
K311	108,24	107,80	107,42	107,82
K313	59,74	58,90	60,02	59,55
K331	74,42	73,57	74,78	74,26
K333	76,21	76,61	77,06	76,63

Table 6. *Percentage ratio of surface*
Tabela 6. *Procentualni odnos površine*

In practice, there is always a difference between the measured value at a given point and the value obtained by the regression equation. Therefore, the implicit form of regression (2) will be:

$$Y_i - b_0 - b_1x_{1i} - b_2x_{2i} - b_3x_{3i} - b_{12}x_{1i}x_{2i} - b_{13}x_{1i}x_{3i} - b_{23}x_{2i}x_{3i} - b_{123}x_{1i}x_{2i}x_{3i} = \xi_i \quad (4)$$

where the size ξ_i represents the difference between the measured value Y_i at i-point and the one obtained by the regression equation. Regression equation coefficients should be such that these differences are minimized, that is:

$$\sum_{i=1}^{8}(Y_i - b_0 - b_1x_{1i} - b_2x_{2i} - b_3x_{3i} - b_{12}x_{1i}x_{2i} - b_{13}x_{1i}x_{3i} - b_{23}x_{2i}x_{3i} - b_{123}x_{1i}x_{2i}x_{3i})^2 = 0 \quad (5)$$

A minimum of some functions, if any, is obtained from the condition that the partial runs at all unknown coefficients are at the same time equal to zero:

$$\frac{\partial U}{\partial b_0} = 0; \quad \frac{\partial U}{\partial b_1} = 0; \quad \dots , \quad \frac{\partial U}{\partial b_{123}} = 0 \quad (6)$$

The values needed to calculate regression coefficients are given in Table 7.

U praksi uvek postoji razlika između izmerene vrednosti u datoj tački i vrednosti dobijene regresijskom jednačinom. Stoga će implicitni oblik regresije (2) biti:

$$Y_i - b_0 - b_1x_{1i} - b_2x_{2i} - b_3x_{3i} - b_{12}x_{1i}x_{2i} - b_{13}x_{1i}x_{3i} - b_{23}x_{2i}x_{3i} - b_{123}x_{1i}x_{2i}x_{3i} = \xi_i \quad (4)$$

pri čemu veličina ξ_i predstavlja razliku između izmerene vrednosti Yi u i-tački i one dobijene jednačinom regresije. Koeficijenti regresijske jednačine bi trebalo da budu takvi da su te razlike svedene na minimum, odnosno:

$$\sum_{i=1}^{8}(Y_i - b_0 - b_1x_{1i} - b_2x_{2i} - b_3x_{3i} - b_{12}x_{1i}x_{2i} - b_{13}x_{1i}x_{3i} - b_{23}x_{2i}x_{3i} - b_{123}x_{1i}x_{2i}x_{3i})^2 = 0 \quad (5)$$

Minimum nekih funkcija, ako ih ima, dobijen je iz uslova da su delimični prolazi kod svih nepoznatih koeficijenata, istovremeno jednaki nuli

$$\frac{\partial U}{\partial b_0} = 0; \quad \frac{\partial U}{\partial b_1} = 0; \quad \dots , \quad \frac{\partial U}{\partial b_{123}} = 0 \quad (6)$$

Vrednosti potrebne za izračunavanje koeficijenata regresije date su u Tabeli 7.

Sample mark	$\overline{Y}_i$	$\overline{Y}_i x_1$	$\overline{Y}_i x_2$	$\overline{Y}_i x_3$
K111	94,37	–94,37	–94,37	–94,37
K113	121,62	–121,62	–121,62	121,62
K131	142,02	–142,02	142,02	–142,02
K133	136,96	–136,96	136,96	136,96
K311	107,82	107,82	–107,82	–107,82
K313	59,55	59,55	–59,55	59,55
K331	74,26	74,26	74,26	–74,26
K333	76,63	76,63	76,63	76,63
Σ	813,23	-176,71	46,51	-23,71
Sample mark	$\overline{Y}_i x_1x_2$	$\overline{Y}_i x_1x_3$	$\overline{Y}_i x_2x_3$	$\overline{Y}_i x_1x_2x_3$
K111	94,37	94,37	94,37	–94,37
K113	121,62	–121,62	–121,62	121,62
K131	–142,02	142,02	–142,02	142,02
K133	-136,96	–136,96	136,96	–136,96
K311	–107,82	–107,82	107,82	107,82
K313	–59,55	59,55	–59,55	–59,55
K331	74,26	–74,26	–74,26	–74,26
K333	76,63	76,63	76,63	76,63
Σ	-79,47	-68,09	18,33	82,95

Table 7. *Values needed to calculate regression coefficients*
Tabela 7. *Vrednosti potrebne za izračunavanje koeficijenata regresije*

After entering values from Table 7 into equations for calculating unknown regression factors:

$$b_0 = (\sum_{i=1}^{8} Y_i)/8 \qquad b_1 = (\sum_{i=1}^{8} Y_i x_{1i})/8$$
$$b_2 = (\sum_{i=1}^{8} Y_i x_{2i})/8 \qquad b_3 = (\sum_{i=1}^{8} Y_i x_{3i})/8 \quad (7)$$
$$b_{12} = (\sum_{i=1}^{8} Y_i x_{1i}x_{2i})/8 \qquad b_{13} = (\sum_{i=1}^{8} Y_i x_{1i}x_{3i})/8$$
$$b_{23} = (\sum_{i=1}^{8} Y_i x_{2i}x_{3i})/8 \qquad b_{123} = (\sum_{i=1}^{8} Y_i x_{1i}x_{2i}x_{3i})/8 .$$

Nakon unosa vrednosti iz Tabele 7 u jednačine za izračunavanje nepoznatih regresijskih faktora:

$$b_0 = (\sum_{i=1}^{8} Y_i)/8 \qquad b_1 = (\sum_{i=1}^{8} Y_i x_{1i})/8$$
$$b_2 = (\sum_{i=1}^{8} Y_i x_{2i})/8 \qquad b_3 = (\sum_{i=1}^{8} Y_i x_{3i})/8 \quad (7)$$
$$b_{12} = (\sum_{i=1}^{8} Y_i x_{1i}x_{2i})/8 \qquad b_{13} = (\sum_{i=1}^{8} Y_i x_{1i}x_{3i})/8$$
$$b_{23} = (\sum_{i=1}^{8} Y_i x_{2i}x_{3i})/8 \qquad b_{123} = (\sum_{i=1}^{8} Y_i x_{1i}x_{2i}x_{3i})/8 .$$

their values are obtained:
b_0 = + 101,65; b_1 = – 22,09; b_2 = + 5,81; b_3 = – 2,96; b_{12} = – 9,93; b_{13} = – 8,51; b_{23} = + 2,29; b_{123} = + 10,37
on the basis of which a regression model (8) is obtained in coded coordinates:

$$Y_i = 101,65 - 22,09x_1 + 5,81x_2 - 2,96x_3 - 9,93x_1x_2 - 8,51x_1x_3 + 2,29x_2x_3 + 10,37x_1x_2x_3 \quad (8)$$

After checking the significance of the regression coefficients and the adequacy of the model, it can be seen that all coefficients significant and adequate model.

Returning to the natural coordinates, we obtain the equations of the functional dependence of the transverse inclination of the burner (P) in function of the longitudinal inclination of the burner and the power of the current:

- longitudinal inclination of burners 100° and current strength 240 A:

$$Y = 100,09 + 0,67\ P \quad (9)$$

- longitudinal inclination of burners 100° and current strength 220 A:

$$Y = 89,59 - 3,10\ P \quad (10)$$

- longitudinal inclination of burners 80° and current strength 240 A:

$$Y = 107,13 - 3,39\ P \quad (11)$$

- longitudinal inclination of burners 80° and current strength 220 A:

$$Y = 105,79 - 3,02\ P \quad (12)$$

The date functions can be drawn in the diagram shown in Figure 8.

njihove dobijene vrednosti su:
b_0 = + 101,65; b_1 = – 22,09; b_2 = + 5,81; b_3 = – 2,96; b_{12} = – 9,93; b_{13} = – 8,51; b_{23} = + 2,29; b_{123} = + 10,37
na osnovu kojeg se dobije regresijski model (8) u kodiranim koordinatama

$$Y_i = 101,65 - 22,09x_1 + 5,81x_2 - 2,96x_3 - 9,93x_1x_2 - 8,51x_1x_3 + 2,29x_2x_3 + 10,37x_1x_2x_3 \quad (8)$$

Posle provere značaja regresijskih koeficijenata i adekvatnosti modela, može se videti da su svi koeficijenti značajni a model adekvatan.

Vraćajući se prirodnim koordinatama, dobijamo jednačine funkcionalne zavisnosti poprečnog nagiba plamenika (P) u funkciji uzdužnog nagiba plamenika i jačine struje:

- uzdužni nagib gorionika 100° i jačina struje 240 A:

$$Y = 100,09 + 0,67\ P \quad (9)$$

- uzdužni nagib gorionika 100° i jačina struje 220 A:

$$Y = 89,59 - 3,10\ P \quad (10)$$

- uzdužni nagib gorionika 80° i jačina struje 240 A:

$$Y = 107,13 - 3,39\ P \quad (11)$$

- uzdužni nagib gorionika 80° i jačina struje 220 A:

$$Y = 105,79 - 3,02\ P \quad (12)$$

Funkcije se mogu nacrtati na dijagramu prikazanom na slici 8.

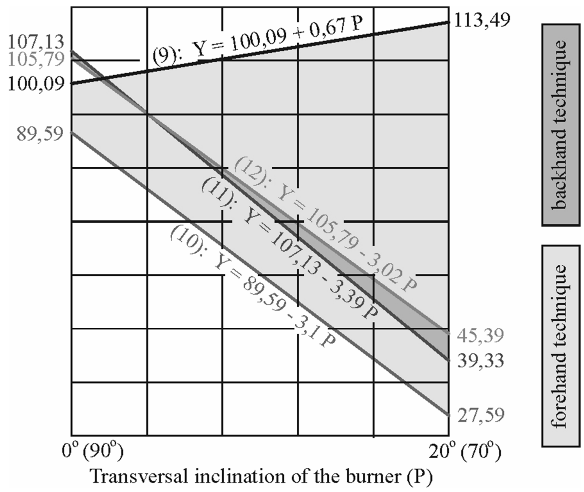

***Figure 8.** The function graph is defined by the continuity of the surface interval*
***Slika 8.** Grafikon funkcije definisan je kontinuitetom površinskog interval*

5. Conclusion

Taking into account that the levels for all three variables included continuous areas of change, that is, the start and end limits of varying intervals of certain influencing factors, for the values that can be varied within the variation interval, the output size will have the value between two directions on

5. Zaključak

Uzimajući u obzir da nivoi za sve tri promenljive uključuju neprekidna područja promene, odnosno početne i krajnje granice različitih intervala određenih uticajnih faktora, za vrednosti koje mogu varirati u intervalu varijacije, veličina izlaza će imati vrednost između dva smera na grafikonu.

the graph.
This means that the two directions, with the same technique of welding, a different current, limiting the area of the chart inside the can for any value of current in the interval of variation (for a given value of lateral inclination of the burner) to determine the functional relation of the dependent parameter - the relationship molten gutter.
The width of the interval defines the influence of the influence on the current. If the influence of the variation interval of the current current is higher then the width of the interval is higher. Worth and vice versa.
The increase in the interval indicates that the rise in the lateral inclination value increases and the percentage of the prewired base material of the groove side increases.
The percentage ratio of the overlapped webs of the spine determines the geometrical characteristics of the shape of the seam and the HAZ, the size and layout of the crystal structure and their mechanical characteristics.
Due to the greater penetration and symmetry seam, regardless of the value of the lateral inclination of the torch, the roots passage recommended application backhand techniques.
When working forehand technique, it is desirable that the part of the burner be in the straight vertical perpendicular to the seam - a fast lateral inclination.

References
Literatura

[1] Dobraš D., The doctoral dissertation, " Investigation of the influence of transverse inclination of burners in modern welding methods MAG" was defended in 2012 at the Faculty of Mechanical Engineering of the University of Banja Luka

To znači da dva pravca, istom tehnikom zavarivanja, različitim jačinama struje, ograničavaju područje grafikona unutar karte za bilo koju vrednost struje u intervalu varijacije (za datu vrednost bočnog nagiba gorionika) za određivanje funkcionalnog odnosa zavisnog parametra - odnos rastopljenog žljeba.
Širina intervala definiše uticaj na struju. Ako je uticaj intervala varijacije trenutne struje veći, tada je širina intervala veća. Vredi i obrnuto.
Povećanje intervala ukazuje da se povećava vrednost bočnog nagiba i povećava procenat prethodno vezanog osnovnog materijala na strani žljeba.
Procentualni odnos preklopljenih mreža određuje geometrijske karakteristike oblika šava i ZUT, veličinu i raspored kristalne strukture i njihove mehaničke karakteristike.
Zbog većeg uvarivanja i simetričnog šava, bez obzira na vrednost bočnog nagiba pištolja, za koreni prolaz je preporučljiva tehnika nanošenja unazad.
Kada se radi tehnikom unapred, poželjno je da deo gorionika bude u vertikali normalno na šav - brz bočni nagib.