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Uporaba tehnologije eksplozijskega navarjanja v postopku izdelave hidravličnih valjev

The application of explosive cladding technology in the process of hydraulic-cylinder production

Vid Jovišević - Mirko Soković

V prispevku sta prikazani tehnologiji oblikovanja drsnih dvojic s standardnim postopkom navarjanja brona z elektrodo in z eksplozijskim navarjanjem pločevine iz brona na drsne ploskve hidravličnega valja. Raziskovane so bile mikrotrdota, mikrostruktura in vezna (strižna) trdnost mejne plasti bimetalnega spoja v prečnem prerezu testnega hidravličnega valja. Primerjalni rezultati uporabe teh dveh tehnologij so podani na podlagi metalografskih in mehanskih raziskav mejne plasti med bronom CuSn6 in jeklom za hidravlične valje Č.1213 (ISO TS5).

(Ključne besede: navarjanje eksplozijsko, valji hidravlični, trdnost strižna, plasti mejne, broni-jekla)

This paper treats the technologies for glide-pairs forming using bronze cladding and using the sheet-bronze explosive cladding technique over the glide surfaces of a steel hydraulic cylinder. In the paper the microhardness, the microstructure and the bond strength of the interface of a bi-metallic joint on the cross-section of the test hydraulic cylinder were investigated. A parallel results survey of the application of these two technologies is shown based on metallographic and mechanical investigations of the interface between the CuSn6 bronze and the TS5 steel cylinder.

(Keywords: explosive cladding, hydraulic cylinder, bond strength, bronze-steel interface)

0 UVOD

Pri postopku izdelave hidravličnih valjev se uporablja tehnologija navarjanja brona z namenom oblikovanja drsnih dvojic, narejenih iz različnih materialov. Tako se izognemo hladnemu zvarjanju (zaribavanju) drsnih dvojic pri preobremenitvah med delom (uporaba valjev na hidravličnih stiskalnicah za upogibanje pločevine).

Hidravlični valj in bat kot drsna dvojica pri delovanju hidravličnih stiskalnic običajno niso izpostavljeni posebnim dinamičnim preobremenitvam, ki bi povzročale nenormalno delovanje, ki bi vodilo do hladnega zvarjanja. Vendar se v praksi pojavljajo primeri hladnega zvarjanja teh dvojic. Kot vzroke za te pojave lahko označimo:
- nepravilno definirane tolerance ujemov teh dvojic,
- neustrezno kakovost obdelave drsnih površin,

0 INTRODUCTION

In the process of hydraulic-cylinder production, bronze cladding technology is applied in order to form gliding pairs that are made of various materials. In this way the possibility of the cold welding of the gliding pairs during overloading in the working process (the application of the cylinder on a hydraulic press for sheet-metal bending) is eliminated.

The hydraulic cylinder and the piston, as a gliding pair in the function of hydraulic presses, are not exposed to any special dynamic overloading that can cause an abnormal working process and lead to cold welding, however, in practice there are cases of the cold welding of these pairs. The causes of this cold welding are identified as:
- irregularly defined structure tolerances,
- in adequate processing quality of the gliding surfaces,

- nečistoče v olju,
- kakovost navarjanja brona in
- kakovost samega brona.

Med vsemi navedenimi vzroki so bolj izpostavljeni tisti, ki se kažejo med postopkom navarjanja brona, predvsem zaradi zapletenosti tehnološkega postopka in vpliva varilca nanj. Navarjanje brona je trajen postopek, kar povzroča nastajanje poroznih površin ter pojav trdih con. Vse to vpliva na kakovost drsnih površin in povzroča nezaželene posledice.

Zaradi tega so bile raziskave avtorjev tega prispevka usmerjene na iskanje alternativne tehnologije za oblikovanje drsnih dvojic iz različnih materialov za primer hidravličnih stiskalnic za upogibanje pločevine.

Tehnologija eksplozijskega navarjanja je bila uporabljena za izdelavo bimetalnega materiala (bron, navarjen na jeklo za hidravlične valje), ki bo imel izboljšane fizikalno-mehanske lastnosti pri sami uporabi ([1] in [2]). Ta tehnologija temelji na detonaciji eksploziva, katerega energija se prenaša prek določenega posrednika na material, ki se navarja. Podrobni opis postopka eksplozijskega spajanja je podan v [3] do [5]. Za potrebe teh raziskav so bili poskusi izvedeni v improviziranih razmerah [6]. Rezultati, doseženi z uporabo te tehnologije pri izdelavi hidravličnih valjev stiskalnic za upogibanje pločevine, so podani v nadaljevanju.

1 SEDANJA TEHNOLOGIJA IZDELAVE HIDRAVLIČNIH VALJEV

Proizvodnja hidravličnih valjev (sl. 1) poteka po običajni tehnologiji ([7] in [8]). Kot pomembnejši tehnološki opravili lahko izpostavimo: navarjanje brona z elektrodo na predhodno pripravljeno notranjo površino jeklenega hidravličnega valja ter struženje.

Navarjanje brona se izvaja v naslednjih korakih:
- čiščenje in razmaščevanje površine pred navarjanjem,
- nanašanje topila na površino (*CASTOLIN 18*),
- predgrevanje valja do 300 °C in
- nanašanje (navarjanje) brona na površino z elektrodo *CASTOLIN CP 146*.

Posameznih faz pri opravilu struženja je lahko več in glede na njihovo izvajanje dosežemo ustrezne končne mere valjev.

Sedanji tehnološki postopek izdelave hidravličnih valjev spremljajo naslednje omejitve:

- dirt in the oil,
- bronze cladding quality,
- bronze material quality.

Of all the causes that are given as examples, those which are manifested in the process of bronze cladding are the most obvious, and this is because of the complexity of the technological process and its being subject to the influence of the welder. Bronze cladding has no continuous flow, which leads to the formation of porous surfaces and the appearance of hard zones. This all has an influence on the quality of the gliding surfaces and causes negative results.

For this reason we have investigated alternative gliding-pairs forming technologies from various materials, as in the example of the hydraulic cylinders of presses for sheet-metal bending.

The technology of explosive cladding has been used for the production of bi-metal materials (bronze-clad steel for hydraulic cylinders) featuring high physical-mechanical and service properties ([1] and [2]). This technology is based on an explosive detonation, whose energy is transferred by a special medium to the material that is applied. A detailed description of the explosive technique is given in [3] to [5]. According to the needs of these investigations, the experiments were performed under improvised conditions [6]. The results that are achieved by the application of this technology to the production of the hydraulic cylinders of presses for sheet-metal bending are given in advance.

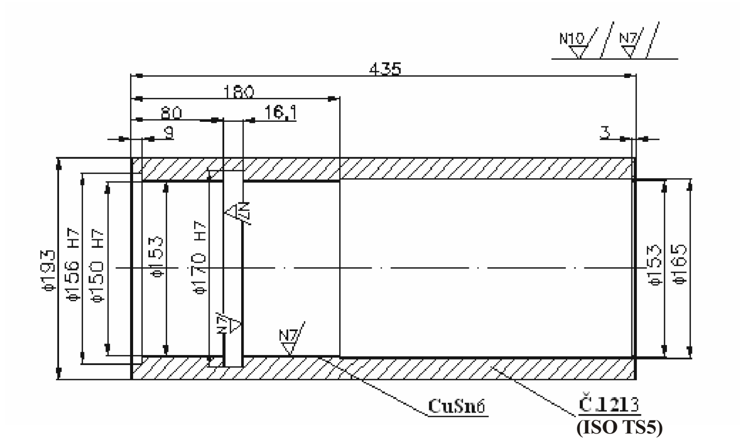
1 PRESENT TECHNOLOGY FOR THE PRODUCTION OF HYDRAULIC CYLINDERS

The production of hydraulic cylinders (Fig. 1) is carried out according to standard technology ([7] and [8]). The main operations are bronze cladding on the previously prepared inner surface of the steel hydraulic cylinder and turning.

The bronze cladding is carried out as follows:
- cleaning and removing grease from the surface before cladding,
- application of dissolving material on the surface (*CASTOLIN 18*),
- cylinder pre-warming up to 300 °C,
- application (cladding) of bronze on the surface using electrode *CASTOLIN CP 146*.

The particular phases during the turning operation are numerous, and according to the sequence in which they one performed, the final measures of the cylinder are achieved.

The present technological process of the hydraulic- cylinder production is limited by the following:



Sl. 1. *Hidravlični valj*
Fig. 1. *Hydraulic cylinder*

- poroznost navarjene plasti brona,
- potrebe po uvajanju opravila žarjenja zaradi pojava trdih con in
- težave pri izdelavi utora za tesnilo zaradi trdih con na meji (spoju) med bronom in jeklom.

Omenjene omejitve so temelj za oblikovanje zahtev po uvajanju novih tehnologij za ustvarjanje drsnih dvojic v izdelavi hidravličnih valjev.

2 TEHNOLOGIJA EKSPLOZIJSKEGA NAVARJANJA PRI IZDELAVI HIDRAVLIČNIH VALJEV

Tehnika eksplozijskega navarjanja je metoda deformacijskega oblikovanja, ki izrablja energijo ob detonaciji eksploziva. Ta energija se prenaša po zraku, vodi, pesku ali materialih PVC na material, ki se preoblikuje.

Količina eksploziva in sredstvo, prek katerega se prenaša energija, sta elementa za določanje celotne potrebne energije za preoblikovanje. To energijo je zelo težko nadzirati zaradi vpliva številnih neznanih dejavnikov ter nezmožnosti oblikovanja matematičnih modelov. Zaradi tega določamo elemente za doseganje zahtevane kakovosti postopka oblikovanja s številnimi poskusi.

Z detonacijo eksploziva ustvarimo zelo visoke tlake, ki so potrebni za preoblikovanje kovin in zlitin v zelo kratkem času, kolikor traja sam postopek. Doseganje predpisane kakovosti izdelka zagotavljamo z:
- vrsto eksploziva,
- s tehnološkimi karakteristikami eksploziva,
- lego namestitve eksploziva,
- delovnim sredstvom, v katerem poteka postopek in

- the porosity of the cladded bronze layer,
- the need to introduce of heating operations because of the appearance of hard zones,
- the difficulties in cutting a groove for gasket because of the hard zones on the boundary where the bronze and steel join.

The limitations given are the basic ones for making requests to introduce new technologies for the gliding pair's formation in hydraulic-cylinder production.

2 EXPLOSIVE CLADDING TECHNOLOGY IN HYDRAULIC-CYLINDER PRODUCTION

Explosive cladding is a method of processing by deforming that uses the energy of explosive detonation. Air, water, sand or PVC are the materials used to transmit this energy.

The size of the explosion and the average energy transmission are the elements for defining of total energy needed for the deforming. This energy is hard to control because of the influences of unknown factors and the impossibility of performing mathematical models. Thus, numerous experiments are used to determine the elements to achieve the demanded quality of processing.

With explosive detonation, the very high pressures needed for metal shaping are provided in a very short time. The production quality depends on the following:
- the type of explosive,
- the technological properties of the explosive,
- the place for setting the explosion,
- the working medium in which the process is being

- izkušnjami na področju preoblikovanja z eksplozivom.

Omenjene lastnosti eksplozijskega navarjanja so uporabljene v izdelavi hidravličnih valjev kot alternativa običajnem navarjanju brona z elektrodo na notranjo površino valja.

Dotikalna drsna površina je vgrajena v hidravlični valj z uporabo tehnike eksplozijskega navarjanja po naslednjem tehnološkem postopku:

- priprava cevi iz pločevine iz brona CuSn6,
- varjenje cevi iz brona vzdolž sestava oboda valja,
- postavitev cevi v valj,
- postavitev eksploziva v notranjost valja,
- postavitev valja v vodo,
- proženje eksplozije v notranjosti valja.

Rezultat opisanega tehnološkega postopka je spojitev brona (cevi) na notranjo površino valja.

3 EKSPERIMENTALNO DELO

Zmožnosti uporabe tehnologije eksplozijskega navarjanja, v primerjavi s sedanjo običajno tehnologijo navarjanja brona z elektrodo na notranjo površino hidravličnega valja, so določene na podlagi metalografskih in mehanskih raziskav spoja bimetalne plasti (valj iz jekla Č. 1213, navarjen z bronom CuSn6). Metalografske raziskave so bile opravljene na vzorcih, odvzetih iz hidravličnega valja, ki je bil navarjen z bronom po običajni tehnologiji in iz valja, pri katerem je bila uporabljena tehnologija eksplozijskega navarjanja. Načrt jemanja vzorcev je prikazan na sliki 2.

carried out,

- the experiences in the field of explosive shaping.

The given possibilities of explosive cladding are applied in hydraulic-cylinder production as an alternative to the standard operation of bronze cladding on the inner surface of the cylinder.

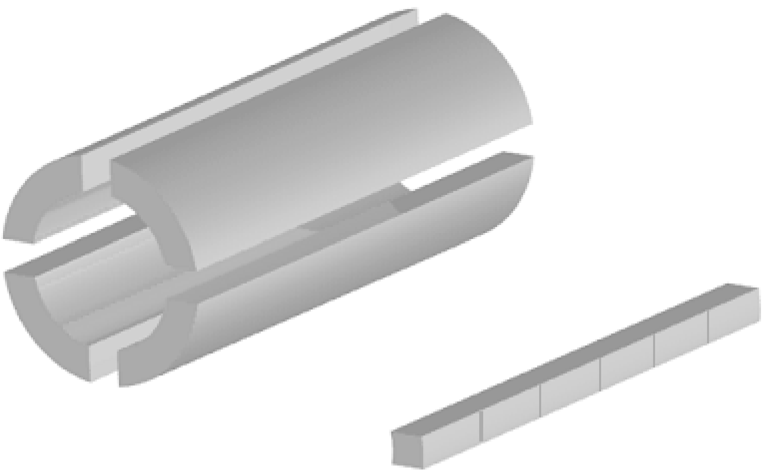
The contact gliding surface is built in the hydraulic cylinder by the application of explosive cladding technology according to the following procedure:

- preparation of tubes from bronze sheet metal,
- bronze tube welding along the connection line,
- placing the tube into the cylinder,
- placing the explosive inside the cylinder,
- placing the cylinder into the water,
- explosion initiation inside the cylinder.

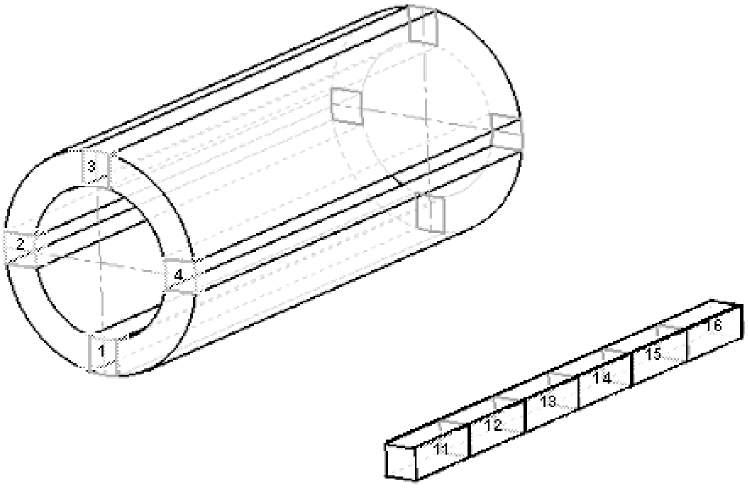
As a result the bronze sheet-metal tube on the inner surface of the cylinder is applied.

3 EXPERIMENTAL WORK

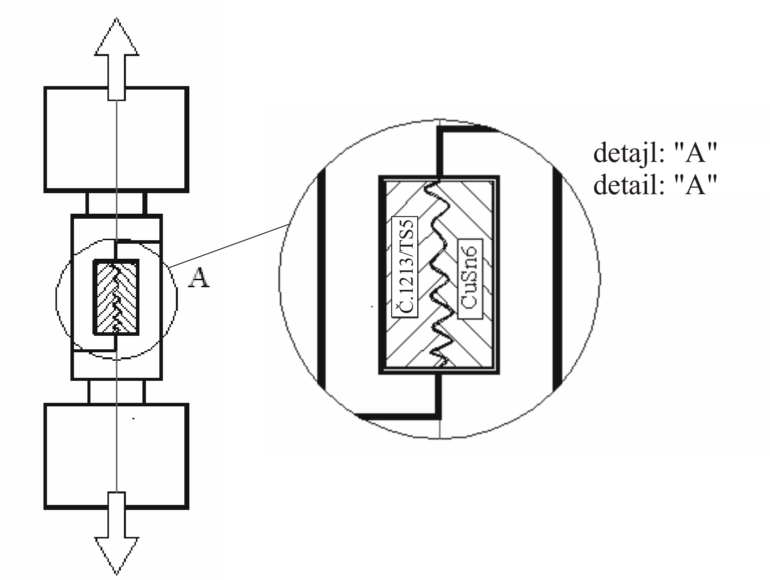
The possibilities of applying explosive cladding technology rather than the present standard bronze cladding technology on the inner surface of a hydraulic cylinder are determined on the basis of metallographic and mechanical investigations of the joint of the bi-metal layer (TS5 steel cylinder clad with CuSn6 bronze). Metallographic investigations were carried out on samples taken from a hydraulic cylinder on which standard bronze cladding on the inner surface was performed, and also from a hydraulic cylinder on which explosive cladding technology was applied. The plan of investigated samples is given in Fig. 2.



Sl.. 2. *Načrt jemanja vzorcev*
Fig. 2. *Plan of investigated samples*



Sl. 3. *Določanje lege jemanja vzorcev*
Fig. 3. *Determining the position of the investigated samples*



Sl. 4. *Preizkušanci, ki omogočajo vzporedno delovanje strižnih sil glede na spoj*
Fig. 4. *Test tubes that enable the parallel action of shear forces in relation to the joint*

Glede na podani načrt je bilo pripravljenih 24 vzorcev, na katerih so potekale raziskave spoja bron/jeklo za običajno tehnologijo navarjanja in tudi za tehnologijo eksplozijskega navarjanja (sl. 3).

Za določanje največje strižne trdnosti mejne plasti spoja bron/jeklo so bili izdelani posebni preizkušanci, ki so omogočali vzporedno delovanje strižnih sil glede na spoj (sl. 4).

According to the given plan, 24 samples were prepared, on which the investigation of the bronze/steel joint was carried out for the standard bronze cladding technology and also for the explosive cladding technology (Fig. 3).

For testing the maximum shearing stresses at the bronze/steel joint interface a special shaped test is used, this enables the parallel action of shearing forces in relation to the connection (Fig. 4).

3.1 Vzorci, narejeni po običajni tehnologiji navarjanja brona

Mikrostruktura vmesnika med bronom in notranjo površino jeklenega valja v primeru običajnega postopka navarjanja z elektrodo je prikazana na sliki 5. Močno so izražene tri cone:
- bron,
- jeklo in
- mejna plast.

Strukturi brona in jekla sta ločeni z vzporedno oblikovano vezno plastjo, ki povezuje ta dva osnovna materiala. Zaradi svoje izrazite ravnosti ta vezna plast ne zagotavlja velike trdnosti materiala (natezne, strižne).

Rezultati meritev strižne trdnosti vezne plasti pri različnih vzorcih, narejenih z navarjanjem z elektrodo, so zelo spremenljivi (198,8 ± 50,5 MPa), kar je posledica kakovosti navarjanja brona in je odvisna od dela posameznega varilca. Mikrostruktura površine striga v vezni plasti bron/jeklo pri vzorcu, ki je bil navarjen z elektrodo, je prikazana na sliki 6. Porušitev zaradi delovanja strižnih napetosti je potekala vzdolž vezne plasti povišane trdote.

3.2 Vzorci, narejeni po tehnologiji eksplozijskega navarjanja

Mikrostruktura mejne plasti bron/jeklo po eksplozijskem navarjanju je prikazana na sliki 7. Zaradi velikega specifičnega pritiska po eksploziji se je mikrostruktura spremenila v ozki coni dotika

3.1 Samples made using the standard bronze-cladding technology

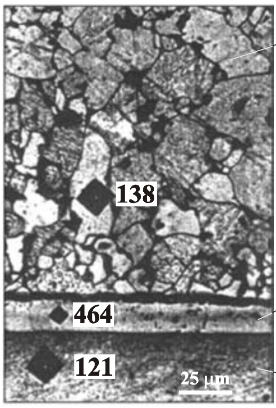
The microstructure at the interface between the bronze and the inner surface of the steel cylinder in the standard process of cladding by electrode is shown in Fig. 5. There are three zones:
- Bronze,
- Steel,
- Joint interface.

The structure of the bronze and steel is separated parallels by the formed layer that joins these two basic materials. Because of its flat configuration, this joint layer does not guarantee that the material is very strong (stretching, shearing).

The results of shear-strength measurements in the joint interface of the different samples, which are made by electrode cladding, are variable (198.8 ± 50.5 MPa), which is the result of a bronze-welding quality that depends on the welder's work. The microstructure of the sheared surface for the bronze/steel interface by electrode cladding is shown in Fig. 6. The fracture due to shearing stresses occurs on the interface layer of great hardness.

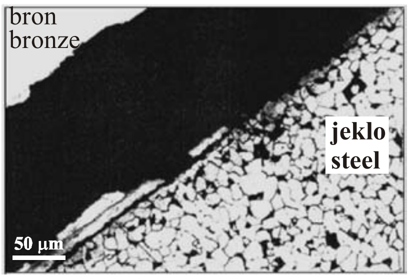
3.2 Samples made using explosive cladding technology

The microstructure at the bronze/steel interface after explosive cladding is shown in Fig. 7. Because of the great and specific pressure after the explosion the microstructure was changed in the narrow contact zone



Sl. 5. *Območje spoja in rezultati merjenja mikrotrdote $HV_{0.01}$ (vzorci standardno navarjeni z bronom)*

Fig. 5. *Joint region and the results of $HV_{0.01}$ microhardness tests (samples after standard bronze cladding)*



Sl. 6. *Površina porušitve zaradi strižnih napetosti (standardno navarjanje brona)*

Fig. 6. *Fracture surface due to shearing stresses (standard bronze cladding)*

dveh materialov, kar je vplivalo na oblikovanje valovite dotikalne površine med bronom in jeklom, ki pa je zelo značilna za takšen tip spajanja (sl. 8). Takšna oblika spoja bolje prenaša obremenitev. Vrednosti mikrotrdote, izmerjene na eksplozijsko navarjenem vzorcu, so podane na sliki 9.

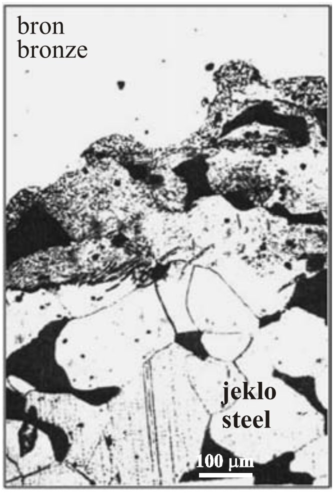
Pri eksplozijskem navarjanju imamo zelo majhno spremenljivost rezultatov strižne trdnosti pri različnih vzorcih (382,1 ± 11,5 MPa), v primerjavi z vzorci, ki so bili standardno navarjeni z elektrodo.

Rezultati meritev globine penetrirane plasti valovite oblike (sl. 10) na vseh štirih skupinah

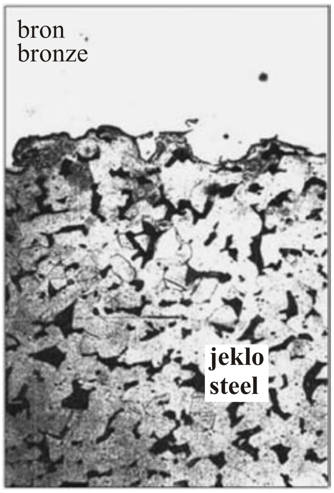
of two materials, which had an influence on the forming of a wavy joining surface between the bronze and the steel. The wavy shape of the contact layer is characteristic for this type of joint, which is shown in Fig. 8. This way of connecting has a greater ability to carry a load. The values of the microhardness that are measured on the explosive cladded samples are shown in Fig. 9.

During explosive cladding there is a very small variability in the shear strengths of the samples (382.1 ± 11.5 MPa) in comparison to the samples made by standard electrode cladding.

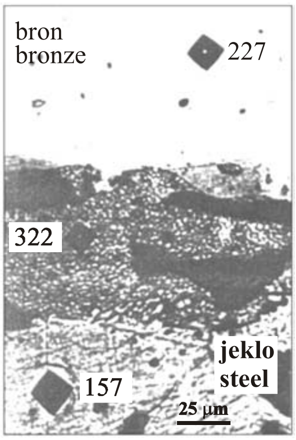
The measurement results for the penetrated layer of the wavy shape on four groups of samples



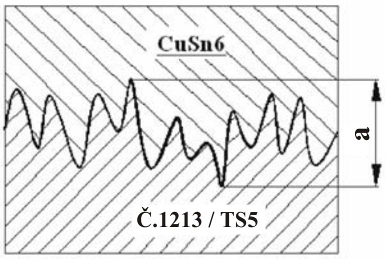
Sl. 7. *Mikrostruktura spoja bron/jeklo (eksplozijsko navarjanje)*
Fig. 7. *Microstructure of the bronze/steel joint (explosive cladding)*



Sl. 8. *Značilna valovita oblika dotikalne površine (eksplozijsko navarjanje)*
Fig. 8. *Characteristic wavy shape of contact layer (explosive cladding)*



Sl. 9. *Območje spoja in rezultati merjenja mikrotrdote $HV_{0,01}$ (vzorci eksplozijsko navarjeni)*
Fig. 9. *Joint region and the results of $HV_{0.01}$ microhardness tests (explosive cladding)*



Sl. 10. *Značilna valovita oblika mejne plasti pri eksplozijskem navarjanju*
Fig. 10. *Characteristic wavy shape of interface layer by explosive cladding*

Preglednica 1. *Globina valovitosti penetrirane plasti (a) na različnih eksplozijsko navarjenih vzorcih (glede na sl. 3)*
Table 1. *Depth of wavy-shaped penetrating layer (a) on the different explosive clad samples (according to Fig. 3)*

Številka vzorca Sample number	**a mm**	**Številka vzorca Sample number**	**a mm**	**Številka vzorca Sample number**	**a mm**	**Številka vzorca Sample number**	**a mm**
11	0,12	21	0,14	31	0,12	41	0,12
12	0,24	22	0,18	32	0,14	42	0,10
13	0,40	23	0,18	33	0,12	43	0,18
14	0,30	24	0,18	34	0,16	44	0,24
15	0,28	25	0,18	35	0,16	45	0,20
16	0,26	26	0,18	36	0,18	46	0,16

Preglednica 2. *Primerjava mikrotrdot v spoju bron/jeklo na vzorcih pri različnih tehnologijah navarjanja*
Table 2. *Comparison of the microhardness of the joint of (bronze/steel) bi-metal samples for different cladding technologies*

Cone spoja površin Joint surface zones	**Mikrotrdota / Microhardness $HV_{0.01}$**	
	Navarjanje z elektrodo Electrode cladding	**Eksplozijsko navarjanje Explosive cladding**
bron / bronze	121	227
mejna plast / interface layer	464	322
jeklo / steel	138	157

vzorcev so podani v preglednici 1. Ugotovljena povprečna globina plasti, ki je bila a = 0,18 mm, omogoča visoko raven varnosti spoja bron/jeklo. Prikazi posameznih spojev bron/jeklo za prvo skupino vzorcev od 11 do 16 (sl. 3) so zbrani na slikah 11a do 11f.

4 RAZPRAVA

Mejna plast med bronom in jeklom na vzorcih, narejenih z običajnim navarjanjem brona, je zelo trda in povezuje dve strukturi, ki pa zaradi izrazite ravnosti ne zagotavlja velike strižne trdnosti ter dobrega dotika dveh različnih materialov.

Mikrotrdota mejne plasti je manjša v primeru vzorcev narejenih z eksplozijskim navarjanjem (pregl. 2), kar je z vidika obdelave z odrezovanjem bolj ugodno.

Vrednosti strižne trdnosti pri vzorcih, narejenih s standardnim postopkom navarjanja z elektrodo, so zelo spremenljivi (198,8 ± 50,5 MPa), kar je posledica kakovosti navarjanja brona in je odvisna od dela varilca. Pri eksplozivnem navarjanju pa je spremenljivost razmeroma majhna (382,1 ± 11,5 MPa).

Mikrostruktura in površina striga mejne plasti bron/jeklo pri navarjanju z elektrodo je

are given in Table 1. The average width of the layer, which is a = 0.18 mm, is set, and that enables a high level of bronze/steel joint safety (Fig. 10). The survey of the bronze/steel interface is given for the first group of samples, from 11 to 16 (Fig. 3), in Figs. 11a to 11f.

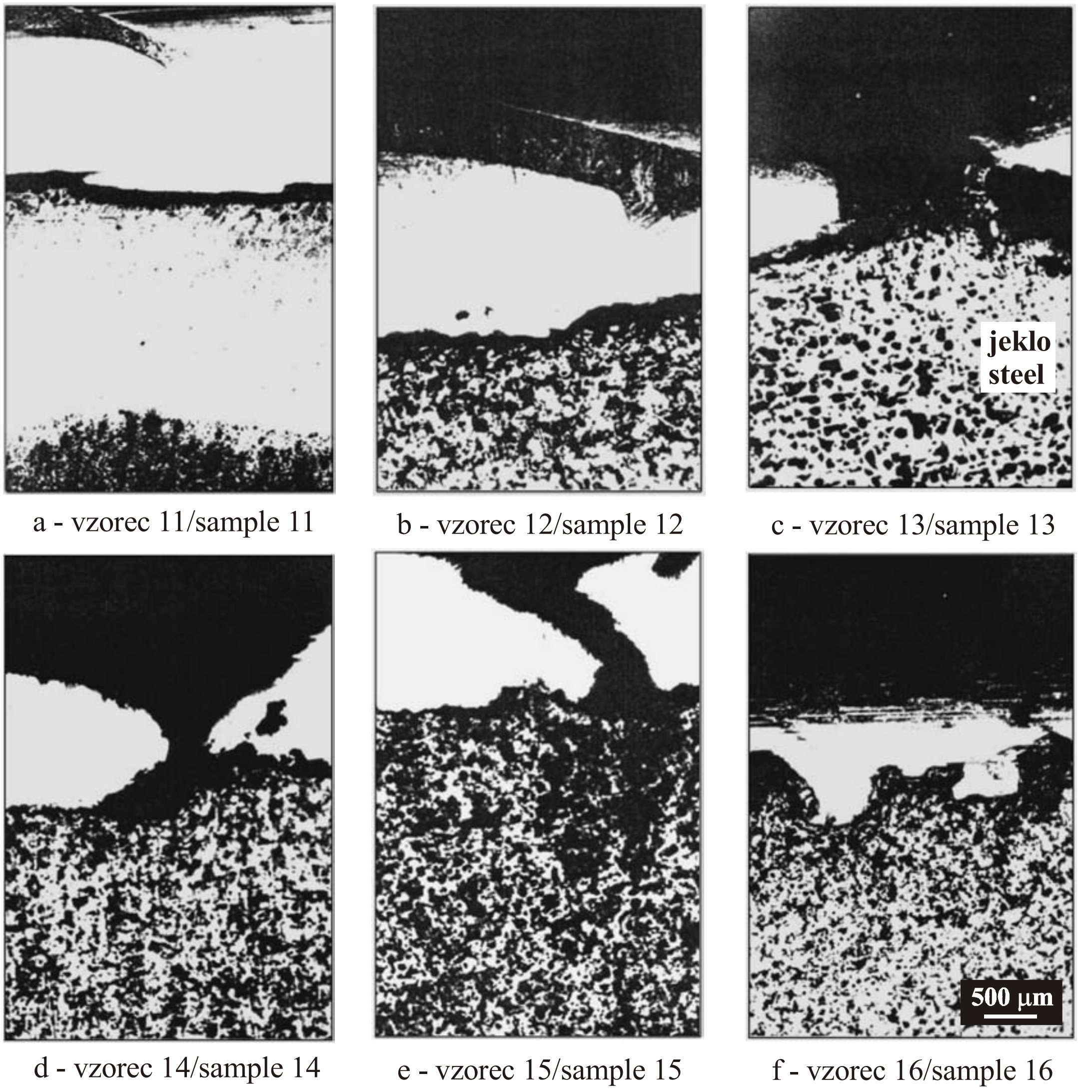
4 DISCUSSION

The interface layer between the bronze and the steel for samples made using standard bronze cladding is very hard and joins two structures, but because of its flat configuration it does not guarantee great shearing strength and good contact between the two materials.

The hardness of the interface layer is less in the case of the samples made by explosive cladding, which is more satisfactory considering the cutting processes (Tab. 2).

The shearing stresses of the samples made by standard electrode cladding have a very variable character (198,8 ± 50,5 MPa), which is the result of bronze-welding quality that depends on the welder's work. By using explosive cladding there is very little deviation of the shearing stresses (382,1 ± 11,5 MPa).

The microstructure and the sliding surface at the bronze/steel interface using electrode cladding



Sl. 11. *Morfologija mejne plasti bron/jeklo, značilna za obravnavane raziskave v tej študiji (vzorci po eksplozijskem navarjanju)*

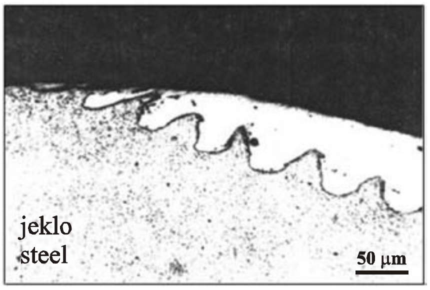
Fig. 11. *Morphology of the bronze/steel interfaces typical of the investigations discussed in this study (samples after explosive cladding)*

prikazana na sliki 6. Porušitev zaradi strižnih napetosti je potekala vzdolž mejne plasti z veliko trdoto.

Mikrostruktura in površina ločevanja v mejni plasti bron/jeklo eksplozijsko navarjenih vzorcev sta prikazani na sliki 12. Kot posledica strižnih napetosti je potekala porušitev v coni brona, kar pomeni, da je vezna plast, nastala z uporabo tehnologije eksplozijskega navarjanja, večje trdote in strižne trdnosti.

are shown in Fig. 6. The fracture during shearing stresses happens along the joint layer of great hardness.

The microstructure and the shape of the sliding surface in the bronze/steel interface after explosive cladding are shown in Fig. 12. As a result of sliding, a fracture occured along the bronze zone, which means that the joint layer is formed according to the technology of explosive cladding with greater hardness and shearing strength of the material.



Sl. 12. *Oblika površine ločevanja v mejni plasti bron/jeklo pri eksplozijsko navarjenih vzorcih*
Fig. 12. *Shape of the sliding surface in the bronze/steel interface by the explosive clad samples*

5 SKLEPNE UGOTOVITVE

Rezultati raziskav kažejo, da imajo hidravlični valji, narejeni po tehnologiji eksplozijskega navarjanja, boljše strukturne in mehanske lastnosti v mejni plasti bron/jeklo v primerjavi s hidravličnimi valji, narejenimi z običajnim navarjanjem brona z elektrodo.

Valovita dotikalna površina med bronom in jeklom, ki nastane pri postopku eksplozijskega navarjanja, ima bistveno večjo strižno trdnost v primerjavi z ravno dotikalno površino, ki nastane pri običajnem postopku navarjanja brona. To potrjujejo rezultati doseženih strižnih napetosti, pri katerih so srednje vrednosti teh napetosti pri vzorcih, ki so bili eksplozijsko navarjeni, bistveno večje od povprečnih vrednosti pri vzorcih, ki so bili navarjeni po običajni tehnologiji.

Na podlagi doseženih rezultatov pri uporabi eksplozijskega navarjanja v proizvodnji hidravličnih valjev, ki so podani v prispevku, lahko sklepamo, da je mogoče omenjeno tehnologijo uspešno uporabiti in ustvariti boljše rezultate v primerjavi s sedanjo tehnologijo. Kljub temu je uporaba te tehnologije omejena zaradi naslednjih razlogov:

1. drsne lastnosti pločevine iz brona, ki se uporablja pri eksplozijskem navarjanju, je treba preveriti s kemičnimi analizami;
2. ni definiranih obdelovalnih sistemov, na katerih bi bilo mogoče nadzorovati energijo, ki nastane ob eksploziji;
3. potrebe po preverjanju rezultatov raziskav v dejanskih razmerah uporabe drsne dvojice pri delovanju hidravličnih stiskalnic za upogibanje.

5 CONCLUSIONS

The results of our investigations show that hydraulic cylinders made using explosive cladding technology have better structural and mechanical properties at the bronze/steel interface compared to hydraulic cylinders made using standard bronze cladding.

A wavy contact surface between the bronze and the steel that appears with explosive cladding technology gives considerably greater shearing strength to the material compared to the flat connecting surface that appears with the classical bronze cladding method. This is confirmed by the results of the shearing stresses, where the average shearing-stress value for samples made with explosive cladding technology is greater than the shearing-stress average value for the samples made with classical bronze-cladding technology.

According to the results of the explosive cladding technology in hydraulic-cylinder production, it can be concluded that this technology is successfully applied and that better results than with the present technology are achieved. However, the application of this technology is limited, for the following reasons:

1. The gliding properties of the bronze sheet metal that is applied by the explosion need to be checked by chemical analyses.
2. There are no defined systems of processing with which the energy dissipation during the explosion could be controlled.
3. There is a need to check the results in real conditions for a gliding pair during the work of the hydraulic press for sheet-metal bending.

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Naslova avtorjev: prof.dr. Vid Jovišević
Fakulteta za strojništvo
Univerza v Banjaluki
V. S. Stepanovića
78000 Banjaluka
Bosna in Hercegovina

prof.dr. Mirko Soković
Fakulteta za strojništvo
Univerza v Ljubljani
Aškerčeva 6
1000 Ljubljana
mirko.sokovic@fs.uni-lj.si

Authors' Addresses: Prof.Dr. Vid Jovišević
Faculty of Mechanical Eng.
University of Banjaluka
V. S. Stepanovića
78000 Banjaluka
Bosnia and Herzegovina

Prof.Dr. Mirko Soković
Faculty of Mechanical Eng.
University of Ljubljana
Aškerčeva 6
SI-1000 Ljubljana, Slovenia
mirko.sokovic@fs.uni-lj.si

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