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# LIGHTWEIGT SUPPORTIVE WEAR PROTECTION SYSTEMS AGAINST EROSIVE WEAR BY FINE PARTICLES

# PODRŠKA MALE TEŽINE SISTEMIMA ZAŠTITE OD HABANJA USLED TRENJA EROZIJOM FINIM ČESTICAMA

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**Key words:** wear and corrosion, wear protection, hardfacing, weld coating

## ABSTRACT

Machines and equipment wear lead to annual losses in billions. Usually highly stressed mechanical components are not directly hardfaced for wear protection, rather they are protected by prefabricated plates which are coated by welding methods for wear protection, the plates are adapted and mounted to the structures to be protected by welding or mounting screws. This procedure leads to an increase in weight of the wear protected components, which is not advantageous, especially at high speeds for ventilators subjected to wear. The direct hardfacing of high-strength structures by traditional gas metal arc welding ( GMAW) processes typically leads to high dilution, large energy input and a large heat-affected zone (HAZ) which makes it meaningless, since the required mechanical properties for high strength steels will be irreversibly lost [ 1-3].

By using a modern controlled short arc (CSA) welding method, it is possible to reduce the energy input considerably in the base material. A new application is the surfacing of high-strength steels with the aim of both providing effective protection against wear as well as to preserve the mechanical properties of hardfaced steel. The aim is to support lightweight objects through this concept, leading to a cost advantage in the overall system [ 1-3]. As part of this contribution, the possibility to hardface high-strength steels grade (S960) with the CSA welding process is reported. The mechanical-technological properties of the coated steels are carefully studied as well as the wear resistance and behavior of the applied coatings. The common application of the technology is for structural components for high-speed wear-exposed ventilators [1-3].

## REZIME

Trošenje mašina i opreme dovodi do godišnjih gubitaka u milijardama. Obično vrlo naglašene mehaničke komponente nisu direktno zaštićene od habanja tvrdim navarima, već su zaštićene prefabrikovanim pločama koje su prevučene zavarivanjem za zaštitu od habanja, a koje su prilagođene i montirane na konsrtrukcije koje treba zaštititi zavarivanjem ili montažnim vijcima. Ova procedura dovodi do povećanja težine komponenata zaštićenih od habanja, što nije povoljno, posebno kod ventilatora sa velikim brzinama podložnim habanju. Direktno tvrdo navarivanje konstrukcija visoke čvrstoće tradicionalnim postupcima zavarivanja u zaštiti gasa (MIG/MAG-GMAV) obično dovodi do visokog razblaživanja (mešanja), velikog unosa energije i velike zone uticaja toplote (ZUT-HAZ) što ga čini beznačajnim, s obzirom na to da će zahtevane mehaničke osobine čelika visoke čvrstoće biti nepovratno izgubljene [1-3].

Korišćenjem modernog postupka zavarivanja sa kontrolisanim kratkim lukom (CSA), moguće je znatno umanjiti unos energije u osnovni materijal. Nova primena je navarivanje čelika visoke čvrstoće sa ciljem da se obezbedi efikasna zaštita od habanja, kao i da se očuvaju mehaničke osobine tvrdo navarenog čelika. Cilj je, kroz ovaj koncept, podrška lakim objektima, što dovodi do troškovne prednosti u celokupnom sistemu [1-3]. Kao deo ovog doprinosa, ovde se izveštava o mogućnosti tvrdog navarivanja čelika (S960) visoke čvrstoće, postupkom zavarivanja CSA. Mehaničko-tehnološke osobine obloženih čelika pažljivo se ispituju, kao i otpornost na habanje i ponašanje nanetih prevlaka. Uobičajena primena ove tehnologije je za konstrukcione komponente ventilatora sa visokom brzinom sa visokim stepenom habanja [1-3].

## 1. Introduction

Wear and corrosion are important factors in the failure and breakdown of mechanical parts of machines. In the Federal Republic of Germany, repair and downtime causes losses of 2-4% of the GDP which corresponds to an average amount of about 85 billion Euros [4]. In view of these huge costs, there has been research to find and develop materials which can withstand the stresses better and longer and thus reduce the expenses [1-3].

Industrial fans are affected by such wear during their operation, so that regular maintenance and repair is required. One way to reduce the wear is the use of prefabricated wear plates, which are provided by specialised suppliers. They consist of a substrate material on which, by different welding/coating techniques, in particular iron- or nickel-based hard alloys are applied. The produced plates are then adapted to the contours of the fans to be protected and applied to the structural component selectively, for example by screws or weld, Fig. 1.

## 1. Uvod

Zaštita i korozija su važni faktori u otkazu i razgradnji mehaničkih delova mašina. U Saveznoj Republici Nemačkoj, popravke i vreme zastoja uzrokuju gubitak od 2-4% BDP-a koji odgovara prosečnom iznosu od oko 85 milijardi evra [4]. S obzirom na ove ogromne troškove, došlo je do istraživanja da se pronađu i razviju materijali koji mogu izdržati napon bolje i duže i time smanjiti troškove [1-3].

Industrijski ventilatori su podložni takvom habanju tokom rada, tako da je potrebno redovno održavanje i popravka. Jedan od načina da se smanji habanje je upotreba prefabrikovanih ploča otpornih na habanje, koje pružaju specijalizovani dobavljači. Sastoji se od materijala podloge na kome se primenjuju različite tehnike zavarivanja / prevlaka, posebno tvrdih legura na bazi železa ili nikla. Proizvedene ploče se zatim prilagođavaju konturama ventilatora koji se moraju zaštititi i selektivno primeniti na konstrukcionu komponentu, na primer vijcima ili zavarenim spojevima, sl.1.

***Fig.1.*** *Application of separate wear plates on the structural material of a worn-out industrial ventilator (5).*
***Sl.1.*** *Primena odvojenih ploča otpornih na habanje na konstrukcijskom materijalu istrošenog industrijskog ventilatora (5).*

The range of materials that can be used is limited. For example no (high-)boron containing alloys are applied on composite sheets using this method, because these layers easily flake and fall off in subsequent forming. Additionally the hard phase morphology (especially hard phase spacing, size as well as the uniformity of the rnicrostructure) is not feasible to obtain through conventional open arc (OA)/GMAW methods, as it is required for the erosion wear by fine particles. A further disadvantage is that the main structural component

Raspon materijala koji se mogu koristiti je ograničen. Na primer, na kompozitnim pločama se ne nanose nikakve legure koje sadrže bor (visoki sadržaj), koristeći ovu metodu, jer se ti slojevi lako odlepljuju i otpadaju pri naknadnom oblikovanju. Pored toga, morfologija tvrde faze (naročito razmak između tvrdih faza, veličina kao i jednoobraznost mikrostrukture) nije izvodljiva uobičajenim metodama otvorenog luka (OA-otvoreni luk) / GMAW-MIG-MAG), kao što je potrebno kod habanje erozijom finim česticama. Još jedan

is not directly hardfaced and protected. This is because the available conventional welding processes such as Plasma-Transferred-Arc (PTA), OA and GMAW induce too much thermal stresses in the components so that their original mechanical properties are irreversibly lost and therefore they cannot be taken into consideration as a fundamental cross-section in the design calculations of the fan [1-3].
Therefore necessarly wear protection plates must be used, whereby additional weight is caused by the wear plates as well as considerable additional efforts and costs in transport, energy requirements and construction foundations etc. [1-3].
One possible solution is the development of requircd and suitable coating process for a wear protection system by welding for highly stressed structural components made of high and ultra high strength fine grained steel materials by a modem contolled (low energy) welding process to protect lightweight ventilators [1-3].

nedostatak je da glavna konstrukciona komponenta nije direktno tvrdo navarena i zaštićena. To je zato što dostupni konvencionalni postupci zavarivanja kao što su Plazma-preneseni-luk (PTA), OA i GMAW stvaraju previše termičkih naprezanja u komponenti, tako da se njihova originalna mehanička svojstva nepovratno gube i stoga ne mogu uzeti u obzir kao fundamentalni poprečni presek u projektnim proračunima ventilatora [1-3].
Zbog toga se moraju koristiti zaštitne ploče, pri čemu dodatnu težinu izazivaju ploče za habanje, kao i znatni dodatni napori i troškovi u transportu, energetskim zahtevima i građevinskim temeljima itd. [1-3].
Jedno od mogućih rešenja je razvoj neophodnog i odgovarajućeg postupka nanošenja prevlaka - prevlačenja za sistem zaštite od habanja, zavarivanjem visoko-naponskih konstrukcionih komponenata izrađenih od finozrnih čeličnih materijala visoke i ultra visoke čvrstoće, moderno kontrolisanim postupkom zavarivanja (niskoenergetski) za zaštitu lakih ventilatora [ 1-3].

## 2.Erosion wear in ventilators' structure

### 2.1 Typical abrasives and wear patterns

The occuring wear in ventilators' stucture is attributed to the particles entrained in the air flow [1-3]. This is because industrial ventilators are used for example in cement, steel, chip wood, plastic as well as chemical plants and refineries in the basic mateial dedusting technology, where the conveying air pushes file, highly ablasive particles, Table 1 [1-3]. The sucked particles sometimes induce a considerable wear aftack through impingement of the structural materials of the ventilator. such as blades, top and bottom plates, Fig. 2 [1-3].

## 2.Erozija na konstrukciji ventilatora

### 2.1. Tipični abrazivi i obrasci habanja

Izraženo habanje na konstrukciji ventilatora se pripisuje česticama koje su ušle u vazdušni tok [1-3]. To je zato što se industrijski ventilatori koriste na primer u cementaram, čeličana, drvnoj industriji, industriji plastike, kao i hemijskim postrojenjima i rafinerijama kao osnovna tehnološka tehnologija otprašivanja, gde transportni vazduh gura kolonu, visoko abrazivnih čestica, tabela 1 [1-3]. Usisane čestice ponekad izazivaju značajno oštećenje habanjem kroz udaranje konstrukcijskih materijala ventilatora. kao što su lopatice, gornje i donje ploče slika 2 [1-3].

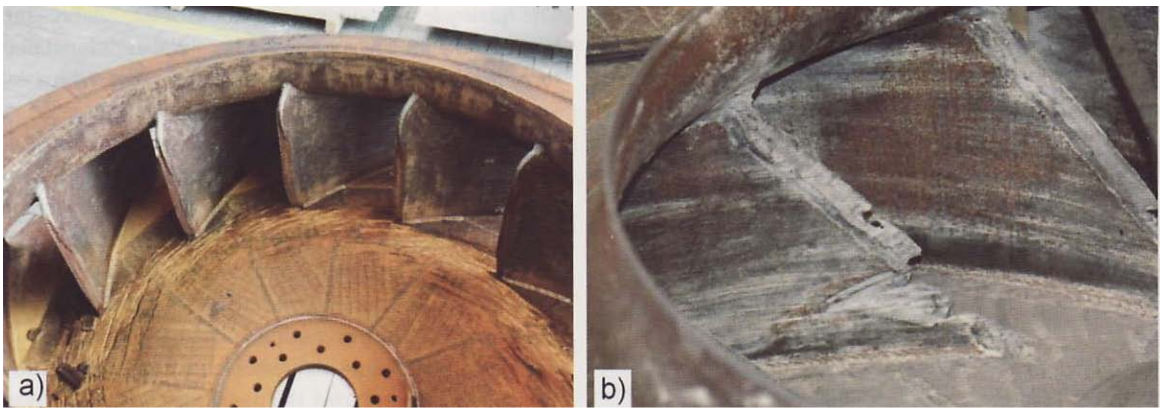


***Fig.2.*** *Wear of industrial ventilators after deployment: a) Wear of bottom plate, b) Wear of fan blades [5].*
***Sl. 2.*** *Habanje ndustrijskih ventilatora nakon upotrebe: a) habanje donje ploče, b) habanje lopatica ventilatora [5].*

## 2.2. Conventional wear protection

As a wear protection solution, because of the required wear reserves and respectively layer thickness as well as the dynamic wear stresses, the protective layer coatings applied by welding technology are preferred. The wear protection materials consist of a relatively tough-hard solid solution matrix in which the wear-protective brittle hard materials arc incorporated [1-3]. For wear protection high-alloy iron and nickel-based alloys are used,Table 2 [1-3].

These are usually applied via wired arc or bonded powder plasma process on substrate material of the type S235, S355 and in some exceptional cases S690 and S960. In such way, wear protection plates of different thicknes are prepared. These produced layers have a multiphase microstructure consisting of locally formed or foreign precipitated metal carbides or borides or a combination of these hard materials. All alloys are commonly processed by welding with high energy input (PTA, OA and GMAW). With the costly PTA process expensive powdered hard phase strengthened nickel alloys are processed with dilution less than 10%, while the main application area for the lower cost GMAW and OA methods lies in the processing of iron-based materials. With the GMAW/OA procedure usually a dilution between 20-40% is achieved, Table 3.

## 2.2 Konvencionalna zaštita od habanja

Kao rešenje za zaštitu od habanja, zbog potrebnih rezervi za habanje, odnosno debljine sloja, kao i dinamičkih napona habanja, poželjno je zaštitne slojeve naneti zavarivanjem. Materijali za zaštitu od habanja sastoje se od matrice relativno žilavo/ tvrdog čvrstog rastvora u kojoj su ugrađeni krti, tvrdi materijali za zaštitu od habanja [1-3]. Za zaštitu od habanja koriste se visoko legirano železoe i legure na bazi nikla, tabela 2 [1-3].

Oni se obično nanose elektrolučnim postupcima sa žicom i plazma postupcima praškom za vezivanje na materijalu podloge tipa S235, S355 i u nekim izuzetnim slučajevima S690 i S960. Na taj način se pripremaju zaštitne ploče različitih debljina. Ovi proizvedeni slojevi imaju multifaznu mikrostrukturu koja se sastoji od lokalno formiranih ili stranih taloga metalnih karbida ili borida ili kombinacije ovih tvrdih materijala. Sve legure obično se zavaruju sa visoko-energetskim unosom (PTA, OA i GMAW). Skupim PTA postupkom, skupe ojačane niklove legure u prahu se nanose sa stepenom mešanja manjim od 10%, dok su glavna područja primene manje skupih postupaka GMAW i OA kod obrade materijala zasnovanih na železu. Postupcima GMAW / OA obično se postiže stepen mešanja između 20-40%, tabela 3.

| Abrasive Particles | Average particle size |
|---|---|
| Raw powder dust | ~ 8 µm |
| Sinter dust | 5-15 µm |
| Dusts from steelmaking | < 20 µm |
| Cement raw powder | 8-15 µm |
| Cement dust | 10-20 µm |

*Abrasive Particles-- Čestice abraziva; Raw powdwe dust- Praškasta sirovina; Sinter dust- Prašina sintera; Dusts from steelmaking- Prašina pri proizvodnji čelika; Cement raw powder- Prah sirovog cementa; Cement dust- Cementna prašina; Average particle size- Prosečna veličina čestice*

***Table 1.*** *Average particle size for typical abrasives with industrial ventilators (5)*

***Tabela 1.*** *Prosečna veličina čestica tipičnih abraziva kod industrijskih ventilatora (5)*

| Matrix | Hard phase formers | Welding process |
|---|---|---|
| Fe | Cr, (Nb, V, Mo, W), (C, B) | OA/GMAW |
| Fe | C, Cr, cast tungsten carbide (CTC) | OA/GMAW |
| Ni | Cr, Mo, CTC | PTA, GMAW |

*Matrix-matrica; Hard phase formers-Stvaraoci tvrde faze; Welding process-Postupak zavarivanja*

***Table 2.*** *Standard wear protection materials for ventilators structure.*

***Tabela 2.*** *Standardni materijali za zaštitu od habanja konstrukcije ventilatora.*

| Welding process | Depostion rate in kg/h | Dilution in % | Layer thickness in mm |
|---|---|---|---|
| GMAW/OA | 8-9 | 20-40 | 4-8 |
| PTA | ≤ 15 | 5-10 | 2-7 |

*Welding process-Postupak zavarivanja; Deposition rate-Brzina deponovanja; Dilution-Stepen mešanja; Layer thickness-Debljina sloja*

***Table 3.*** *Standard processes for applying hardfacing for ventilators' structure [6].*
***Tabela 3.*** *Standardni postupci za nanošenje tvrdih navara za konstrukciju ventilatora,[6].*

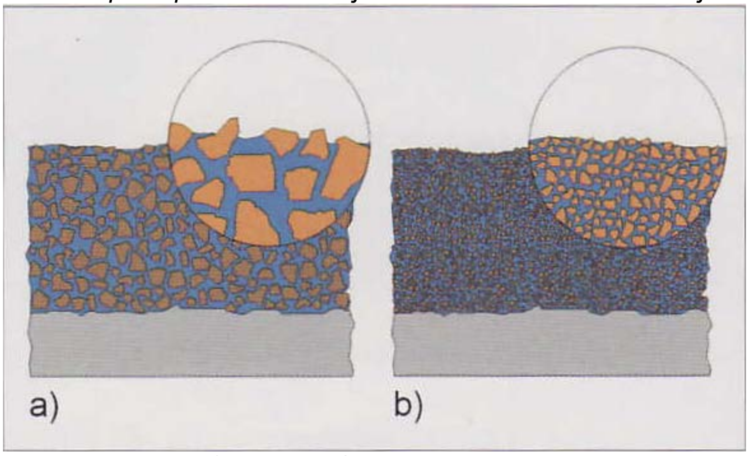


***Fig.3.*** *Wear protedive measures by grain refinement: a) conventional hard alloy with large hard phase spacing (- 30-50 μm ), higher wear with fine abrasive attack, b) customised hard alloy with very small hard phase intewals for protection against fine abrasive wear applications [7].*
***Sl 3.*** *Mere zaštite od habanja rafinacijom zrna: a) konvencionalna tvrda legura sa velikim razmakom tvrdih faza (- 30-50 μm), veća habanja napadom finih abraziva, b) prilagođena tvrda legura sa vrlo malim intervalima tvrdih faza za zaštitu od finih abraziva [7].*

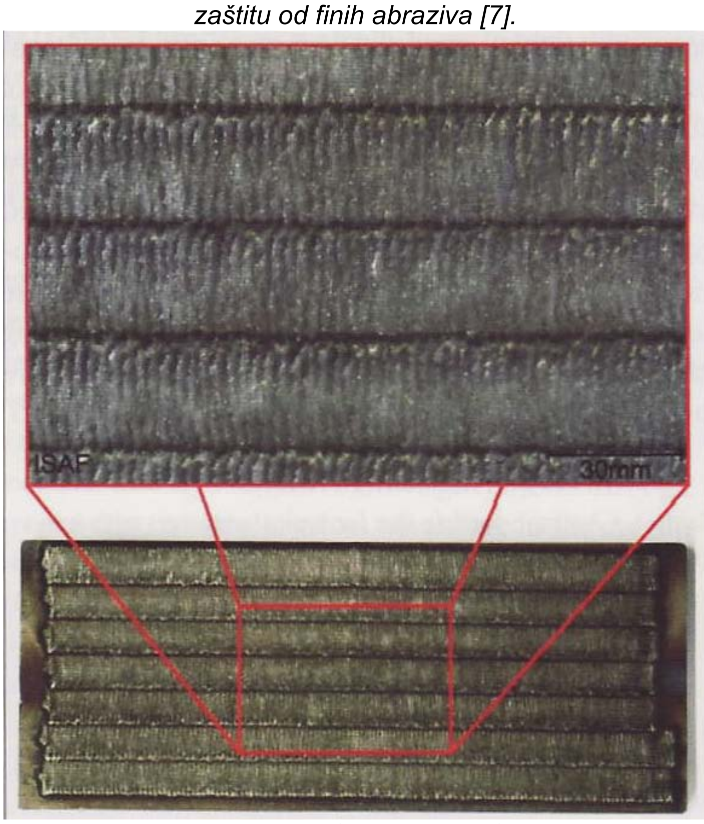


***Fig.4 .*** *CSA structural component coating: Fe-Basis + Cr-boride + VC, ventilator component factory OeldE GmbH (Picture: ISAF)*
***Sl..4.*** *CSA konstrukciona komponenta: Fe-osnova + Cr-borid + VC, fabrika komponenti ventilatora OeldE GmbH (Slika: ISAF)*

The quality feature dilution describes is the relationship between the mixing zone of the base and additional material to the total area of the weld cross section. With a decreasing degree of dilution the film quality increases, wherein a minimum of about 3% is however necessary to ensure adhesion especially under dynamic stress [1-3].

**2.3 High perfomance wear protection systems**

The protection effect of hard alloys is based on the fact that the brittle hard phases prevent the attacking hard abrasive particles from penetating the matrix. If the distance between the hard phases is greater than the average particle size of attacking particles, the metal matrix is washed out and there are significant signs of wear, Fig. 3 [1-3].

The considered abrasive particles here, Table 1, show in comparison to other wear protective usual applications - such as in the mining industry - an extremely small grain size in the order of about 10 μm. Therefore a finely dispersed distribution of the hard phases (< 12 μm) independent of the base alloy is absolutely necessary in order to achieve an improvement in the wear resistance. In addition to the high-quality nickel-based alloys, there are altemative lower cost iron-based alloys. The ones which are used in fans stucture are high and ultra-high fine-grained structural steels of classes S690+ and S960+ which should be protected by a modem low energy controlled short arc (CSA) welding process without the original material losing its original properties excessively. This hardfaced base material can be used as a highly stressed structural material, also the lightweight objects (obtaining the base material properties) are realised and as considerable life extension (properties of the coatings) can be achieved [1-3].

**3. Short arc techniques**

The CSA processes cause only slight thermal strains in the involved base material, because overall a low energy input (short arc technique) is used while high short circuit currents are avoided. CSA processes have been developed to connect thin sheets by welding. In order to avoid high energy input and uncontrolled spatter duringg the breaking of short circuit current, the maximum power is significandy lowered during re-ignition of the arc. This leads to a significandy lower thermal influence on the material during melting [1-3, 8].

In addition to joining, this technology is also advantageous for hardfacing [9-11]. For example, corrosion-resistant hardfacings are produced with the CSA technology on an industrial scale [12]. Through conventional short arc prccesses the introduced energy input to the substate is normally only reduced for inadequate weld beads formation. With the CSA processes the short circuit current

Kvalitet vezivanja se opisuje kao odnos između zone mešanja osnovnog i dodatnog materijala prema ukupnoj površini preseka šava. Sa smanjenjem stepena mešanja, povećava se kvalitet filmova, pri čemu je minimum oko 3% neophodan da bi se obezbedila adhezija posebno u slučaju dinamičkih naprezanja [1-3],

**2.3 Sistemi za zaštitu od habanja visokih performansi**

Zaštitni efekat tvrdih legura zasniva se na činjenici da krke tvrde faze sprečavaju napade tvrdih abrazivnih čestica koje udaraju u matricu. Ako je rastojanje između tvrdih faza veće od prosečne veličine čestica udarajućih čestica, metalna matrica se spira i nastaju značajni znaci habanja, slika 3 [1-3].

Smatra se da abrazivne čestice, ovde navedene u tabeli 1, u poređenju sa ostalim primenama zaštite od habanja - kao što je u rudarskoj industriji – imaju izuzetno mala zrna u rasponu od oko 10 μm. Zbog toga je fina raspodela tvrdih faza (<12 mm) nezavisna od legure osnove, apsolutno neophodna kako bi se postiglo poboljšanje otpornosti na habanje. Pored visokokvalitetnih legura na bazi nikla, postoje i alternativne jeftinije legure na bazi železoa. One koje se koriste u ventilatorima su visoki i ultra visoki finozrni konstrukcioni čelici klase S690 + i S960 + koje treba zaštititi modernim postupkom zavarivanja niskoenergetskim kratkim lukom (CSA) bez preteranog gubljenja osobina originalnog materijala. Ovaj tvrdo navareni materijal se može koristiti kao visoko naponski konstrukcioni materijal, takođe se realizuju laki objekti (postizanje svojstava osnovnog materijala) kao i značajno produženje životnog veka (osobine prevlaka) [1-3].

**3. Tehnike kratkog luka**

Postupci CSA izazivaju samo blage termalne napore u uključenom osnovnom materijalu, jer se u celosti koristi niskoenergetski unos (tehnika kratkog luka), dok se izbegavaju velike struje kratkog spoja. CSA postupci razvijeni su za spajanje tankih ploča zavarivanjem. Da bi se izbegao veliki unos energije i nekontrolisano razbrizgavanje („pucne"), tokom prekida struje kratkog spoja, maksimalna snaga je značajno spuštena tokom ponovnog paljenja luka. To dovodi do znatno manjeg termičkog uticaja na materijal tokom topljenja [1-3, 8].

Pored spajanjaa, ova tehnologija je takođe pogodna za tvrdo navarivanje [9-11]. Na primer, tvrdi navari otporni na koroziju izvode se tehnologijom CSA na industrijskom nivou [12]. Kroz konvencionalne postupke kratkim lukom, unos energije na podlogu se obično smanjuje samo kod neadekvatno formiranje zavara u šavu. Postupcima

and the curent rise during the arc re-ignition is limited after the mateial transfer in contolled short circuit technology. The droplet detachment can be further enhanced by the mechanical support by the reversal of the wire feed [1-3]. Table 4 provides an overview of selected presendy available process techniques in connection with the control methods used.
The current developments focus on a material side matching the additional material as well as the use of the process to apply hardfacing on thermally sensitive materials. Investigations [9, 11, 13] have shown that refining the hard phases over conventional process is possible. An increase in performance of the coatings against fine abrasive or erosive stress wear in practice is therefore expected in this context [1-3, 14].

CSA, struja kratkog spoja i povećanje struje tokom reaktivacije luka ograničeno je nakon prenosa materijala kontrolisanom tehnologijom kratkog spoja. Odvođenje kapi se dalje može poboljšati mehaničkom podrškom pomoću obrtanja žice [1-3]. U tabeli 4 dat je pregled odabranih tehnika koje su dostupne u prethodnom periodu u vezi sa korišćenjem metoda kontrolisanja.
Aktuelni razvoj se fokusira na podudarne dodatne materijale, kao i na korišćenje postupka za tvrdo navarivanje na termički osjetljivim materijalima. Ispitivanja [9, 11, 13] su pokazala da je rafinisanje tvrdih faza u odnosu na konvencionalni proces, moguće. U tom kontekstu se očekuje povećanje performansi prevlaka protiv finih abraziva ili habanja erozivnim naponima u praksi [1-3, 14].

| CSA process | Manufacturer |
|---|---|
| **Electronic control** | |
| AC-MIG | OTC Daihen Europe |
| coldArc® | EWM Hightec Welding |
| CP (Cold Process) | CLOOS |
| RMDTM (Regulated Metal Deposition) | Miller Electric |
| TST (Tension surface Transfer) | Lincoln Electric |
| **Electronic and mechanical control** | |
| CMT (Cold Metal Transfer) | Fronius International |
| CSC (Controlled Short Circuit) | Miller Electric |

***Table 4.*** *Selected CSA processes and manufacturers [13].*
***Tabela 4.*** *Odabrani postupci CSA i proizvođači [13].*

| Type | Material density in g/cm³ | Layer hardness in $HR_C$ |
|---|---|---|
| FeCrB | 7.2 | 56.6 |
| FeCrNbVBC | 7.1 | 65 |
| FeCrC | 7.6 | 63-66 |

***Table 5 .*** *Properties of weld coating*
***Tabela 5.*** *Osobine zavarenih prevlaka*

## 4. Experimental

By the CSA process hardfacing was performed on fine grained steel of grade S960QL. As additional materials iron based flux cored wires (Φ 1.6 mm) with characteristic hard phases were processed [1-3].
Hereby, a high chromium high boron containing hard alloy, also Cr-boride forming Fe-based alloy with additional alloy contents of VC and NbC as well as a reference anti -wear material, a conventional high-chromium high carbon Fe-based

## 4. Eksperiment

Postupkom CSA je obavljeno tvrdo navarivanje na finozrnom čeliku klase S960KL. Kao dodatni materijali korišćene su punjene žice na bazi železa (PH 1,6 mm) sa karakterističnim tvrdim fazama [1-3].
Ovde su korišćene tvrde legure sa visokim sadržajem hroma i bora, takođe legure na bazi železa koje stvaraju Cr-borid sa dodatnim legiranjem VC i NbC, kao i referentni anti-habajući materijal, konvencionalne legure tipa FeCrC.

type FeCrC were used. The layers produced were both metallographically and wear technicallv qualified [1-3].

**4.1 Hardfacings**

With the selected flux-cored wire materials planar wear-resistant coatings were applied to the structural material in a weaving beads technique with a weaving width of 20 mm, Fig. 4 [I 3]. Film thicknesses between 2 and 2.5 mm were generated. As a protective gas, an argon-carbon dioxide mixture was used. AII samples with applied layers were cut by electrical discharge machining and material densities were determined pycnometrically, Table 5 [1-3].

The multilayer composites produced were investigated metallographically. Macro-hardness (Rockwell C) and micro-hardness measurements ($HV_1$) were performed in THE region of the HAZ I1-3].

Proizvedeni slojevi bili su ispitani metallografski i tehnikama ispitivanja habanja [1-3].

**4.1. Tvrdo navarivanje**

Odabranim materijalima u obliku punjene žice, nanete su pločaste prevlake otporne na habanje na konstrukcioni materijal tehnikom njihanja, širine 20 mm, slika 4 [I 3]. Dobijene su debljine filma od 2 do 2,5 mm. Kao zaštitni gas korišćena je smeša argon-ugljen-dioksida. Svi uzorci sa nanetim slojevima su sečeni mašinama sa električnom pražnjenjem, a gustine materijala određene su piknometrijski, tabela 5 [1-3].

Dobijeni višeslojni kompoziti su metalografski ispitani. Makro-tvrdoća (Rockvell C) i merenja mikro tvrdoće (HV1) izvedena su u regionu ZUT [1-3].

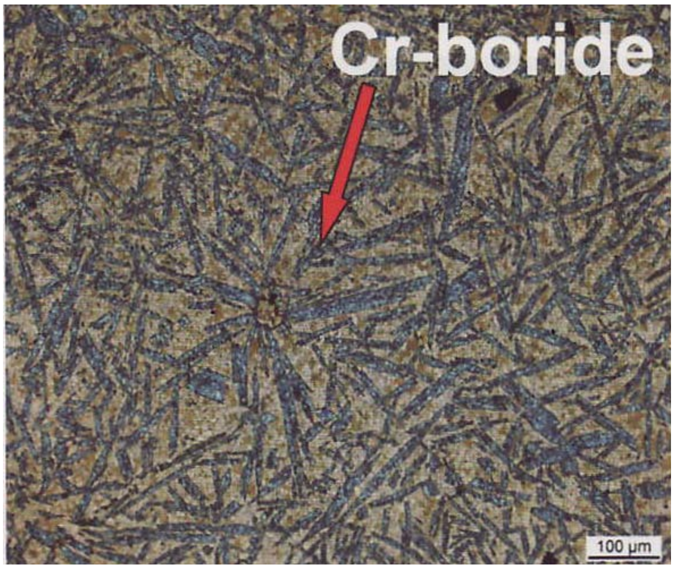


***Fig. 5.*** *CSA welding: FeCr*
***Sl. 5.*** *CSA zavarivanje: FeCr*

**4.2 Metallographic analysis**

After processing with the CSA process, the microstrucrure of hardfacing tlpe FeCrB shows a random distribution of the hard chromium boride phase with very small hard phase gaps, Fig. 5 [1-31].

The newly developed wear protection material of the type FeCTNbVBC shows additional vanadium carbide hard phases, which precipitate between the boride hard phases and thus further reduce the hard phase spacing, Fig. 6. Hence, the preparation of the corresponding hard-facings can be expected to perform somewhat better in the target application than the FeCrB hardfacings allows a furrther improvement in coating properties to be expected [1-3].

**4.2. Metalografska analiza**

Posle nanošenja postupkom CSA, mikrostruktura tvrdog navara tlpa FeCrB pokazuje slučajnu raspodelu tvrde hrom boridne faze sa veoma malim zazorima na tvrdoj fazi,slika 5 [1-31].

Novorazvijeni materijal za zaštitu od habanja tipa FeCTNbVBC pokazuje dodatnu tvrdu fazu vanadijum karbida, koje precipitiraju između boridnih tvrdih faza i time dodatno smanjuju razmak između tvrdih faza, slika 6. Stoga se može očekivati da priprema odgovarajućih tvrdih navara može da se izvede nešto bolje u ciljanoj primeni nego FeCrB tvrdi navari, što omogućava unapređenje poboljšanja svojstava prevlaka [1-3].

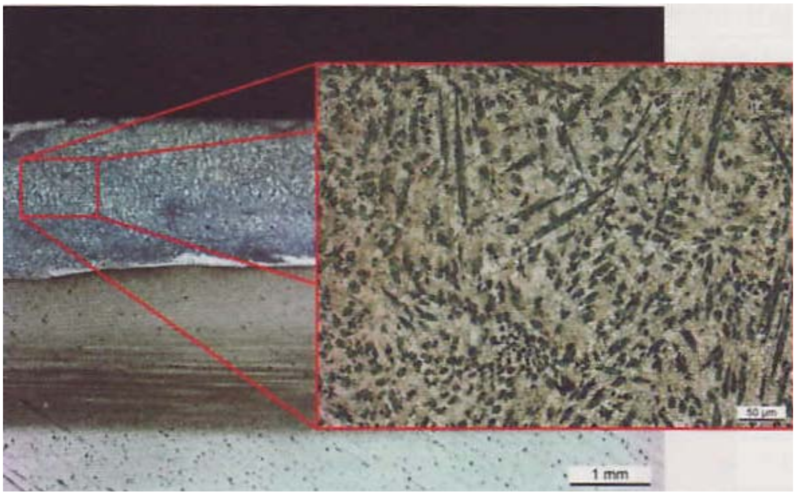


***Fig. 6 .*** *CSA welding FeCTNbVBC*
***Sl. 6 .*** *CSA zavarivanje FeCTNbVBC*

**4.3. Wear tests**

The wear resistance of the hardfacings was assessed according to DIN 50332. The test bench consists essenrially ofa blast chamber, an resevoir with a metering system for controlling the abrasive particles mass flow rate, a compressed air supply, an injector and the sample holder, Fig.7 [1-3]

**4.3. Ispitivanje habanja**

Otpornost na habanje tvrdog navara je ocenjivana u skladu sa DIN 50332. Ispitna klupa se sastoji od eksplozivne komore, rezervoara sa dozirnim sistemom za kontrolu masenog protoka abrazivnih čestica, snabdevačem komprimovanog vazduha, injektorom i držačem uzorka, sl..7 [1-3]

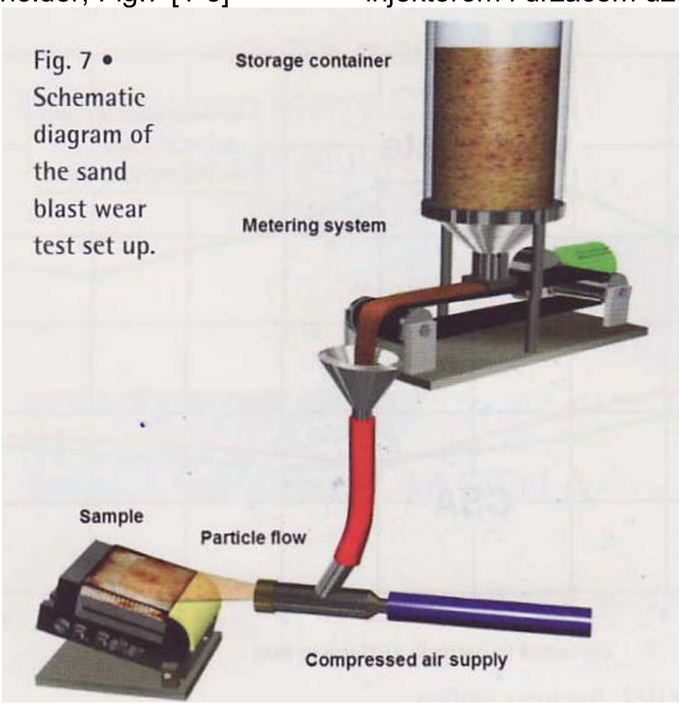


Fig.7
Sl.7

The abrasive particle volume flow supplied to the injector is adjusted via a dosing system. The free flowing particles with the guided gas beam cause a ramming or tapping material damage depending on the stress angle. For the tests, a blast angle of 10' (inclined blast abrasion stress) was set at the seam transition because practical experience showed a particular vulnerability here. The test took place on the weld seam with cement as abrasive particles. A palticle size analysis of the used abrasive particles

Zapreminski protok abrazivnih čestica koji se isporučuje u injektor podešava se putem dozirnog sistema. Čestice slobodne tečnosti sa vođenim gasnim snopom uzrokuju oštećenje materijala ili pucanje materijala u zavisnosti od ugla napona. Za ispitivanje, ugao naleta od $10^0$(nagnuti napon od abrazije) postavljen je na presk šava, jer je praktično iskustvo pokazalo posebnu ranjivost ovde. Test se odvijao na zavarenom spoju sa cementom kao abrazivnim česticama. Analiza showed a mean particle diameter of $d_{50}$ = 16 μm. The variable test parameters are the form and amount of abrasive particles as well as the distance between the sample and injector outlet, table 6 [1-3].

Through the wear tests, a significantly improved wear performance can be demonstrated for the wires processed with the CSA method in comparison to the GMAW welded flux-cored wires (for example NiCrBSi + CTC), Fig. 8. The hardfacings of the new wear resistant materials with precipitated hard phases in the matrix and at the same time very small hard phase spacing in conjunction with the low thermal influence ofthe CSA welding coating process technology (dilution < 10%) provide an increase in service life of 325 to about 400% against traditional wear solutions (Fe-Cr-C-Mo-B-wear plates), also an incrcase of about 150-175% while compared to conventional coating methods [ 1-3]. By reducing the hard phase spacing for FeCrNbVBC, the expected increase in the wear resistance cannot be confirmed yet [1-3].

veličine čestice korišćenih abrazivnih čestica pokazala je srednji prečnik čestica $d_{50}$ = 16 μm. Promenljivi parametri testa su oblik i količina abrazivnih čestica, kao i rastojanje između izlaza uzorka i injektora, tabela 6 [1-3].

Kroz testove habanja, može se dokazati značajno poboljšanje performansi habanja sa žicama nanetim postupkom CSA u poređenju sa GMAW zavarivanjem punjenim žicama (na primer NiCrBSi + CTC), slika 8. Tvrdi navari od novih materijala otpornih na habanje sa precipitiranim tvrdim fazama u matrici i istovremeno sa vrlo malim rastojanjem tvrdih faza u kombinaciji sa malim toplotnim uticajem tehnologije zavarivanja CSA (stepen mešanja <10%) omogućavaju povećanje veka trajanja od 325 do oko 400% naspram tradicionalnog rešenja za habanje (Fe-Cr-C-Mo-B-ploče za habanje), takođe povećanje od oko 150-175% u poređenju sa klasičnim metodama prevlaka [1-3]. Smanjivanjem rastojanja tvrdih faza za FeCrNbVBC, očekivano povećanje otpornosti na habanje još ne može biti potvrđeno [1-3].

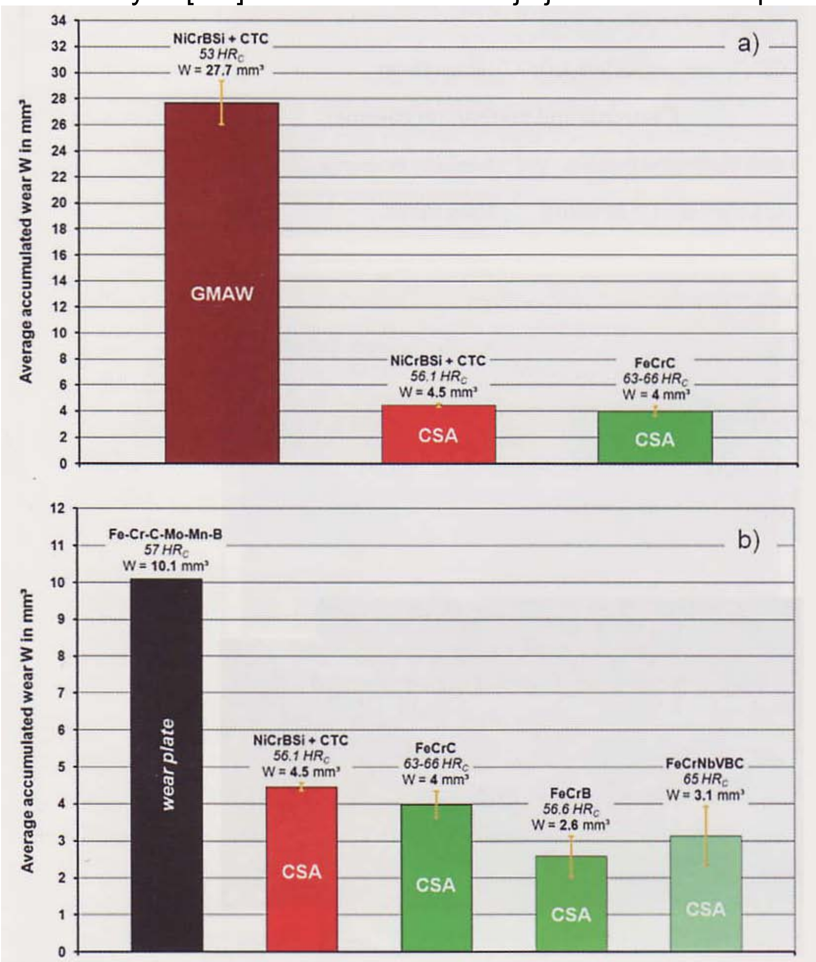


***Fig. 8.*** *Average accumulated material removal by wear under 100 inclined blast abrasion stress: a) GMAW vs. CSA hardfacing, b) Novel high performance wear protection system*

***Sl.8.*** *Prosečno nakupljeno uklanjanje materijala habanjem ispod 100 nagnutog naprezanja od abrazije: a) GMAV nasuprot. CSA tvrdo navarivanje, b) Novi sistem zaštite od habanja visokih performansi*

**5.Potential for lightweights**

To apply for the lightweight objects, a layer thickness between 2 and 2.5 mm was sought. The HAZ thickness was about 3mm in all welds and therefore shows, in comparison to conventionally layered composites, reliably a width of substantially less than 5 mm with which the residual load-bearing cross-section was considerably enlarged. In conjunction with a dilution zone ofless than 1.5 mm it is therefore largely possible to preserve the basic material properties with all coatings [3-1].

**5.1 Hardness measurement in the heat-affected zone**

Additional micro-hardness measurements (HV1) were caried out in the HAZ, Fig. 9. Through the low energy CSA process the hardening in the HAZ as well as in the temperature-sensitive base material can be cleary reduced in comparison to the GMAW variant. A significant increase in hardness was observed in the weld metal both with the conventionally employed FeCrC alloy as well as the newly developed high-performance wear-resistant alloy [1-3]. A reduction in the HAZ expansion is permitted with the CSA process and also confirmed through the series of hardness measurement [1-3].

**5.Potencijal za male težine**

Za primenu na lakim predmetima tražena je debljina sloja od 2 do 2,5 mm. Debljina ZUT-a je bila oko 3 mm u svim zavarenim spojevima i prema tome pokazuje, u poređenju sa konvencionalno slojevitim kompozitima, pouzdano širinu znatno manju od 5 mm sa kojom je preostali presek nosivosti znatno uvećan. Zbog toga je u kombinaciji sa zonama mešanja manjim od 1,5 mm, u velikoj meri je moguće sačuvati osnovne osobine materijala svim prevlakama [3-1].

**5.1 Merenje tvrdoće u zoni uticaja toplote**

Dodatna merenja mikro-tvrdoće (HV1) su obavljena na ZUT-u, slika 9. Kroz nisko energetski CSA postupak, otvrdnjavanje ZUT-a kao i u temperaturno osetljivom osnovnom materijalu može biti vidno smanjeno u poređenju sa varijantom GMAW . Značajno povećanje tvrdoće primećeno je u metalu šava i sa konvencionalno korišćenom FeCrC legurom, kao i sa novim razvijenim legurama otpornim na habanje visokih performansi [1-3]. Smanjenje širenja ZUTa je dozvoljeno zahvaljujući CSA postupku a potvrđeno je kroz seriju merenja tvrdoće [1-3].

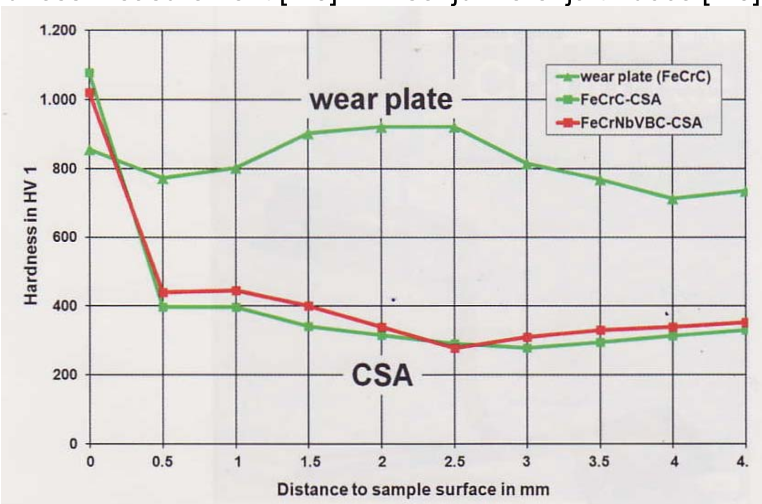


***Fig.9.*** *Expansion of the HAZ: Hardness profiles.*

***Fig.9.*** *Širenje ZUT: Profili tvrdoće*

| | |
|---|---|
| Wear test | Sand blast wear test (DIN 50332) |
| Abrasive particles | Cement powder |
| Stress angel | 10° (inclined blast wear) |
| Pressure | 7.5 bar |
| Sample distance | 20 mm |
| Abrasive particle mass flow rate | 140 g/min |
| Test duration | 2 h |

***Table 6 .*** *Test parameters*

***Tabela 6.*** *Parametri ispitivanja*

### 5.2 Mechanical-technological tests

To fufther verify the mechanical technological properties of the composites, tensile tests were performed on the coated structural samples. For this flat tensile test, specimens (DIN 50125, Form E, sample thickness: a = 10 mm, sample width: b = 30 mm) were cut with the hardfaced layer using water jet cutting technique and the direction was chosen traverse the welding direction of the longitudinal sample, in order to accommodate as many undercuts as possible from the weaving weld beads during the test, Fig. 10.

### 5.2. Mehaničko-tehnološka ispitivanja

Da bi se utvrdile mehaničko-tehnološke osobine kompozita, izvedene su ispitivanja zatezanjem na prevučenim konstrukcionim uzorcima. Za ovaj test ravnog zatezanja, epruvete (DIN 50125, oblik E, debljina epruvete a = 10 mm, širina epruvete: b = 30 mm) su se presečene zajedno sa slojem tvrdog navara vodenim mlazom i izabran je pravac poprečno na smer zavarivanja kod uzdužnog uzorka, kako bi pri ispitivanju bilo što više prokapina usled njihanja zavara, slika 10.

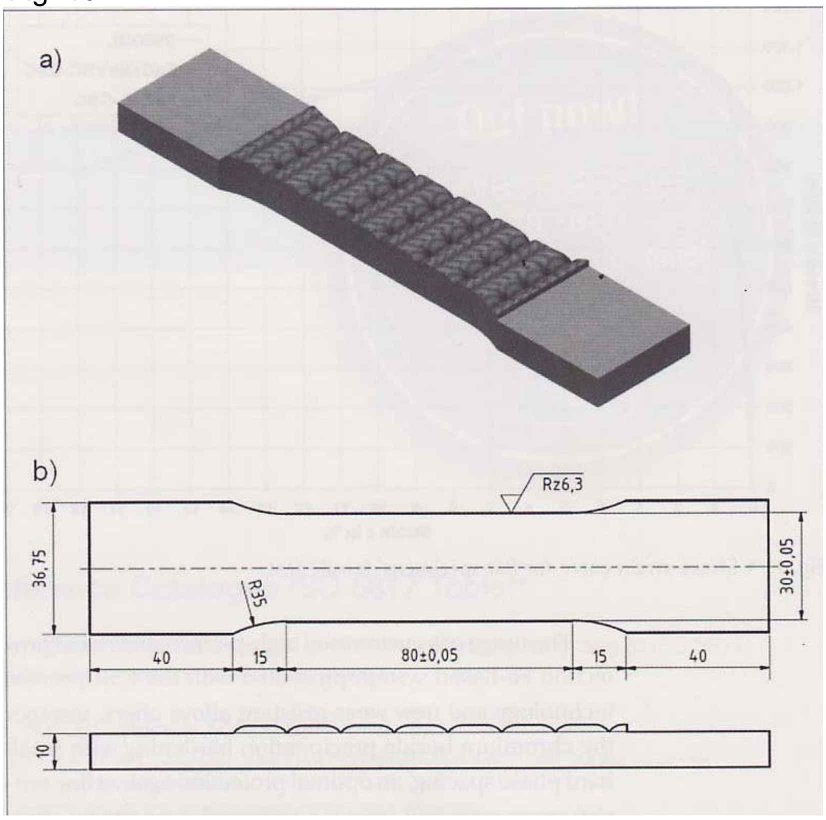


***Fig. 10 .*** *Flat tensile test specimen geometry: a) 3D-CAD-Model (isometric), b) Engineering drawing*
***Sl. 10.*** *Geometrija epruvete za ispitivanje zatezanjem: a) 3D-CAD-model (izometrijski), b) Inženjerski crtež*

As it is demonstrated by the tensile tests, Fig. 11, the minimum elastic extension of the examined base material (S960QL) lies at about 950 MPa ($\sigma_y$= 960 MPa according to manufacturer) and at about a minimum ultimate tensile strength (UTS) of 1075 MPa the elongation was 1B% at fracture ($\xi_{min}$ = 10%).

Low energy coated tensile test specimens for the FeCrC alloy with the CSA process showed an ultimate tensile strength of up to 800 MPa. The elongation lies approximately between 7 and 8.5%. The interesting present type of wear stress Cr-boride strengthened hard alloy (here for example the FeCrNbVBC alloy) has a UTS of at least 750 MPa at an elongation of 7% at fracture.

Kao što je pokazano ispitivanjem zatezanjem, slika 11, minimalna elastična ekstenzija ispitivanog osnovnog materijala {S960KL) leži na oko 950 MPa ($\sigma_y$ = 960 MPa prema proizvođaču) i pri približno minimalnoj konačnoj zateznoj čvrstoći (UTS) od 1.075 MPa, izduženje je bilo 18% pri prelomu (ξmin = 10%).

Epruvete za ispitivanje zatezanjem obložene niskoenergetskim postupkom CSA legurom FeCrC pokazale su konačnu čvrstoću pri zatezanju do 800 MPa. Izduženje leži približno između 7 i 8,5%. Od interesa je za prisutni tip napona habanja da Cr-boridom ojačane tvrde legure (ovde npr. legura FeCrNbVBC) ima UTS od najmanje 750 MPa pri izduženju od 7% na prelomu.

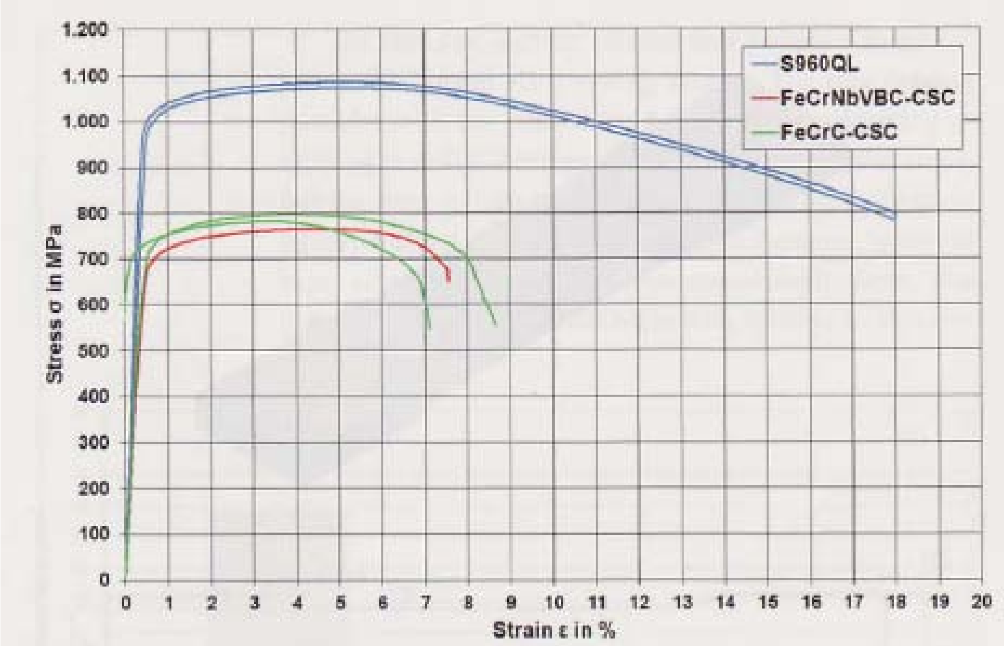


***Fig. 11.*** *Stress-strain curve for flat specimens' tensile test.*
***Sl. 11.*** *Kriva napon-deformacija kod ispitivanja zatezanjem ravne epruvete*

## 6. Conclusions

Typical and novel wire-based high performance wear protection alloys were processed and produced with the CSA process and partially compared with the conventionally GMAW produced layers. It was found that by using the CSA process with alloys characterised by hard phases, a hard phase refining occurs in the processing of nickel alloys containing cast tungsten carbide the occurring hard phase decay can be significantly reduced. This in turn significantly increases the layer quality and, in comparison to conventional coatings, an increase in the wear resistance through a sand blast wear test accordingto DIN 50332 can be determined.

The usage of a customised high-performance wear protection Fe-based system presented with the CSA process technology and new wear resistant alloys offers, trough the chromium boride precipitation hardening with small hard phase spacing, an optimal protection against fine erosive stress wear and creates a technical-economical alternative to the expensive nickel-based alloys.

Through the energy reduction with the CSA process, the suppoft of structural lightweight objects for the ventilators technology can also be achieved, firstly because the HAZ has a small expansion and the residual cross-section is correspondingly large, secondly the structural components can be protected and hardfaced directly. Thus the use of wear plates is eliminated.

## 6. Zaključci

Tipične i nove žice na bazi legura visokih performansi zaštite od habanja su primenjene i nanete CSA postupkom i delimično upoređene sa slojevima dobijenim konvencionalnim GMAW postupkom. Utvrđeno je da se korišćenjem CSA postupka sa legurama koje karakterišu tvrde faze, javlja rafinacija tvrde faze kod primene legura nikla, koje sadrže liveni volfram karbid, tako da može doći do značajnog smanjenja propadanja tvrde faze. Ovo zauzvrat značajno povećava kvalitet sloja i, u poređenju sa konvencionalnim prevlakama, može se odrediti povećanje otpornosti na habanje testom habanja peskom u skladu sa DIN 50332.

Korišćenje prilagođenog sistema za zaštitu od habanja visokih performansi na bazi Fe, postignutih tehnologijom CSA postupka i ponudom novih legura otpornih na habanje, kroz otvrdnjavanje precipitacijom hrom borida s malim razmakom tvrdih faza, optimalna je zaštita od finog erozivnog opterećenja i stvara tehno-ekonomičnu alternativu skupim legurama na bazi nikla.

Kroz smanjenje energije zahvaljujući CSA postupku, može se postići i nadgradnja konstruktivnih lakih objekata za ventilatorsku tehnologiju, pre svega zato što ZUT ima malu ekspanziju, a preostali poprečni presek je odgovarajuće velik, drugo, konstrukcione komponente mogu biti zaštićene i direktno tvrdo navarene. Tako se eliminiše upotreba ploča za habanje.

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**Literatura i refrence**

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***<u>Podsećamo vas da obnovite vaše članstvo u DUZS i pretplatu za naš časopis.</u>***