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HARDFACING MATERIAL SOLUTIONS FOR HIGH PERFORMANCE COATINGS IN WEAR AND CORROSION APPLICATIONS

REŠENJA ZA MATERIJALE ZA TVRDO NAVARIVANJE ZA VISOKOKVALITETNE OBLOGE U APLIKACIJAMA HABANJA I KOROZIJE

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Abstract

The protection of machinery and structural components by thermal coatings is of huge economic importance. Each hour of downtime, caused by deficient coatings as a result of wear and corrosion, costs a fortune. Savings by reducing these downtime hours can be achieved by applying optimized functional coatings which show enhanced properties. The main welding processes for applying coatings are GMAW or OA, PTA or Laser, each with their pros and cons. The PTA process can be seen as the intermediate process bridging the low cost, high deposition rate and the expensive but high end Laser. Recently, the PTA and especially the laser process are gaining more attention and market shares.

Nowadays the flux-cored wires can be upgraded more and more with for instance complex carbides and achieve coatings similar to the high performance coatings obtained by PTA and Laser welding but at much lower costs.

The common problems accompanying the GMAW process: a large heat affected zone and dilution, can be circumvented by using the cold metal transfer (CMT), the AC-GMAW- and the GMAW hot wire process, allowing the flux-cored wires to fully deploy their large potential and compete with the welding techniques. The current paper will describe the modern GMAW hot wire process and then deal with innovative materials and process concepts for the high performance flux-cored wire to give a competitive alternative for the PTA process and expensive laser.

Rezime

Zaštita mašina i strukturnih komponenti termičkim nabrizgavanjem je od ogromnog ekonomskog značaja. Svaki sat zastoja, uzrokovan nedostajućom prevlakom kao rezultat habanja i korozije, košta bogatstvo. Ušteda smanjenjem vremena zastoja može se postići primenom optimizovanih funkcionalnih nanosa koji pokazuju poboljšana svojstva. Glavni postupci zavarivanja za nanošenje su MIG/MAG ili otvorenim lukom OA, plazma PTA ili Laser, svaki sa svojim za i protiv. Proces PTA se može posmatrati kao srednji proces koji premošćuje niske troškove, veliku brzinu nanošenja između skupog ali visokoučinskog lasera. Nedavno, PTA i posebno laserski proces dobijaju više pažnje i tržišnih udela.

Danas se punjene žice mogu sve više nadograditi sa, na primer, složenim karbidima i postižu se nanosi slični visokokvalitetnim nanosima dobijenim PTA i Laserskim zavarivanjem, ali uz znatno niže troškove.

Uobičajeni problemi koji prate proces MAG: velika zona uticaja toplote i mešanje, mogu se zaobići korišćenjem hladnog prenosa metala (CMT), AC-MAG i MAG sa vrućom žicom, čime se punjenim žicama omogućuje da se potpuno razvije njihov veliki potencijal i konkurišu tehnikama zavarivanja. Sadašnji rad će opisati savremeni MAG proces sa vrućom žicom, a zatim se baviti inovativnim materijalima i procesnim konceptima za punjene žice visokog učinka kako bi se dobila konkurentna alternativa za PTA proces i skupi laser.



1. Introduction

The application welding method examined in the scope of this paper is a combination of the classical GMAW welding plus additional infeed of a second flux-cored wire that is supplied as a hot wire with another current source. Only the infeed GMAW wire ignites a transferring electric arc in this, and the hot wire is subsequently guided hot into the still-liquid melt by resistance heating. Basic advantages are provided by a very low thermal stress on the material supplied by hot wire in the range of the nickel-based alloys reinforced with tungsten carbide. Too-high thermal stress, e.g. by a transferred electric arc when welding, leads to disintegration of fused tungsten carbide FTC (W_2C/WC) to tungsten monocarbide (WC) while emitting tungsten. The high hardness and high wear resistance of the FTC is reduced by this process [1]. At the same time, the dissolution of the carbides reduces the carbide size, which reduces the wear resistance of the coating [2].

1. Uvod

Primenjeni metod zavarivanja koji je ispitan u okviru ovog rada je kombinacija klasičnog MAG zavarivanja i dodatnog napajanja druge punjene žice koja se isporučuje kao vruća žica sa drugim izvorom struje. Samo u dovodnoj MAG žici se u tom stanju pali električni luk koji se prenosi, a vruća žica se zatim vruće uvodi u rastop koji je još u tečnom stanju pomoću elektrootpornog grejanja. Osnovne prednosti obezbeđuje veoma nizak termički napon na materijal koji se dobija vrućom žicom u rasponu od legura na bazi nikla ojačanog volframovim karbidom. Previše visoki termički napon, npr. prenošenim električnim lukom pri zavarivanju, dovodi do raspadanja rastopljenog volfram-karbida FTC (W_2C / VC) do volfram monocarbida (VC) sa emitovanjem volframa. Visoka tvrdoća i visoka otpornost na habanje FTC se smanjuje ovim procesom [1]. Istovremeno, rastvaranje karbida smanjuje veličinu karbida, što smanjuje otpornost na habanje nanosa [2].

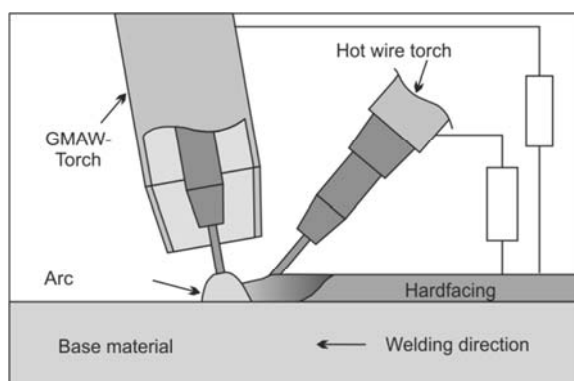


Figure 1. Schematic GMAW hot wire procedure

Slika 1. Šema procesa MAG sa vrućom žicom

The GMAW hot wire process was examined in terms of process characteristics and use of flux-cored wire diameters up to 2.4 mm. Here, larger particles can be used in the FTC-reinforced nickel-base alloys in addition to increase the content of FTC filler as well. For validation of these effects, also three other typical hardfacing alloys were examined. Here, the respective economical most relevant flux-cored wire alloys were chosen based on iron, nickel and cobalt [3]-[4].

2. Materials, machines and examination methods used

The welding tests were conducted with the welding system DURWELD Alpha made by DURUM VERSCHLEISS-SCHUTZ GmbH, equipped with two power sources from EWM AG. An EWM Alpha Q552 pulse was used as GMAW power source and an EWM TETRIX 552 as hot wire power source. The principle and setup of welding technology is shown in figure 1. S235 JR was used as base

Proces MAG sa vrućom žicom ispitan je u pogledu karakteristika procesa korišćenjem punjene žice prečnika do 2,4 mm. U ovom slučaju, veće čestice se mogu koristiti na FTC legurama na bazi nikla, kao i na povećanju sadržaja FTC punila. Za validaciju ovih efekata, ispitane su i tri druge tipične legure za tvrdo navarivanje. Ovde su odabrane odgovarajuće ekonomski najrelevantnije legure žice sa punjenjem na bazi gvožđa, nikla i kobalta [3]-[4].

2. Materijali, mašine i metode ispitivanja koje se koriste

Testovi zavarivanja su izvedeni na sistemu za zavarivanje DURVELD Alpha firme DURUM VERSCHLEISS-SCHUTZ GmbH, opremljenim sa dva izvora napajanja od EWM AG. Pulsni EWM Alpha K552 je korišćen kao izvor napajanja za MAG i EWM TETRIKS 552 kao izvor napajanja za vruću žicu. Princip i podešavanje tehnologije zavarivanja prikazani su na slici 1. S235 JR je



material for welding tests. The examined alloys are indicated in table 1.

For experimental examination, four test materials were chosen to examine the procedure on different alloy base types. The materials here were chosen insofar as they had a high relevance for practice in addition to fundamentally different properties and applications of use:

DURMAT® FD 61: Fe-based alloy with complex carbides for wear protection

DUROLIT 6: Co-base alloy with eutectic precipitations

DUROLOY SE 12/50: self-fluxing Ni-based alloy with good abrasion and corrosion resistance

DURMAT® NIFD: Ni-based with FTC reinforcement for highest wear protection

korišćen kao osnovni materijal za ispitivanje zavarivanja. Ispitivane legure su navedene u tabeli 1.

Za eksperimentalno ispitivanje odabrana su četiri ispitna materijala za ispitivanje postupka na različitim osnovnim tipovima legura. Materijali koji su ovde odabrani bili su odabrani u meri u kojoj su oni imali veliku važnost za praksu pored fundamentalno različitih svojstava i primena:

- DURMAT® FD 61: Legura na bazi Fe sa kompleksnim karbidima za zaštitu od habanja

- DUROLIT 6: Legura sa bazom sa eutektnim talozima

- DUROLOI SE 12/50: samolepljiva legura na bazi Ni sa dobrom otpornošću na habanje i koroziju

- DURMAT® NIFD: Ni-bazirano sa FTC ojačanjem za najveću zaštitu od habanja.

Flux-cored wire Punjena žica DURMAT®	Main alloying additions in the used flux-cored wire (wt.%) Glavni legirajući elementi u korišćenim punjenim žicama					
	C	Cr	B	W	+	Bal.
FD61	5.2	22.0	<1.0	--	Nb: 7.0	Fe
DUROLOY 6	1.1	27.0	--	4.5	Fe: <4.0	Co
SE12/50	0.6	20.0	2.8	1.09	Si: 4.9 Mo: 2.5	Ni
NIFD	< 1.0	<5.0	<2.0	--	FTC 60%	Ni

Table 1: Chemical composition of the flux-cored wire alloy types examined

Tabela 1. Hemijski sastav ispitivanih punjenih žica

The focus of examination was on the FTC-reinforced nickel base alloy DURMAT® NIFD, which is the industrial standard at very high requirements. Furthermore, the highly chrome- and carbon-containing iron-based alloy DURMAT® FD 61 was chosen in the area of the classical wear protection. DURMAT® NIFD as pseudo alloys with a matrix of nickel and a high share of boron as well as large, embedded FTC particles offers a high degree of protection against abrasion and erosion. DURMAT® FD 61 offers a high content of primarily precipitated chrome and niobium carbides in eutectically reinforced austenitic matrix.

The very high content of primary carbides and high hardness in excess of 65 HRC offer good protection against abrasion and erosion as well. In addition, a nickel-based alloy and a cobalt-based alloy, which are also widely used, were examined for combined wear and corrosion resistance. The DUROLIT 6 alloy is used in many areas in which not only wear properties, but also good corrosion resistance and/or good high-temperature properties are required.

This alloy type typically has a hardness of 40-43 HRC and can be used through the network of

Fokus ispitivanja je bio na FTC-ojačanoj leguri na bazi nikla DURMAT® NIFD, koja je industrijski standard po veoma visokim zahtevima. Pored toga, u oblasti klasične zaštite od habanja izabrana je legura na bazi gvožđa sa visokim sadržajem hroma i ugljenika, DURMAT® FD 61. DURMAT® NIFD kao pseudo-legure sa matricom nikla i visokim udelom bora, kao i velikih, ugrađenih FTC čestica pruža visok stepen zaštite od abrazije i erozije. DURMAT® FD 61 nudi visok sadržaj primarno istaloženog hroma i niobijum karbida u eutektni ojačanoj austenitnoj matrici.

Vrlo visok sadržaj primarnih karbida i visoka tvrdoća iznad 65 HRC nude dobru zaštitu od abrazije i erozije. Pored toga, ispitivana je legura na bazi nikla i legura na bazi kobalta, koje su takođe u širokoj upotrebi, za kombinovanu otpornost na habanje i koroziju. Legura DUROLIT 6 se koristi u mnogim oblastima u kojima su potrebna ne samo svojstva otpornosti na habanje, već i dobra otpornost na koroziju i/ili dobra svojstva na visokim temperaturama.

Ovaj tip legure obično ima tvrdoću od 40-43 HRC i može se koristiti preko mreže hroma i volframovih karbida eutektni raspoređenih u CoCr matrici pri



chrome and tungsten carbides eutectically distributed in a CoCr matrix at a usage temperature of up to 900 °C, since it does not significantly reduce hardness across a large temperature range. DUROLOY SE 12/50 was chosen as a fourth alloy type that has high shares of chrome, silicone and boron, which gives it high corrosion resistance along with high hardness of approx. 50 HRC. This material is classically used to replace cobalt-based alloys. The flux-cored wires used were made by DURUM VERSCHLEISS-SCHUTZ GMBH in Germany. The same flux-cored wire diameter and alloy type was used for GMAW and for hot wire process. The respective hot wires, however, were optimized successively for use as hot wire according to the results from the preceding examination.

3. Process analysis and process optimization

Within the scope of this paper, the process behavior of the alloy DURMAT® NIFD was examined in detail. First, the behavior of the alloy in terms of energy introduction in conventional GMAW-welding was examined. For this, the welding voltage and wire feed rate were set at a wire diameter 1.2 mm and 2.4 mm so that different electric welding arc types formed.

According to the information in literature, the arc types short arc (KLB), transfer arc and spray arc were set [5]. Due to the low thermal stability of the hard phase FTC, which is very important for wear protection of this alloy, the hard phase content preserved completely as FTC was chosen as an evaluation criterion. Welding took place using stringer bead technique with a welding speed of 60 cm/min. Figure 2 shows the content of preserved FTC particles depending on the electric welding arc types used or the different welding voltages. It is clear that the increased energy input, e.g. in the arc types transitional arc and spray arc, clearly reduces the preserved FTC content. A considerable share of the WSC enclosed in the wire at the beginning is broken down into WC and carbon by the thermal effect of the electric arc during welding.

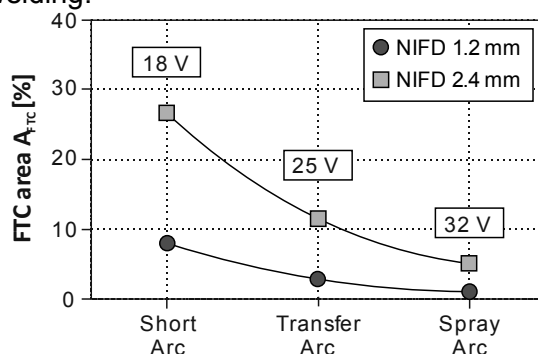


Figure 2: Interrelation between electric arc type and area percentage of the FTC share received

Slika 2. Međusobni odnos tipa luka i procenta površine zadržanog FTC

temperaturi upotrebe do 900 °C, budući da ne smanjuje značajno tvrdoću u velikom temperaturnom opsegu. DUROLOY SE 12/50 je izabran kao četvrti tip legure koja ima visok udeo hroma, silicijuma i bora, što joj daje visoku otpornost na koroziju uz visoku tvrdoću od cca. 50 HRC. Ovaj materijal se klasično koristi za zamenu legura na bazi kobalta.

Korišćene punjene žice proizvela je kompanija DURUM VERSCHLEISS-SCHUTZ GMBH u Nemačkoj. Za MAG i za proces sa vrućom žicom korišćen je isti prečnik punjene žice i tip legure. Odgovarajuće vruće žice, međutim, optimizovane su sukcesivno za upotrebu prema rezultatima iz prethodnog ispitivanja.

3. Analiza procesa i optimizacija procesa

U okviru ovog rada detaljno je ispitano ponašanje legure DURMAT® NIFD. Prvo, ispitano je ponašanje legure u smislu uvođenja energije kod konvencionalnog MAG-zavarivanja. Za to su napon zavarivanja i brzina dodavanja žice podešeni na prečnik žice 1,2 mm i 2,4 mm, tako da su formirani različiti oblici električnog luka.

Prema informacijama u literaturi, postavljeni su kratki lukovi tipa luka (KLB), prenosni luk i sprej luk [5].

Zbog niske termičke stabilnosti tvrde faze FTC, koja je veoma važna za zaštitu od habanja ove legure, kao kriterijum za ocenjivanje, izabran je sadržaj čvrste faze u potpunosti kao FTC. Zavarivanje je vršeno tehnikom pravih zavara sa brzinom zavarivanja od 60 cm / min. Na slici 2 prikazan je sadržaj sačuvanih čestica FTC u zavisnosti od korišćenih tipova električnog luka ili različitih napona zavarivanja. Jasno je da povećani unos energije, npr. u prelaznom tipu luka i sprej luku, očigledno se smanjuje očuvani sadržaj FTC. Značajan udeo WSC-a koji se nalazi u žici na početku je podeljen na WC i ugljenik toplotnim efektom električnog luka tokom zavarivanja.



Therefore, it could be confirmed that the alloy type DURMAT[®] NIFD has much better layer properties when welding with lower voltages in the short electric arc. Large voltage ranges lead to clear carbide dissolution. Additionally, it is evident that the flux-cored wire diameter of 2.4 mm has an advantage concerning the remaining carbide share in all electric arc types due to using larger FTC particles. For the further examination, the GMAW-wire was used in the short electric arc mode in the range of the FTC-reinforced nickel-based alloy DURMAT[®] NIFD. The additional hot wire was supplied to the process as another step now. In this case, wires with diameters 1.2 mm and 2.4 mm were examined in accordance with the preceding GMAW welding tests in order to examine the influence of the different hard phase contents and hard phase sizes. Firstly, the influence of the welding speed in string bead technique on the resulting contents of intact FTC when using both flux-cored wire diameters was examined. Reduction of the section energy coincides with reduction of the thermal stress on the hard phases due to the heat discharge that is usually 3-dimensional in surface welding. The ratio between GMAW wire and hot wire was stipulated at 3:2 here and all other welding parameters were kept constant. Evaluation of the area shares took place by ImageJ software in the cross-section. It could be shown here that the share of preserved FTC particles rises for both wire diameters as the welding speed increases and reaches a maximum at these parameters when a welding speed of 60 cm/min is reached.

Figure 3 shows the cross-section of DURMAT[®] NIFD with diameters of 1.2 mm and 2.4 mm of this test series with a welding speed of 60 cm/min. The cross-section shows that use of 1.2 mm wires leads to a highly homogeneous distribution of the carbides, but the carbides were dissolved slightly due to their low particle size.

Stoga se može potvrditi da tip legure DURMAT[®] NIFD ima mnogo bolje osobine sloja pri zavarivanju sa nižim naponom u kratko spojenom luku. Veliki rasponi napona dovode do jasnog rastvaranja karbida. Dodatno, očigledno je da prečnik punjene žice od 2,4 mm ima prednost u odnosu na preostali udeo karbida u svim tipovima luka usled korišćenja većih čestica FTC. Za dalje ispitivanje, MAG-žica je korišćena u kratkom luku u opsegu FTC-ojačane legure na bazi nikla DURMAT[®] NIFD.

Dodatna vruća žica je isporučena procesu kao još jedan korak. U ovom slučaju, ispitivane su žice prečnika 1,2 mm i 2,4 mm u skladu sa prethodnim testovima MAG zavarivanja kako bi se ispitaio uticaj različitih sadržaja tvrde faze i veličina tvrde faze. Prvo, ispitan je uticaj brzine zavarivanja u tehnici pravih zavara na rezultujući sadržaj netaknute FTC kod upotrebe oba prečnika punjene žice. Redukcija energije preseka podudara se sa redukcijom toplotnog napreznja na tvrdim fazama usled toplotnog pražnjenja koje je obično 3-dimenzionalno u površinskom zavarivanju. Odnos između MAG žice i vruće žice je ovde određen na 3: 2 i svi ostali parametri zavarivanja su ostali konstantni. Evaluacija udela područja obavljena je pomoću ImageJ softvera poprečnog preseka. Ovde se može pokazati da se udeo očuvanih čestica FTC-a povećava za oba prečnika žice, jer se brzina zavarivanja povećava i na tim parametrima dostiže maksimum kada se postigne brzina zavarivanja od 60 cm / min.

Slika 3 prikazuje poprečni presek DURMAT[®] NIFD prečnika od 1.2 mm i 2.4 mm, ove serije testova sa brzinom zavarivanja od 60 cm / min. Poprečni presek pokazuje da upotreba žica od 1,2 mm dovodi do veoma homogene raspodele karbida, ali su karbidi neznatno rastvoreni zbog njihove male veličine čestica.

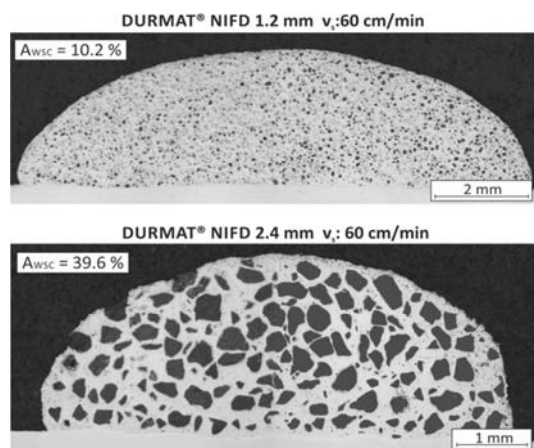


Figure 3: Cross-section of GMAW hot wire hardfacing: Welding speed $v_s = 60\text{cm/min}$
Slika 3. Poprečni presek tvrdog navara MAG sa vrućom žicom Brzina zavarivanja $v_s = 60\text{cm/min}$

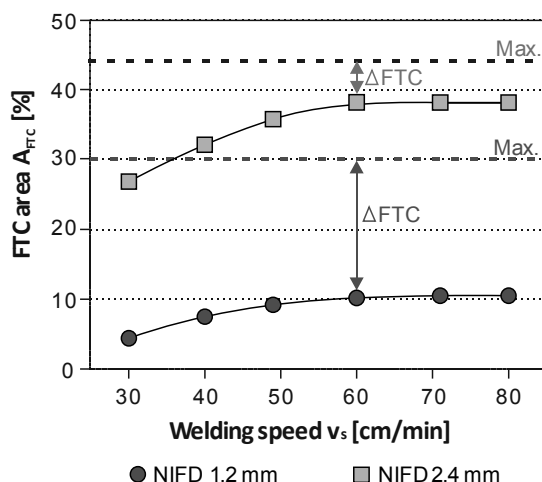


Figure 4: Connection between welding speed v_s and area percent of the FTC share received
Slika 4. Veza između brzine zavarivanja v_s i procenta površine zadržanog FTC

Nevertheless, completely intact FTC-particles will remain in the layer when using of an additional hot wire. The cross-section of the weld performed with 2.4 mm flux-cored wire diameter shows that a much higher content of FTC is completely preserved. The combination of much larger FTC particles with the hot wire method shows that the FTC particles can be preserved nearly entirely. On the one hand, this is because the share of WSC supplied by the hot wire cannot be overheated by the electric arc. On the other hand, however, the melt of the MIG/MAG wire is effectively cooled down by the supply of the hot wire. The interrelation between the welding speed and the area percentage of the completely preserved FTC is shown in figure 4.

Additionally, it becomes clear that use of larger FTC particles at a 2.4 mm flux-cored wire diameter achieves nearly the theoretical maximum of preserved FTC particles due to the low energy introduction to the hot wire. The difference ΔFTC between the theoretical maximum content and the content of intact FTC contained in the cross-section could be clearly reduced as compared to the 1.2 mm flux-cored wire and is shown in figure 5.

Additionally, the interrelation between the hot wire performance and the hot wire infeed was examined. The available performance range was between 0 and 560 A. Additionally, the operating point or the voltage applied to the hot wire could be adjusted in the hot wire power source. It was possible to feed in the hot wire, based on feed rate, so that no electric arc was ignited between the melting bath and the hot wire. The tests showed that there is a linear correlation between the hot wire infeed and the hot wire performance. The operating point could also be chosen so that low voltages in the range of 1 – 4 V were used at all times. This permitted introduction of the material

Ipak, potpuno netaknute FTC-čestice će ostati u sloju kada se koristi dodatna vruća žica. Poprečni presek navara izveden prečnikom od 2,4 mm punjene žicom pokazuje da je veći sadržaj FTC potpuno očuvan. Kombinacija mnogo većih FTC čestica metodom vruće žice pokazuje da se FTC čestice mogu sačuvati skoro u potpunosti. S jedne strane, to je zbog toga što udeo WSC koji se dobija od vruće žice ne može da se pregreje električnim lukom. S druge strane, međutim, rastop MIG / MAG žice se efektivno hladi dodavanjem vruće žice. Veza između brzine zavarivanja i procenta površine potpuno očuvanog FTC prikazana je na slici 4.

Pored toga, postaje jasno da korišćenje većih čestica FTC punjenom žicom prečnika od 2,4 mm postiže skoro teoretski maksimum očuvanih FTC čestica zbog uvođenja niske energije u vruću žicu. Razlika ΔFTC između teoretskog maksimalnog sadržaja i sadržaja netaknutog FTC sadržanog u poprečnom preseku može se jasno smanjiti u poređenju sa punjenom žicom od 1,2 mm i prikazana je na slici 5.

Pored toga, ispitan je i odnos između karakteristika vruće žice i napajanja vrućom žicom. Raspon dostupnih performansi bio je između 0 i 560 A. Dodatno, radna tačka ili napon koji se primenjuje na vruću žicu može se podesiti u izvoru napajanja vruće žice. Bilo je moguće napajati vruću žicu, na osnovu brzine napajanja, tako da nije došlo do paljenja električnog luka između tečneog kupatila i vruće žice. Testovi su pokazali da postoji linearna korelacija između napajanja vrućom žicom i performansi vruće žice. Radna tačka se takođe može izabrati tako da se u svakom trenutku koriste niski naponi u opsegu od 1 - 4 V. Ovo je omogućilo unošenje udela materijala kroz vruću žicu bez jake termičke dezintegracije FTC.

Ispitivanja su takođe pokazala dva jaka uticaja na topljenja vruće žice. S jedne strane, polaritet izvora



share introduced through the hot wire without any strong thermal disintegration of the FTCs. The examinations also showed two strong influences on the melting behavior of the hot wire. On the one hand, polarity of the hot wire power source influences deflection of the electric arc. The same polarity of both circuits produces a magnetic field through the wires through which current flows, according to Ampere's law on forces, which slightly deflects the electric arc towards the hot wire. This effect is usually known as the magnetic arc blowing effect in welding. By reverse polarity of the circuits, rejection of the electric arc from the hot wire can be achieved. Figure 5 schematically shows the influence of the power source polarity or magnetic fields on the position of the electric arc in welding. The distance between GMAW wire and hot wire was found to be a second great factor of influence. The hot wire must be introduced into the still liquid melting bath, but must not submerge in the preceding electric arc too far, since this in turn strongly increases the risk of thermal disintegration. Here, a complex interrelation between the variable hot wire infeed, hot wire power, hot wire position and hot wire polarity resulted. With the parameters chosen correctly, a stable process could be ensured at all times, though the welding process with additional hot wire is subject to limits here as well. It has become clear that introduction of the hot wire required increase of the main wire voltage by 1 – 2 V in order to achieve consistent process stability.

struje vruće žice utiče na odklon električnog luka. Isti polaritet oba kruga proizvodi magnetno polje kroz žice kroz koje struji struja, prema Amperovom zakonu o silama, blago skreće električni luk prema vrućoj žici. Ovaj efekat je obično poznat kao efekat produvavanja magnetnog luka pri zavarivanju. Obrnutim polaritetom kola može se postići odbijanje električnog luka od vruće žice. Slika 5 shematski prikazuje uticaj polariteta izvora napajanja ili magnetnih polja na položaj električnog luka u zavarivanju.

Utvrđeno je da je udaljenost između žice za MAG i vruće žice, drugi veliki faktor uticaja. Vruća žica se mora uvesti u još tečno kupatilo, ali se ne sme preterano uroniti u prethodni električni luk, jer to opet povećava rizik od termičkog raspadanja. Ovde je došlo do složene međusobne povezanosti između varijabilnog dovoda vruće žice, snage vruće žice, pozicije vruće žice i polariteta vruće žice. Sa ispravno izabranim parametrima, u svakom trenutku bi se mogao osigurati stabilan proces, iako je i proces zavarivanja dodatnom žicom podložan ograničenjima. Postalo je jasno da je uvođenje vruće žice zahtevalo povećanje glavnog napona žice za 1 - 2 V kako bi se postigla stalna stabilnost procesa.

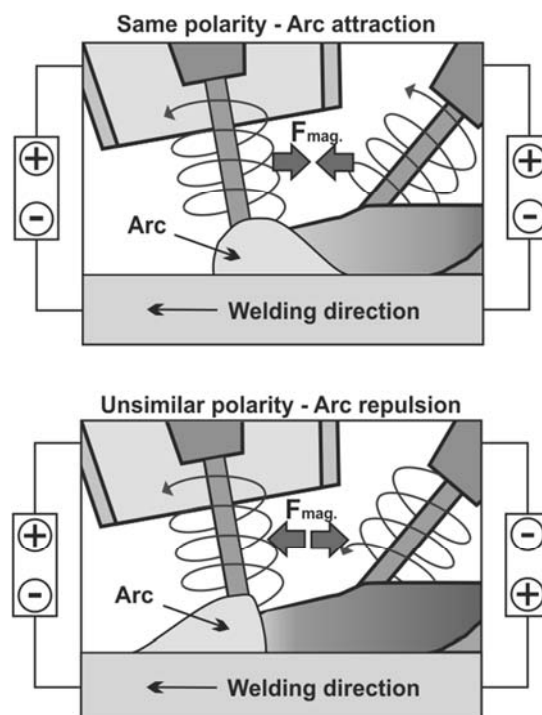


Figure 5: Influence of the magnetic fields on the position of the electric arc in welding: different polarity
Slika 5. Uticaj magnetnih polja na položaj električnog luka pri zavarivanju: Različiti polaritet



It has also become clear that the magnetic field produced by the hot wire may impair process stability of the GMAW wire if the distance is too short, when the GMAW wire is welded in the short electric arc. Here, further tests are performed at the moment, which examine the influence of optimized characteristic curves for the short electric arc range and for the impulse electric arc range.

4. Metallographic results

Use of the oscillating welding technique was examined in detail for practice examination of the alloys. Here, the slower welding speed directly increases the section energy, which usually leads to a slight to medium reduction of the FTC particles in the range of the nickel-based alloys with FTC reinforcement, though the influence of fluctuating process stability can be clearly minimized in this manner. For all alloy types, the influence of increasing addition of a hot wire to the microstructure was examined systematically. Therefore feed rate, voltage and current of the GMAW wire have been kept constant while the feeding rate of the hot wire has been increased. Equally, the welding speed was increased at the same time in order to produce a comparable bead geometry. The further process parameters, such as free wire lengths, oscillation parameters, angles of attack, etc. were kept constant. It becomes clear that a small addition of hot wire already essentially influences the resulting layer structures. Thus, the addition of hot wire can clearly improve the distribution of FTC particles in the layer, and significantly increase the share of FTC particles received. It is equally visible that the FTC grain size used is nearly completely preserved due to the low thermal stress at the highest hot wire feed rate even at a high melting rate of 10.8 kg/h. For the alloy version DUROLIT 6, thermal stress of the wire filling is desired, in contrast to the FTC-containing nickel-based alloys, in order to produce a homogeneous structure without defects and segregations. Since the technical properties of this alloy are primarily determined by the chemical composition, the mixture with the base material is decisive. It has become clear that a very low dilution of less than 10% can be reached with a 1-layer welding already, and that the hardness of pure welding material is already achieved. This could also be confirmed by the chemical composition at the surface. The 1-layer weld already completely achieved the technical properties of the alloy.

The material DUROLOY 12/50 was chosen as an alternative to cobalt-based alloys with a hardness of 48-52 HRC. Since this alloy is also primarily

Takođe je postalo jasno da magnetno polje koje proizvodi vruća žica može da naruši stabilnost procesa MAG žicom ako je udaljenost mala, kada se MAG žica koristi kratko spojenim lukom. Ovde se u ovom trenutku sprovode dalja ispitivanja koja ispituju uticaj optimiziranih karakterističnih krivih za raspon kratko spojenog luka i za raspon impulsnog električnog luka.

4. Metallographic results

Primena tehnike oscilujućeg zavarivanja detaljno je ispitana kroz praktično ispitivanje legura. Ovde, sporija brzina zavarivanja direktno povećava energiju preseka, što obično dovodi od manje do srednje redukcije FTC čestica u opsegu legura na bazi nikla sa FTC pojačanjem, mada se uticaj fluktuirajuće stabilnosti procesa može jasno minimizirati u na ovaj način. Za sve tipove legura sistematski je ispitivan uticaj povećanja dodavanja vruće žice na mikrostrukturu. Zbog toga se brzina dodavanja, napon i struja MAG žice održavaju konstantnim dok se brzina dodavanja vruće žice povećava. Isto tako, brzina zavarivanja je povećana u isto vreme kako bi se dobila uporediva geometrija navara. Dalji parametri procesa, kao što su dužina slobodnog kraja žice, parametri oscilacije, uglovi napada, itd. Su ostali konstantni. Postalo je jasno da mali dodatak vruće žice već bitno utiče na strukture nastalih slojeva. Dakle, dodavanje vruće žice može jasno poboljšati distribuciju FTC čestica u sloju, i značajno povećati udeo primljenih FTC čestica. Jednako je vidljivo da je FTC veličina zrna koja se koristi skoro u potpunosti očuvana zbog niskog toplotnog naprezanja pri najvećoj brzini dodavanja vruće žice čak i pri visokoj stopi topljenja od 10,8 kg / h.

Za legure DUROLIT 6, poželjno je termičko naprezanje punjene žice, za razliku od legura na bazi nikla, kako bi se dobila homogena struktura bez defekata i segregacija. Pošto su tehničke osobine ove legure primarno određene hemijskim sastavom, odlučujuća je smeša sa osnovnim materijalom. Postalo je jasno da se vrlo slabo razređivanje manje od 10% može postići već sa 1-slojnim zavarivanjem i da je tvrdoća čistog materijala za zavarivanje već postignuta. Ovo se takođe može potvrditi hemijskim sastavom na površini. 1-slojng navara koji je već u potpunosti postigao tehničke osobine legure

Materijal DUROLOY 12/50 je izabran kao alternativa za legure na bazi kobalta tvrdoće od 48-52 HRC. Pošto se ova legura primarno koristi kada je potrebna kombinacija zaštite od habanja i korozije, ispitali smo tvrdoću, hemijski sastav na površini i razblaživanje. Razblaživanje je bilo na niskoj vrednosti od 14.6%. Legura je tako dostigla



used when a combination of wear and corrosion protection is needed, we have examined the hardness, the chemical composition at the surface, and the dilution. The dilution was at a low value of 14.6 %. The alloy thus reached the required hardness with an average of 49.7 HRC in the first layer already. To review the chemical composition, the samples were then polished at the surface and examined with a spark spectrometer (OES). The iron content, e.g., could be lowered by about factor 7 from 20.9 % to 2.85 % at the surface of the 1-layer weld as compared to the MIG welding. Within the scope of the examination, the alloy DURMAT® FD 61 was also welded by oscillation technique and examined, as is common when producing wear plates.

First, it could be shown that the welding type Open Arc (OA), i.e. welding without inert gas with self-protecting flux-cored wires, is possible with the OA hot wire method used in this case with high melting rates of approx. 9 kg/h. It becomes evident that the dilution of only 14.2 % could achieve a Rockwell hardness of 69.2 HRC in the first layer, while the melting rate was very high at the same time. Here, the hardness in the first layer was increased by 4.3 HRC as compared to the open arc welding. Figure 6 shows the cross-sections with indication of the technically relevant parameters and layer properties of the DURMAT® NIFD, DUROLIT 6, DUROLOY SE 12/50 and DURMAT® FD 61 materials when using the GMAW/OA hot wire method.

zahtevanu tvrdoću sa prosekom od 49,7 HRC u prvom sloju. Da bi se pregledao hemijski sastav, uzorci su zatim polirani na površini i ispitani spektrometrom (OES). Sadržaj gvožđa, npr., može se smanjiti za približno faktor 7 sa 20.9% na 2.85% na površini 1-slojnog zavariva u poređenju sa MIG zavarivanjem. U okviru ispitivanja, legura DURMAT® FD 61 je takođe zavarena tehnikom oscilacija i ispitana, kao što je uobičajeno kod izrade ploča za habanje.

Prvo, može se pokazati da je tip zavarivanja otvorenim lukom (OA), tj. zavarivanje bez inertnog gasa samozaštitnim punjenim žicama, moguće sa OA metodom vruće žice koja se koristi u ovom slučaju sa visokim stopama topljenja od oko 9 kg / h. Očigledno je da bi razređivanje od samo 14,2% moglo da postigne tvrdoću od 69,2 HRC u prvom sloju, dok je stopa topljenja bila veoma visoka u isto vreme. Ovde je tvrdoća u prvom sloju povećana za 4,3 HRC u poređenju sa zavarivanjem otvorenim lukom. Na slici 6 prikazani su poprečni preseki sa naznakom tehnički relevantnih parametara i svojstava slojeva materijala DURMAT® NIFD, DUROLIT 6, DUROLOY SE 12/50 i DURMAT® FD 61 kada se koristi metoda MAG / OA vruća žica.

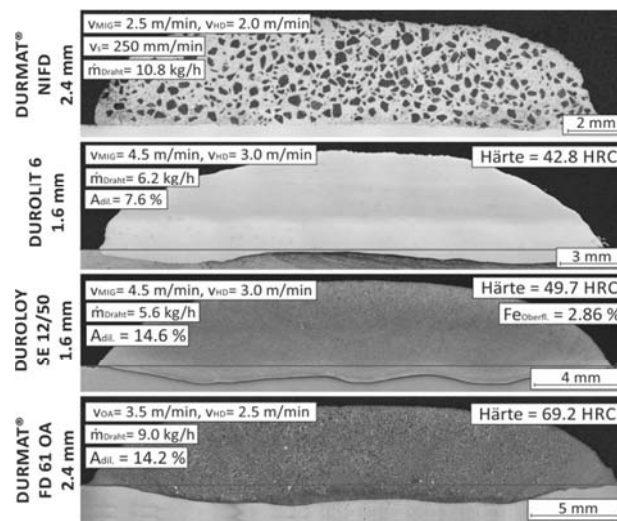


Figure 6: Overview of GMAW hot wire hardfacings
Slika 6. Pregled MAG tvrdog navarivanja sa vrućom žicom

5. Applications

The GMAW hot wire surface welding offers clear advantages for all examined alloy types concerning the layer properties and/or productivity. At the moment, transfer to practice is performed on several sample parts already, since the first

5. Primena

MAG zavarivanje vrućom žicom nudi jasne prednosti za sve ispitivane vrste legura koje su vezane za svojstva sloja i / ili produktivnost. U ovom trenutku, transfer na praksu se već izvodi na nekoliko uzoraka, jer su prvi preliminarni testovi na



preliminary tests using customer parts in the welding plant DURWELD Alpha led to promising results. The welding system is presented in figure 7. One possible area of application for the method in combination with the alloy DURMAT® NIFD is protection of the blade components or taper tap parts in open pit mining, figure 8. The highly wear-stressed areas required highest wear protection, since not only the less aggressive coal, but also regular overlay with many different compositions will be mined to expose the coal.

korisničkim delovima u fabrici za zavarivanje DURVELD Alpha doveli do obećavajućih rezultata. Sistem zavarivanja je prikazan na slici 7. Jedna od mogućih oblasti primene ove metode u kombinaciji sa legurom DURMAT® NIFD je zaštita komponenti sečiva ili konusnih delova u rudniku na otvorenom kopu, slika 8. Područja sa visokim opterećenjem na habanje zahtevaju najveću zaštitu od habanja, jer će ne samo manje agresivni ugalj, već i regularni sloj sa mnogo različitih sastava biti iskopan da bi se izdvojio ugalj.

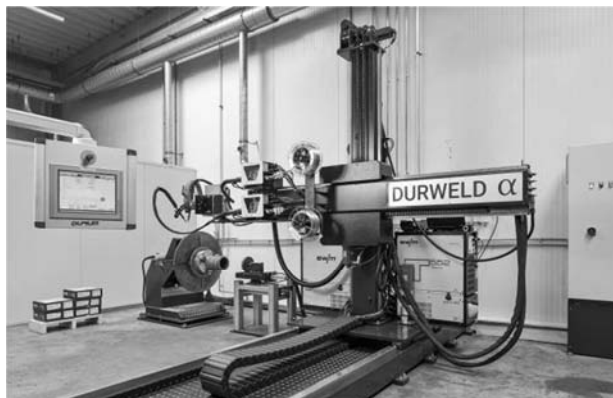


Figure 7: Welding system DURWELD Alpha used with EWM current source techniques
Slika 7. Sistem zavarivanja DURWELD Alpha korišćen sa EWM strujnim izvorima



Figure 8: Potential application: open-cast mining

Slika 8. Potencijalna primena: rudarstvo

6. Conclusion and outlook

Use of the GMAW hot-wire method can significantly increase the share of completely preserved FTC particles in the area of FTC-reinforced nickel-base alloys due to the reduced thermal stress on the filler material. It could be shown in the range of iron-, nickel- and cobalt-base alloys that use of the hot-wire technique reduced the respective dilution with base material and clearly improved the technical properties in single-layer application. Based on these results, further materials are being examined as well, since it can be assumed that at much larger number of materials can be processed with more beneficial properties than can be achieved in the conventional method when using the GMAW

6. Zaključak

Upotreba MAG metode sa vrućom žicom može značajno povećati udeo potpuno sačuvanih FTC čestica u području FTC-ojačanih legura na bazi nikla zbog smanjenog termičkog naprezanja dodatnog materijala. U opsegu legura na bazi gvožđa, nikla i kobalta može se pokazati da je upotreba tehnike vruće žice smanjila odgovarajuće razređivanje- mešanje sa osnovnim materijalom i jasno poboljšala tehnička svojstva u jednoslojnoj primeni. Na osnovu ovih rezultata, u slučaju MAG metode sa vrućom žicom., razmatraju se i drugi materijali, budući da se može pretpostaviti da se mnogo veći broj materijala može obraditi sa povoljnijim svojstvima nego što se postiže



hot-wire method. Additionally, further adjustment of the power source's characteristic curves in the range of the short electric arc and pulse arc to the respective flux-cored wire types is currently underway in order to achieve optimally coordinated process conditions.

konvencionalnom metodom, Dodatno, u toku je dalje prilagođavanje karakterističnih krivih izvora napajanja u opsegu kratko spojenog električnog luka i impulsnog luka prema odgovarajućim vrstama punjene žice kako bi se postigli optimalno koordinirani procesni uslovi.

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