Kobaltove zlitine v lesni industriji
Cobalt Base Alloys in Woodcutting Industry

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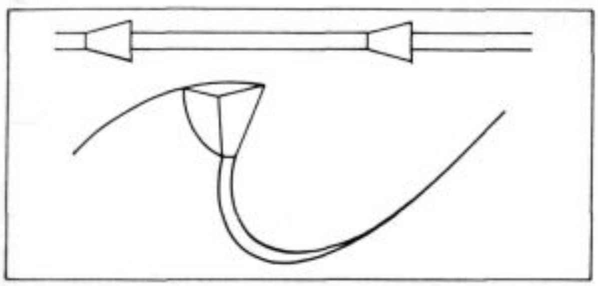
1. UVOD

Več kot dve desetletji je v praksi dobro poznan ugoden učinek navarjanja rezilnega dela zob s kobaltovimi zlitinami-steliti* za izboljšanje rezilne sposobnosti in povečanje vzdržljivosti različnih vrst žag v lesni industriji **(slika 1)**.



Slika 1
Stelitiranje
Obloga konice zoba s posebno kobaltovo zlitino, odporno proti obrabi, omogoča bistveno podaljšanje vzdržljivosti in rezne sposobnosti žag.
Stelitiranje je posebno priporočljivo pri žaganju svežega lesa z mnogoštevilnimi kremenčevimi vključki.

Fig. 1
Stellite Tipping
Tooth tipping with special cobalt base alloy resistant against abrasion enables significant prolongation of lifetime and cutting ability of saws.
Stellite tipping is especially recommended for sawing fresh, nontreated wood with many inclusions of silicon oxides.

Postopek prostega ročnega navarjanja zob na žagah se kljub poznanemu in dokazanemu zelo ugodnemu učinku dolga leta ni širše uveljavil. To ugotovitev lahko v veliki meri povezujemo s potrebo zahtevnega, zamudnega in zelo strokovnega dela, s slabim materialnim izkoristkom drage zlitine in z zahtevnostjo brušenja zob.

V strokovnih krogih se je za postopek nanašanja kobaltovih zlitin na zobe žag udomačilo ime "stelitiranje". Ta postopek je bil dolgo skoraj izključno prepuščen uporabnikom za vzdrževanje in obnavljanje žag v vsakodnevni praksi.

Specializirani proizvajalci žag so se za nekatere vrste žag usmerili na obloge z lotanjem trdokovinskih ploščic na zobe. Z razvojem specializiranih polavtomatskih in

* Stellite je prva blagovna znamka Cabot Corporation - Stoody Deloro za kobaltove zlitine, odporne proti obrabi in povišanim temperaturam. To ime je danes za veliko skupino kobaltovih zlitin splošno uporabljeno in udomačeno v praksi.

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1. INTRODUCTION

Beneficial effects of saw teeth tipping with cobalt base alloys - stellites for improving cutting ability and lifetime of saws in woodcutting industry are well known more than two decades (**Fig. 1**).*

Although these beneficial effects were known for many years the stellite tipping was not extensively used due to the disadvantages of manual welding procedure which is time consuming and requires a lot of experience in welding and sharpening. Furthermore, this practice is associated with low yield of expensive material. The stellite tipping was therefore applied only by users for maintenance and resharpening of saws. Specialized producers on the other hand introduced hard metal tipping by soldering process. The new progress of stellite tipping arrised with the development of automatic machines for welding and sharpening which were recently introduced by three companies ALLIGATOR (France), ISELI (Switzerland) and VOLLMER (Germany).

Due to the increased productivity achieved by automatic stellite tipping a new network of servicing centers for maintainance of all types of band, gang and circular saws is growing. This professional maintainance technology assures better quality and life time of saws which has direct impact on productivity and economy of saw mill production while at the same time the quality of cut surfaces is improved.

The stellite tipped saws enable an uninterrupted eight-hour sawing with cut length 80-100 km and production over 20 m^3 per shift so that interruptions and changes of saws during one shift are an exception.

This promising progress has encouraged a systematic applied research. With the growing exploitation of stellites in wood cutting technology a need for development of special assortment of alloys devoted to this application is emerging. The need for intensive research in this area is also supported with results of comparative studies which are presented in Section 7. These studies show that cobalt base alloys have a high priority for this application so that optimisation is expected within these grades.

Three grades of stellites (12, 1, 6) are the most frequently used in woodcutting and the most important is grade 12 (See Tab. 1).

The grade 1 was commonly applied for hard wood for many years, but recently the use of this grade has considerably decreased due to experience.

The grade 6 has appeared in general woodcutting technology very recently. Some saw mills applied this

** Stellite is a registered trade mark of Cabot Corporation - Stoody Deloro for cobalt base alloys which are abrasion resistant at room and elevated temperatures. This designation is commonly used for a vide variety of cobalt base alloys.*

polno avtomatiziranih strojev za stelitiranje žag, ki so jih razvile v zadnjem obdobju tri firme ALLIGATOR - Francija, ISELI - Švica in VOLLMER - Nemčija, se je začela situacija na področju stelitiranja žag bistveno spreminjati.

Logična posledica visoke produktivnosti, dosežene z razvojem avtomatskega strojnega stelitiranja, je nastajanje vse širše mreže specializiranih servisnih centrov za stelitiranje in ostrenje vseh vrst žag, tračnih, gaterskih in krožnih.

Vzdrževanje in obnova žag v takih servisnih centrih dosega vrhunsko in zanesljivo kakovost, kar se neposredno odraža v izrednem povečanju produktivnosti žaganja, v ekonomiki proizvodnje z zniževanjem stroškov, ob istočasnem napredku kakovosti rezanih površin in močnem podaljšanju življenjske dobe kvalitetnih žag.

Neprekinjeno osemurno žaganje hlodovine z dolžino poti rezanja 80—100 km in s storilnostjo razreza nad 20 m^3 na izmeno, je danes za žago kar normalni normativ in zastoji zaradi nepričakovanih menjav žag so ob rednem vzdrževanju in kvalitetni obnovi žag že kar izjemen pojav.

Razumljivo je, da je ta napredek vzpodbudil tudi intenzivnejše in bolj sistematične razvojne raziskave.

Dosedanja uporaba standardnih vrst stelitov že napoveduje razvoj optimirane sestave teh zlitin za potrebe stelitiranja žag v lesni industriji in to v nekaj namenskih variantah glede na vrsto rezanega lesa in tehniko žaganja s specifičnimi parametri v proizvodnji.

Tudi primerjalne raziskave stelitiranih žag in tistih z zobmi iz trdih kovin, ki jih bomo na kratko povzeli v poglavju 7, so privedle do presenetljivih spoznanj, ki močno uveljavljajo pomen stelitov v nadaljnjem razvoju.

Kobaltove zlitine so se v primerjalnih raziskavah[1)] izkazale za najboljše, zato optimiranje asortimenta dodajnih materialov za stelitiranje žag pričakujemo med njimi.

Dosedanji tipični asortiment stelitnih zlitin za lesno industrijo lahko omejimo na tri standardne vrste, med katerimi daleč prevladuje poznana zlitina št. 12. (Glej tabela 1)

Za nekatere trde vrste lesa je bila močno uveljavljena in je še veliko uporabljana zlitina št. 1, vendar se prav v zadnjem obdobju na podlagi izkušenj v praksi vloga in pomen stelita 1 v uporabi na tem področju očitno zelo zmanjšuje.

Ob preusmerjanju razvoja, ki izhaja iz bogatih izkušenj zadnjega obdobja izgleda očitno, da so lesarski strokovnjaki v splošnem preveč pomena pripisovali samo trdoti stelitiranih zob[5)]. Nekateri "žagarji", ki jim notranji raziskovalni nagon preprosto ni dopuščal, da bi se povsem prepuščali tradicionalnim pravilom pri izboru stelitov, so uspešno z zelo vzpodbudnimi rezultati zamenjali standardni stelit 12 s stelitom 6 in še naprej raziskujejo nove ideje z industrijskim preizkušanjem vzdržljivosti različno stelitiranih žag.

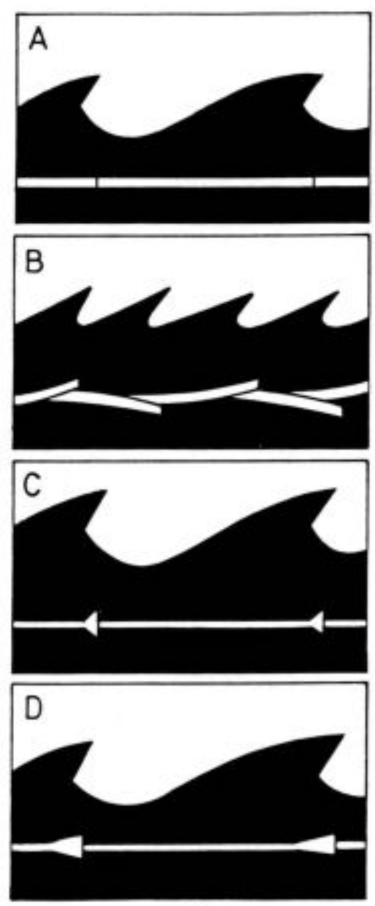
Zelo zanimivi rezultati teh industrijskih raziskav v kombinaciji z metalurškim razmišljanjem o sestavah, lastnostih uporabljenih zlitin in z metalografskimi študijami že nakazujejo nove smeri razvoja z modifikacijami k optimalni sestavi kobaltovih zlitin za stelitiranje žag v dveh ali treh variantah glede na značilnosti vrste rezanega lesa.

S pilotnimi napravami horizontalnega kontinuirnega litja[7, 8, 9)] in z razvojem novih spremljajočih tehnoloških postopkov[10)] že poteka projekt specializacije v proizvodnji kobaltovih zlitin za specifične potrebe v lesni industriji. Razvojne raziskave potekajo v tesni povezavi s proizvajalci strojev za stelitiranje žag, s proizvajalci žag in s servisnimi centri za stelitiranje in ostrenje žag. V tem razvoju želimo zajeti in upoštevati čimveč praktičnih iz-

grade which was not commonly used purely for research interest. The encouraging results confirmed opinion of some researchers[5] that the hardness itself should not be considered as the only decisive property of stellites for cutting ability. The research along these lines which is out of traditional practice is in progress. However, those saw mills which tried grade 6 instead of grade 12 prefer the former one for standard use.

These observations in woodcutting practice in combination with metallurgical knowledge of chemical composition and material properties with respect to metallographic studies of microstructures should provide optimal assortment of stellites for cutting of various woods.

The applied research project in the area described above is being undertaken in pilot plant for horizontal continuous casting (HCC)[7, 8, 9] and subsequent thermomechanical treatment[10]. This research is performed in cooperation with producers of stellite tipping machines, producers of saws and with service centers for stellite tipping and sharpening. It is expected that this joint research programme which considers expertises gained in industry related to woodcutting will result in metallurgical development of products for stellite tipping.



Slika 2

Trakovi žag, zvarjeni in napeti.

A - surovo ozobljeni trak, B - Razperjanje in brušenje zob, C - Nakrčenje vrhov zob in brušenje, D - Stelitiranje in brušenje zob.

Fig. 2

Saw bands, welded and tensioned

A - Saw band with raw teeth, B - Setting and grinding of teeth, C - Swagging of tooth tips and grinding, D - Stellite tipping and grinding of teeth.

kušenj, zbranih v zadnjih letih in le-te usmeriti v metalurški razvoj zlitine za specifične namene in potrebe.

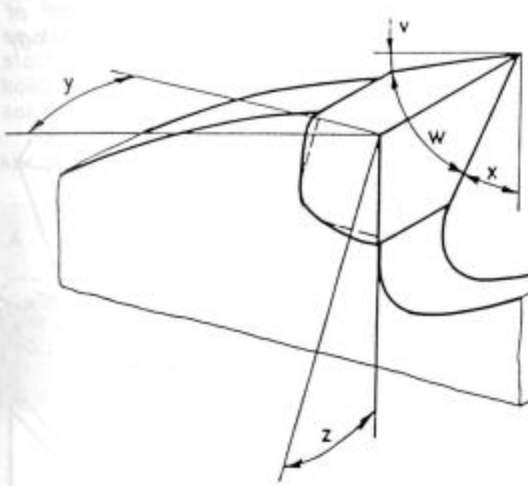
Poleg razvoja asortimenta za optimalni izbor vrste uporabljenih zlitin je pomemben tudi razvoj samih postopkov stelitiranja in posebnih oblik preseka HKL-palic, dodajnih materialov za stelitiranje zob. Ti proizvodi so poznani pod imenom FORM-STELITI in so se doslej izdelovali samo po tehnologiji metalurgije prahov (PM). Danes se kot pomembna dopolnitev asortimenta že uveljavlja tudi uporaba HCC-FORM-STELITOV.

2. VRSTE ŽAG, OBLIKE IN GEOMETRIJA ZOB

Pri stelitiranju enakovredno obravnavamo vse tri osnovne vrste žag, tračne, gaterske in krožne.

Na **sliki 2** je shematično prikazano surovo ozobljenje trakov, razperjanje ali nakrčevanje zob pri klasičnih in stelitiranje zob pri modernih tračnih žagah.

Slika 3 prikazuje geometrijo stelitiranega zoba z vsemi koti, ki so pomembni za ostrenje z ravnim in poševnim brušenjem.



Slika 3
Geometrija zoba žage
X - Cepilni kot, V - Prosti kot.

Fig. 3
Geometry of saw tooth
X - Rake angle, V - Clearance angle.

3. RAZVOJ STELITIRANJA ŽAG

Pri tem moramo omeniti dva bistevno različna pristopa k stelitiranju žag. Od tega je odvisna seveda tudi konstrukcija in način delovanja strojev za stelitiranje.

Postopek I.: Navarjanje zob s TIG postopkom ali s plazmo

Pri postopku stelitiranja z dodajanjem kobaltove zlitine na zob z navarjanjem preko tekoče faze uporabljamo okrogle HCC palice tankih presekov. Daleč največ se uporablja palice standardne dimenzije ∅O3,2 mm. Podajalni mehanizem stroja podaja palico za taljenje nad kokilo.

Pri tem postopku avtomat stroja obda zob žage z bakreno kokilo **(slika 4)**, ki ima določeno obliko zoba in stelit se po TIG postopku ali s plazmo natali v kokilo na vrh zoba. Po strditvi je vrh zoba s stelitom ustrezno oblikovan in stelit trdno zvarjen z osnovo zoba.

Uvedba plazma gorilcev pri teh strojih omogoča povečanje storilnosti stelitiranja in tudi uporabo nekoliko

Besides the development of optimal assortment of applied alloys the development of welding procedures in stellite tipping and application of special shapes of cross section for adding the material in welding is also important. These so called FORMSTELLITES are mainly produced by powder technology but recently HCC is considered as an alternative technology.

2. SAW TYPES, FORMS AND TOOTH GEOMETRY

Stellite tipping is equally treated with all three general types of saws: band saws, gang saws and circular saws.

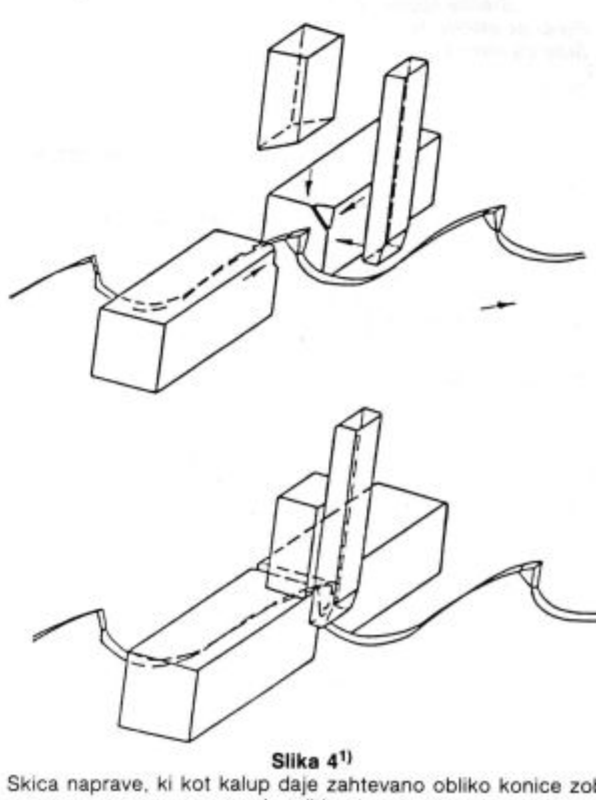
Figure 2 *represents schematically a saw band with raw teeth, setting and swagging of teeth with conventional saws and stellite tipping of teeth. The geometry of stellite tipped tooth with all important angels for sharpening with straight and bevel grinding is shown in* ***Fig. 3****.*

3. DEVELOPMENT OF STELLITE TIPPING

Two essentially different procedures have been introduced in the approach to stellite tipping of saw teeth. The construction and operational characteristics of stellite tipping machines are adjusted to special requirements of the process.

Procedure I.: Stellite tipping with TIG or plasma welding

For stellite tipping with welding through liquid phase HCC rods of small sections are usually used where ∅O3.2 mm is the most commonly applied dimension. The stellite tipping machine automatically supplies the rod to the appropriate position above the mould for melting.

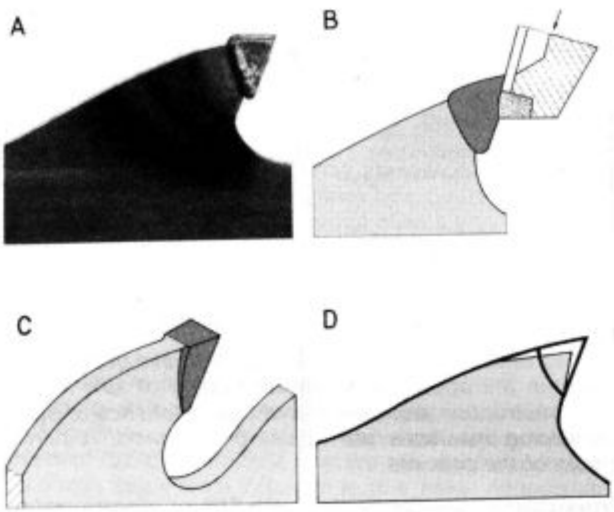


Slika 4[1)]
Skica naprave, ki kot kalup daje zahtevano obliko konice zoba pri stelitiranju.

Fig. 4[1)]
Schematic drawing of a jig which performs the moulding action to give the tip the desired geometry.

debelejših palic, kar se pomembno pozna pri ceni dodajnih materialov oziroma pri stroških stelitiranja v celoti.

Slika 5 prikazuje stelitiran zob in brušenje[3].



Slika 5[3]
Stelitiranje in brušenje zob
A - Oblika stelitiranega zoba, B - Brušenje cepilnega kota, C - Stranske ploskve se brusijo samo na novo stelitiranem zobu,
D - Večkratno prebrušenje cepilnega in prostega kota.

Fig. 5[3]
Stellite tipping and sharpening of teeth
A - Form of stellite tipped tooth, B - Grinding of rake angle, C - Side clearance surfaces are ground only after stellite tipping,
D - Repeated sharpening of rake and clearance angle.

Postopek II.: Uporovno navarjanje stelitnih delcev na zobe

Po drugem osnovnem postopku stelitiranja žag z več variantami se dodajni material-stelit določene oblike v avtomatu uporovno segreje, na stičišču z osnovnim materialom žage natali in vtisne točno v ustrezen položaj na zobu žage. Za ta postopek privarjanja so že ponudili tržišču tudi precizne ulitke stelitov, ali pa oblikovance iz stelitnega prahu, vsestransko oblikovane. S tem naj bi posnemali izkušnje iz uporabe trdokovinskih ploščic, ki se lotajo na zobe žag.

Uporaba teh predoblikovanih koščkov se po začetnih korakih razvoja v stelitiranju žag ni veljavila po pričakovanjih in danes že prevladuje mnenje, da ta prvotno zelo obetajoča pot v nadaljnjem razvoju stelitiranja žag nima perspektive.

Več uporabljajo palice z različnimi oblikami preseka, ki jih avtomat reže ravno ali poševno med postopkom stelitiranja pri podajanju palice. Avtomat lahko delček prej odreže, pa ga nato privari ali pa konec palice privari in jo nato avtomatsko odreže.

Razvoj dodajnih stelitov v obliki palic različnih dimenzij s posebnimi oblikami preseka je odvisen od sistema dodajanja palic za stelitiranje zob pri avtomatskem ali ročnem podajanju na stroju.

Najprej se je razvil postopek z uporabo palic okroglega preseka, ki jih avtomatsko ali ročno krmiljeni stroj za stelitiranje podaja z vrha ali od strani pred cepilno ploskev zoba kot kaže **slika 6**.

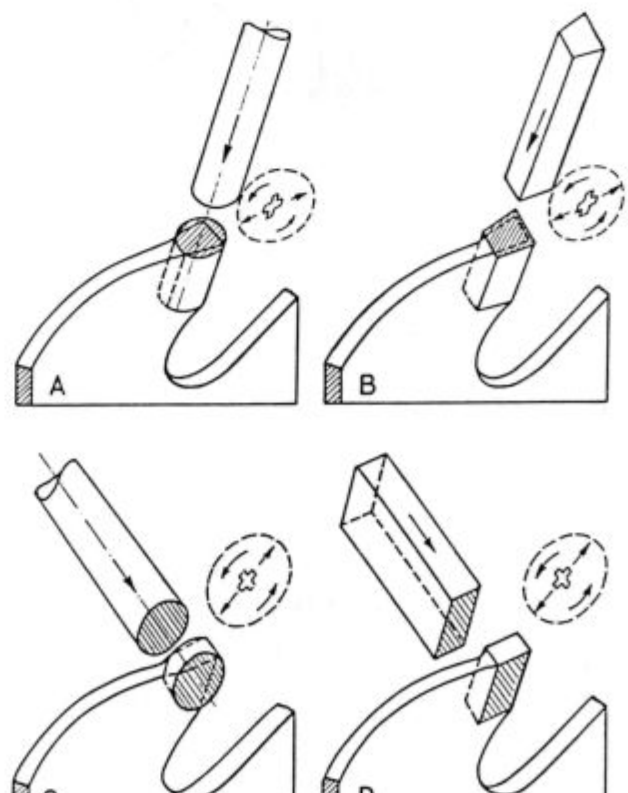
*In this procedure the blocks of cooper are moved to embrace the saw tooth in order to form a mould for the desired geometry. The mould is then filled up by either TIG or plasma melting. After the solidification a preform of the tooth which is welded to the base is obtained (**Fig. 4**).*

The introduction of plasma welding enabled the improvement of productivity and the application of stellite rods of larger section which are considerably cheaper so that plasma welding is reducing the overall production cost of stellite tipping.

Figure 5 *illustrates stellite tipping and sharpening of saw teeth.*

Procedure II.: Resistance welding in stellite tipping

In resistance welding approach the adding material in the form of stellite tip is heated up in automatic machine to melt both materials at the interface between tip and saw base. The machine is then pressing the tip to the exact position on the tooth. For tips used in this approach precision cast stellite pieces or pieces of pressed powder stellites were introduced by analogy with hard metal tipping.



Slika 6
Električno uporovno navarjanje stelitnih delcev na vrh zoba
A - Vertikalno podajanje okroglih stelitnih palic, B - Vertikalno podajanje stelitnih palic trapeznega preseka, C - Horizontalno podajanje okroglih stelitnih palic, D - Horizontalno podajanje stelitnih palic paralelo gramskega preseka.

Fig. 6
Electric resistance welding of stellite tips
A - Vertical adding of round stellite rods, B - Vertical adding of form-stellite rods with trapeze section, C - Horizontal adding of round stellite rods, D - Horizontal adding of form-stellite rods with parallelogram section.

*** 1. varianta: Vertikalno podajanje palic**

Pri tem načinu stelitiranja žag s podajanjem palic okroglega preseka od vrha pred zob žage je povsem razumljivo v fazi brušenja prišlo do ideje za uporabo palic kvadratnih ali pravokotnih in končno trapeznih presekov, tako da ima zob že takoj po stelitiranju nastavljeno ravno cepilno ploskev in predoblikovani stranski ploskvi s prostim kotom. Palico se odreže poševno pod kotom, ki ustreza prostemu kotu zoba. Na ta način se doseže velik prihranek brušenja zob.

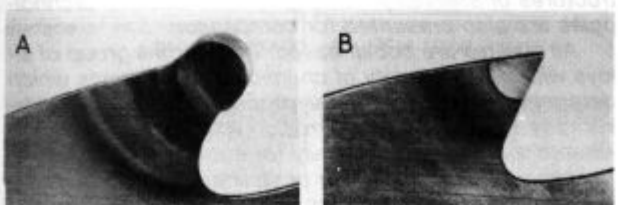
*** 2. varianta: Horizontalno podajanje palic**

Za drugo varianto postopka stelitiranja z uporovnim navarjanjem se uporablja dodajanje palic stelitov od strani. Namesto okroglih palic večjega preseka (**slika 7**[3]) imajo precejšnjo prednost palice s presekom paralelograma (**slika 8**[3]).

Nekaj nevšečnosti pri postopku uporovnega navarjanja form stelitov povzročajo ostanki iztisnjenega materiala. Odstranjevanje teh brad je lahko neprijetna ovira normalnega postopka.

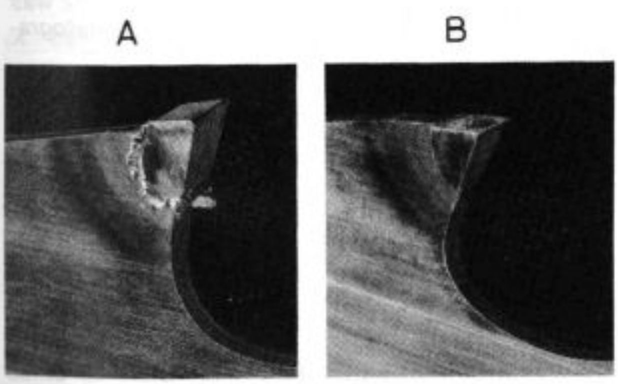
Po stelitiranju se morajo konice zob popuščati, kar se z modernimi stroji opravi v toku samega postopka stelitiranja. Izkušnje kažejo, da med vsemi form-steliti po količini daleč prevladuje uporaba tistih s trapeznim presekom.

Uporaba form-stelitov je kljub višji ceni upravičena, ker omogoča



Slika 7[3]
Uporovno navarjanje zob z okroglim stelitom
A - po stelitiranju, B - po končnem brušenju.

***Fig. 7**[3]*
Stellite tipping with electric resistance welding of round stellite rod
A - after stellite tipping, B - after final sharpening.



Slika 8[3]
Uporovno navarjen zob s form-stelitom paralelogramskega preseka
A - po stelitiranju; B - po končnem brušenju.

***Fig. 8**[3]*
Stellite tipping with electric resistance welding of form-stellite rod with parallelogram section
A - after stellite tipping, B - after final sharpening.

The application of these preformed tips was expected to be successful but very recently more economic procedures are proposed in which rods of various dimensions and cross-sections are automatically supplied and cut at appropriate angles during the process. There are two alternatives: The piece of rod for tooth tip is cut off first and then welded or the end of rod is welded first and then cut off.

The development of stellite rods in various sections and forms depends on adding system of the stellite tipping machine.

*At the beggining round section rods were supplied either from the top or side to the face of the tooth as shown in **Fig. 6**.*

**** Alternative 1: Vertical supply of rods***

In this alternative of stellite tipping the round section rod is supplied from the top and cut at clearance angle. To reduce the waste of material and grinding costs square and rectangular sections were introduced but finally trapeze form sections were accepted as standard. After stellite tipping with trapeze-form rods all main angles of the tooth are close to the final sharpening geometry. Side clearance surfaces are ground only after stellite tipping while repeated sharpening is performed only for rake and clearance angles.

**** Alternative 2: Horizontal supply of rods***

*In this alternative of stellite tipping with resistance welding rods of larger sections are supplied from the side and cut at side clearance angle. Initially round rods (**Fig. 7**) were used but later parallelogram sections were introduced to reduce the waste of material and grinding costs (**Fig. 8**).*

The difficulties can arrise in resistance welding where the material which is pressed to the side needs to be removed.

After stellite tipping the teeth must be tempered. Modern machines include this in automatic procedure.

Production practice shows that number of various forms is reducing towards a limited number of standard forms and that trapeze section forms are preferred.

Although the stellite forms are expensive their application is justified by subsequent costs such as reduced consumption of stellites, up to 60 % shorter sharpening times and lower consumption of abrasive tools.

4. PRODUCTION TECHNOLOGY FOR ADDITIVE MATERIALS IN STELLITE TIPPING

Stellite rods can be produced by two different technologies:

- *Horizontal Continuous Casting (HCC), (**Fig. 9**);*
- *Powder Metallurgy (PM).*

Almost all round section rods are produced by HCC while form stellites on the other hand were until now produced only by PM.

The first samples of form stellites produced in pilot plant MILPP represent a new technology and are now tested by users. The initial results show that this technology will be introduced in practice as complementary rather then competitive to the existing PM technology. The PM form stellites can not be replaced by HCC for special applications and chemical compositions but for common stellite tipping at lower price level and larger quantities an additional market can be opened for the HCC form stellites.

— manjšo porabo stelitov
— do 60 % krajši čas brušenja, ker sta prosti in cepilni kot zoba že podana in
— manjšo porabo brusnih plošč.

4. TEHNOLOGIJA IZDELAVE DODAJNIH MATERIALOV ZA STELITIRANJE ZOB

Za proizvodnjo stelitnih palic sta v uporabi dve osnovni tehnologiji:
— horizontalno kontinuirno litje (HCC),
— metalurgija prahov (PM).

Skoraj vse okrogle palice za stelitiranje so izdelane po HCC tehnologiji (**slika 9**).

Za proizvodnjo form-stelitov v glavnem prevladuje metalurgija prahov.

Prvi vzorci HKL-formstelitov iz pilotne proizvodnje MIL-PP predstavljajo novost in so že na preizkušanju v uporabi. Po prvih izkušnjah pričakujemo, da se bo uporaba HKL-formstelitov v praksi uveljavila bolj kot pomembna dopolnitev in ne toliko kot konkurenčna akternativa dosedanjega asortimetna formstelitov, izdelanih po tehnologiji metalurgije prahov. Cenejši HKL-formsteliti bodo omogočili širšo uporabo te tehnologije stelitiranja, PM-formsteliti pa bodo še naprej nepogrešljivi za specialna področja uporabe.

5. ASORTIMENT ZLITIN ZA STELITIRANJE ŽAG

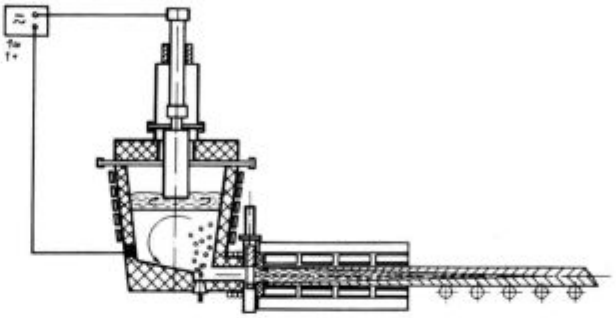
Ker gre pri stelitiranju za tipično interdisciplinarno področje med metalurgijo, lesarstvom, strojništvom in kemijo (korozijo) je prav, če na kratko predstavimo sicer poznane vrste in specifične lastnosti kobaltovih zlitin pod skupnim imenom "steliti". Tudi nekaj primerov mikrostruktur stelitov iz HKL in PM tehnologije zanimivo prikazuje značilnosti teh posebnih zlitin in obeh postopkov.

Skupina stelitov obsega zlitine s precej širokim območjem variacij kemijske sestave. Skupna značilnost vseh stelitov je osnovna sestavina, kobalt. Dodatki drugih kovin v različnih kombinacijah vplivajo na značilne mehanske lastnosti, in s tem tudi neposredno na obstojnost proti obrabi ter na odpornost proti koroziji, ki je pri rezanju svežega lesa izredno pomembna.

Žilavost stelitov, čeprav slaba, je mnogo boljša od izredno krhkih WC-trdin.

Lastnosti stelitov so dobro obstojne tudi pri povišanih temperaturah.

Steliti se odlikujejo z nizkimi koeficienti trenja.



Slika 9
Shema postopka horizontalnega kontinuirnega litja (HKL) tankih palic.

Fig. 9
Scheme of the proces for horizontal continuous casting (HCC) of thin rods.

5. ASSORTMENT OF ALLOYS FOR STELLITE TIPPING

*Since development of stellite tipping requires interdisciplinary cooperation between metallurgists, mechanical and chemical (corrosion) engineers and woodcutting experts it is appropriate to recall well known properties, chemical compositions (**Tab. 1**) and hardness of typical grades for this application. Some typical microstructures of stellites produced by HCC and PM technologies are also presented for comparison.*

All stellites are cobalt based. They form a group of alloys with a wide variety of chemical compositions which determine their mechanical properties, cutting ability, abrasive resistance and corrosion which is recently considered as decisive especially for cutting fresh wood.

Although the toughness of stellites is low it is always much higher then toughness of tungsten carbide grades of hard metals.

Many properties of stellites remain almost unchanged even at elevated temperatures.

The friction caused by stellites is much lower then friction produced by tungsten carbide grades of hard metals.

6. METALLOGRAPHY OF HCC- AND PM- STELLITES[11]

At MIL-PP a modification of standard grade 12 was introduced with designation MILIT 12 W. A metallogra-

Tabela 1: Kemijska sestava in trdota preizkušanih zlitin

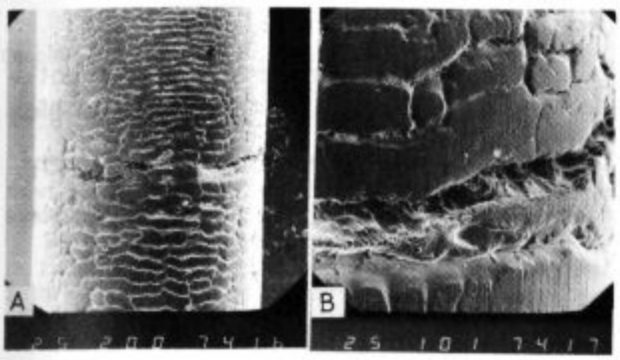
***Table 1:** Chemical composition and hardness of tested alloys*

	Co %	Ni %	Cr %	W %	Si %	B %	Fe %	C %	HRC
I. Štiri zlitine primerjane v raziskovalnem projektu FORINTEK CANADA CORP.[1] *I. Four alloys compared in research project by FORINTEK CANADA CORP.[1]*									
STELLITE 12	59	—	29	9	—	—	—	1.8	47–51
STELLITE 20	45	—	33	18	—	—	—	2.5	55–59
DELORO 50	—	77	10	—	4	1.5	4	0.4	49–52
DELORO 60	—	70	15	—	4.5	3	4.5	0.5	59–62
II. Druge zlitine, uporabljane za rezanje lesa *II. Other alloys, applied in wood cutting*									
STELLITE 1	54	—	30	12	—	—	—	2.5	51–58
STELLITE 6	65	—	28	4	—	—	—	1.1	39–43
(STELLITE F)	39	22	25	12	—	—	—	1.7	40–45

6. METALOGRAFIJA HKL- IN PM-STELITOV[11]

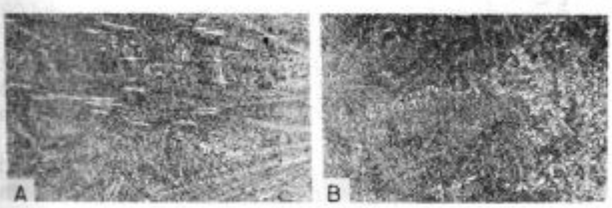
MIL-PP je za stelitiranje žag razvil specialno HKL varianto stelita pod imenom MILIT 12 W s posebno kemijsko sestavo. Za ilustracijo prikazujemo nekaj metalografskih posnetkov HKL-palice ∅O3,2 mm v surovem litem stanju.

Sliki 10 A in B prikazujeta značilno površino HKL palice, posnete z rasterskim elektronskim mikroskopom (REM). Vidi se sled koraka, katere globina znaša poprečno 0,1 mm.



Slika 10
Površina HKL-palice ∅O3,2 mm - Kobaltove zlitine MILIT 12 W (A - REM 20x, B - REM 100x).

Fig. 10
Surface of HCC-rod ∅O3.2 mm - Co base alloy grade MILIT 12W (A - SEM 20x, B - SEM 100x).



Slika 11
Značilna strjevalna mikrostruktura HKL palice ∅O3,2 mm - MILIT 12 W - v litem stanju
(A-prečno 200x; B-vzdolžno na sredini preseka 200x).

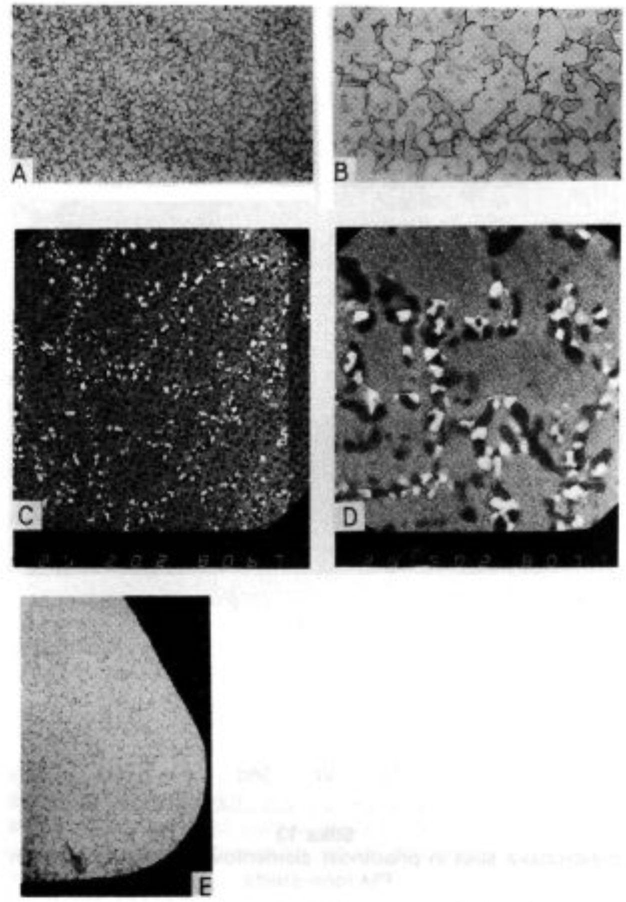
Fig. 11
Characteristic solidification microstructure of HCC-rod ∅O3.2 mm - MILIT 12 W - as cast
(A - transverse 200x, B - longitudinal in the middle of section 200x).

Naslednji dve **sliki 11 A in B** kažeta mikrostrukturo istega vzorca na prečnem in vzdolžnem preseku. Značilna strjevalna mikrostruktura dendritnega tipa s primarnimi in sekundarnimi vejami je izredno fina, kar je posebna prednost HKL-tehnologije.

Nov specialni postopek termomehanske konsolidacije HCC palic[10], ki ga razvija MIL-PP v okviru posebnega projekta specializacije proizvodnega programa kobaltovih zlitin za stelitiranje žag v lesni industriji, obeta še dodatne kakovostne prednosti.

Za razliko od tipične mikrostrukture HKL vzorcev vidimo na naslednjih slikah **12 A, B in C** mikrostrukturo PM-vzorca paralelogramskega preseka, ki je bil izdelan po tehnologiji metalurgije prahov. Očitna je značilna porazdelitev karbidov v matrixu.

Slika 13 prikazuje značilnosti porazdelitve elementov med osnovo in karbidi PM form-stelita.



Slika 12
Značilna mikrostruktura paralelogramskega formstelita izdelanega po tehnologiji metalurgije prahov
(A - pov. 200x, B - pov. 500x, C - REM 2000x, D - REM 5000x, E - pov. 200x ob ostrem kotu paralelograma).

Fig. 12
Characteristic microstructure of parallelogram formstellite produced with powder metallurgy
(A - magn. 200x, B - magn. 500x, C - SEM 2000x, D - SEM 5000x, E - magn. 200x at the sharp angle of parallelogram).

*phic illustration of HCC stellite ∅O3.2 mm in as cast condition made by scanning electron and optical microscope is presented in **figures 10 and 11**, respectively.*

The depth of witness mark on the surface of HCC rods is usually 0.1 mm. The solidified microstructure of dendritic type with primary and secondary branches is very fine which is characteristic for HCC technology.

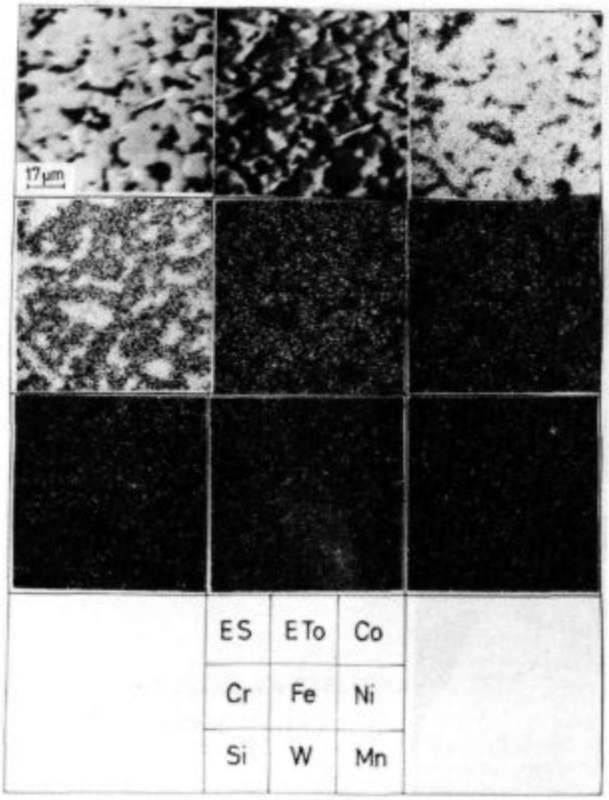
A new thermomechanical consolidation of HCC rods is being developed by MIL-PP and is expected to enable improved quality of stellites for tipping of saws.

*A typical microstructure of PM form stellite with parallelogram cross-section is presented in **Fig. 12** with optical and SEM photographs where characteristic distribution of carbides in the matrix is evident.*

*In **Fig. 13** presence of chemical elements in the matrix and car- bides of PM form stellite is presented.*

7. COMPARATIVE RESEARCH[1, 2]

The research and development center FORINTEK CANADA CORP. published results of a comprehensive research which had a decisive influence on further development of stellite tipping for woodcutting.



Slika 13
Elektronska slika in prisotnost elementov v osnovi in karbidih PM form-stelita.

Fig. 13
Electron picture and distribution of elements in the matrix and carbides of PM form-stellite.

7. PRIMERJALNE RAZISKAVE[1,2]

V laboratorijih raziskovalno-razvojnega centra FORINTEK CANADA CORP. so opravili obsežne raziskave[1], ki so odločilno vplivale na nadaljnji razvoj stelitiranja žag v lesni industriji.

V prvi seriji poskusov so primerjali štiri zlitine odporne proti obrabi pri žaganju svežega lesa. (Tabela 1)

Na **sliki 14** je prikazan način merjenja otopitve rezalnega roba s fotomikroskopijo[1].

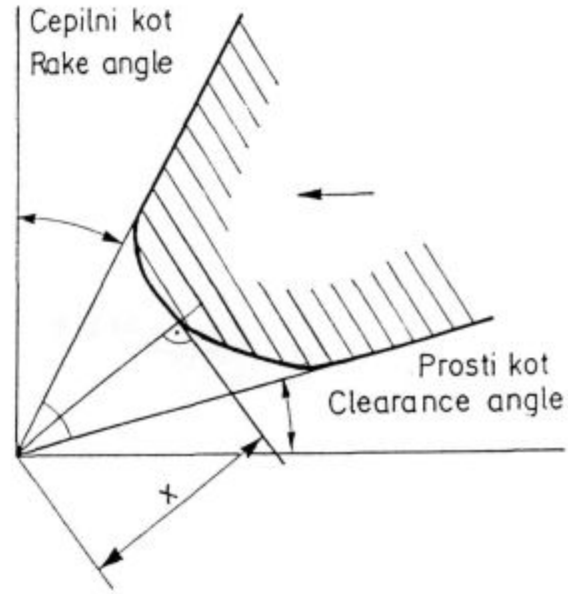
Glede na otopitev rezalnega roba je dal najboljše rezultate nanos zlitine stellite 12 (**slika 15**[1]).

Otopitev zob po 35 km reza, kar ustreza približno 4 uram žaganja, je bila pri jeklenih zobeh kar dvanajstkrat večja kot pri stelitiranih z zlitino stellite 12. Še pomembnejša je ugotovitev, da so jekleni zobje dosegli že po 1 km reza ali 6 minutah tako stopnjo otopitve kot stelitirani zobje po 35 km reza ali 4 urah žaganja.

Krivulja obrabe pri jeklu za žage kaže, da so standardni zobje žage že po eni uri rezanja močno obrabljeni. Zaradi zmanjševanja zastojev je žal kar običajno, da se s tako otopelimi zobmi žaganje nadaljuje. Posledica tega je slaba kvaliteta površine rezanega lesa, neenakomerna debelina in netočnost reza ter seveda močno povečana poraba energije.

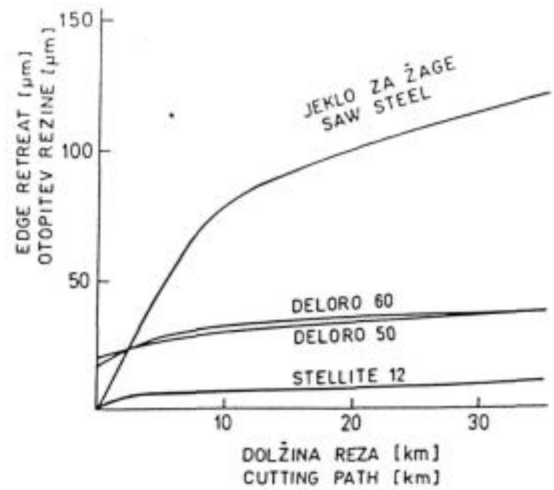
Obe zlitini na osnovi niklja DELORO 50 in 60 po ugotovljenih rezultatih ne moreta konkurirati zlitini stellite 12.

Zlitine stellite 20 že zaradi slabih rezultatov uporabe na žagi z meritvami v laboratoriju sploh niso preizkušali.



Slika 14[1]
Meritev otopitve na zobu žage.

Fig. 14[1]
Measurement of cutting edge retreat on saw tooth.



Slika 15[1]
Otopitev konvencionalnih in obloženih zob na žagah.

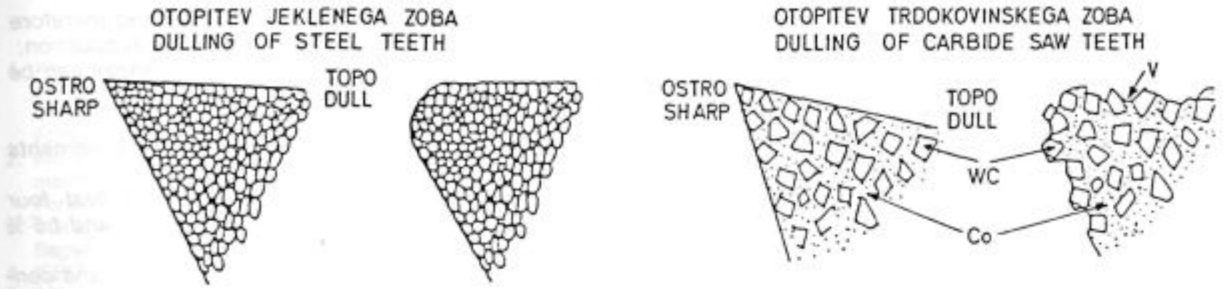
Fig. 15[1]
Dulling of conventional and tipped saw teeth.

*In the first set of experiments four grades of abrasion resistant alloys for cutting fresh wood were tested (**Tab. 1**).*

*In **Fig. 14** a method for measuring dulling of cutting edge with photomicroscopy is presented*[1].

*The best results with respect to dulling of tooth cutting edge were obtained by tipping of stellite grade 12 (**Fig. 15**).*

The dulling of teeth after cut length of 35 km, which corresponds to approximately 4 hours of sawing, was measured for saw steel and stellite 12. The value of cutting edge retreat for saw steel was found to be twelve times higher than for stellite 12. Even more important is the observation that the measured dulling of stellite 12



Slika 16[1)]

Otopitev jeklenih in trdokovinskih zob WC - volframov karbid, Co - osnova, V - prazen prostor, ki je bil prej zapolnjen s kobaltom.

Fig. 16[1)]

Dulling of saw steel teeth and carbide tips WC - tungsten carbide, Co - matrix, V - empty space, formerly occupied by cobalt.

Zanimiva je ugotovitev, da je obstojnost žage v veliki meri odvisna tudi od sposobnosti zlitine na zobeh za kvalitetno brušenje.

Zaključek te serije raziskav je bilo priporočilo uporabe zlitine stellite 12 za stelitiranje vseh vrst žag, ne samo zato, ker je ta zlitina pokazala najboljše rezne sposobnosti, najboljšo obrabno in korozijsko obstojnost, ampak tudi zaradi najboljšega obnašanja pri brušenju. Pri brušenju te zlitine je dosežena najboljša začetna ostrina zob, kar pomembno vpliva na celotno izdržljivost žage.

V drugi seriji posebnih laboratorijskih poskusov z natančnimi meritvami so primerjali obrabo rezalnega roba zlitine stellite 12 z dvema vrstama karbidnih trdin in s standardnim jeklom za žage. Raziskave so opravili za tri tipične vrste lesa. Pri teh poizkusih je bila dolžina reza 80 km, kar ustreza normalno žaganju 7-8 obratovalnih ur.

Slika 16[1)] shematično prikazuje značilnosti otopitve na rezalnem robu jeklenega oziroma trdokovinskega zoba. Obraba oziroma otopitev stelitiranih zob je po mehanizmu podobna jeklenim zobem.

Stelitirani zobje so pokazali v primerjavi z obema karbidnima trdinama (volframov karbid - 6 % Co in volframov karbid - 18 % Co) najmanjšo obrabo in bistveno boljšo vzdržljivost. To pomeni, da imajo stelitirane žage precejšnje prednosti pred trdokovinskimi, posebno pri rezanju svežega lesa in pri tankih rezih. Ta raziskovalna ugotovitev je bila potrjena tudi v industrijski praksi žaganja zadnjih let. Korozijska odpornost zlitine in spoja z osnovo v veliki meri ugotovitev dodatno pojasnjuje. Kislinski ekstrakti svežega lesa napadajo kobalt v osnovni masi in s tem poslabšajo odpornost proti izpadanju volframovih karbidov.

Stelitirane žage bodo pri rezanju svežega lesa popolnoma izpodrinile žage s trdokovinskimi zobmi.

Trdokovinske žage se bodo še naprej obdržale v pohištveni in drugi finalizacijski lesni industriji. Tudi tam ima zaradi problemov odpadanja trdokovinskih ploščic pri velikih hitrostih ter ob udarnih obremenitvah na zob vez med oblogo zoba in osnovno kovino, ki jo dosežemo pri stelitiranju določene prednosti v primerjavi z nalotano trdo kovino.

8. POVZETEK PREDNOSTI STELITIRANJA ŽAG

(a) v primerjavi z uporabo standardnih jeklenih žag:

- Rezna zmogljivost stelitiranih žag je v primerjavi z žagami z razperjenimi zobmi večja, ker reže vsak zob na obeh straneh.
- Hitrost pomika se lahko poveča do 30 %.
- Povečana obstojnost rezalnega roba zob in zmanjšanje zastojev

at 35 km is reached by saw steel already after first kilometre of cut length which corresponds to approximately six minutes of sawing.

Thus the dulling of saw steel teeth is very intensive in initial stages so that sawing after few kilometres of cut length is performed by relatively dull teeth which cause bad surface quality of cut wood, nonuniform thickness and increased energy consumption.

The stellite 12 was found to be superior in comparison to stellite 20 and both nickel base alloys which were considered in these dulling tests.

On the basis of this comparative research a conclusion was made that stellite 12 is highly recommended for all types of saws not only because of its best cutting ability, abrasion and corrosion resistance but also because of its best grindability which enables good sharpening of teeth.

In the second set of laboratory experiments the stellite 12 was compared with two grades of tungsten carbide hard metals for three typical sorts of wood. In these tests a cut length of 80 km was considered.

*In **Fig. 16** the mechanism of dulling is schematically illustrated and compared between saw steel and hard metal. The dulling mechanism of stellite teeth is similar to that of saw steel.*

The results obtained by stellite tipped teeth were better then both tungsten carbide grades with 6 % and 18 % of cobalt. Stellite tipped saws are superior to hard metal saws especially for cutting fresh woods and thin cut. This was also confirmed in practice. The corrosion resistances of stellite 12 and its welding junction are both better than tungsten carbide grades and their soldering junctions. The acid extracts of fresh wood are chemically interacting with cobalt matrix and in this way badly influence the resistance of carbides against separation from cobalt matrix.

Stellite tipped saws will replace hard metal saws in cutting fresh wood while they will retain their position in furniture and other finalising industries employing treated woods. However, even in these applications the stellite tipping has certain advantages especially in the case where high speed cutting causing high impact loads is present.

8. SUMMARIZED ADVANTAGES OF STELLITE TIPPING

(a) Advantages with respect to conventional steel saws:

- *The stellite tipping enables higher cutting productivity with respect to the saws with teeth setting;*
- *The cutting speed can be up to 30 % higher;*

- Manjša hrapavost površin rezanega lesa in večja natančnost reza po daljšem trajanju žaganja. Povečan je izplen rezanega lesa.
- Zmanjšanje potrebne energije. Pri standardnih jeklenih žagah se poraba moči po štiriurnem žaganju v povprečju poveča za 15 %, pri uporabi stelitiranih žag pa samo za 1,5 %.
- Ostrenje žag je bolj ekonomično in poraba žagnih trakov ali diskov je manjša.
- Poprečni proizvodni stroški žaganja so manjši.
  Vse naštete prednosti se dosežejo v glavnem brez povečanja stroškov, ker se stroški stelitiranja skoraj v celoti izravnajo s tem, da ni več potrebno delo z nakrčevanjem in razperjanjem zob.

(b) **v primerjavi z uporabo trdokovinskih žag:**
- Povečana obstojnost rezalnega roba zob.
- Izboljšanje možnosti za žaganje s tanjšim rezom. Varjeni spoj med stelitom in nosilnim jeklom je v splošnem precej trdnejši od lota med karbidno trdino in jeklom.
- Konice stelitov so manj občutljive za poškodbe in nastale poškodbe se dajo lažje popravljati.
- Stroški brušenja so nekoliko manjši, zaradi možnosti uporabe cenejših plošč.
- Nižja cena stelitnih konic.
  Poraba časa in stroški dela za trdokovinske ali stelitne konice zob v praksi ne predstavljajo pomembnih razlik.

(c) **nekaj dodatnih razlogov za uvedbo stelitiranja žag**
- Rezanje trdih in zelo neenakomerno rastočih lesov (exotov) in lesov z mineralnimi vključki je mogoče samo s stelitiranimi žagami.
- V zadnjem času se je izkazalo, da prinaša stelitiranje velike prednosti tudi pri rezanju mehkih lesov.
- Z relativno majhnimi dodatnimi ukrepi za stelitiranje se dosežejo veliki ekonomski uspehi.

9. ZAKLJUČEK

Stelitiranje žag močno podaljšuje življensko dobo zob in ima posebno pri žaganju nesušenih lesov pomembne prednosti pred vsemi danes razpoložljivimi načini zmanjševanja obrabe, vključno z oblaganjem zob s trdokovinskimi konicami. Tehnologija stelitiranja omogoča precejšnje zmanjšanje proizvodnih stroškov ob istočasnem povečevanju produktivnosti in izboljšanju kakovosti. Nabava potrebne opreme za stelitiranje se v večini žagarskih obratov amortizira v kratkem času.

Zelo priporočljivo tehnično, kvalitetno in ekonomsko rešitev predstavlja organiziranje servisnih centrov za stelitiranje in ostrenje vseh vrst žag.

Nadaljnji razvoj na področju stelitiranja žag bo usmerjen v kompletiranje proizvodnih programov kobaltovih zlitin s posebnim poudarkom na specializaciji ponudbe, pri čemer bo imelo optimiranje sestave zlitin za določena področja in namene uporabe prav gotovo vse večji pomen.

- *The life time of cutting edge is longer and therefore enables reduction of interruptions in the production;*
- *A low cut roughness and narrow tolerances can be retained for a longer time;*
- *The yield of wood is higher;*
- *The energy consumption and power requirements are lower.*
- *The increase of power consumption in first four hours is approximately 15 % for steel saws and 1.5 % for stellite tipped saws;*
- *The sharpening of teeth is more economic and consumption of saw bands or discs is lower;*
- *The average production costs are lower.*

All above mentioned advantages can be achieved without additional costs because stellite tipping cost are comparable to the costs related to swagging and setting of conventional steel saws.

(b) ***Advantages with respect to hard metal saws:***
- *The life time of cutting edge of teeth is longer;*
- *A better possibility for sawing with thin cut because the welded stellite junction is stronger than soldered hard metal junction;*
- *The stellite tips are less sensitive to damages and can be easier repaired;*
- *The sharpening costs are lower because cheaper grinding plates can be used;*
- *The price of stellite tips is lower.*

The time consumption and labour costs for hard metal and stellite tipping are approximately the same.

(c) ***Some additional reasons for introduction of stellite tipping***
- *The sawing of certain hard and irregularly grown woods (exots) and woods with mineral inclusions is often possible only with stellite tipped saws;*
- *Recent production experience confirms advantages of stellite tipping also for cutting soft woods;*
- *With modest investments for stellite tipping relatively high savings and improvements can be achieved.*

9. CONCLUSION

The stellite tipping of saws enables longer life time of teeth and has many advantages especially in sawing untreated woods. It is superior to all today known approaches for reduction of teeth wear including hard metal tipping. The technology of stellite tipping enables considerable lowering of production costs while at the same time quality and productivity are improved.

It is expected that stellite tipping and sharpening will be organized in servicing centers. Further developments in stellite tipping will be aimed to an optimized assortment of alloys and forms of products for specialized applications.

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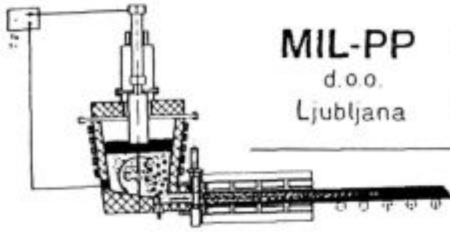

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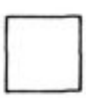
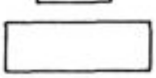
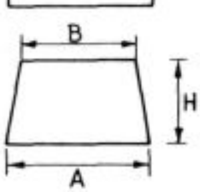
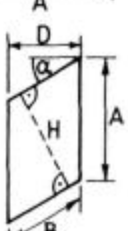
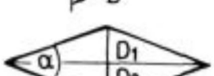
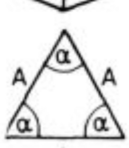
HORIZONTALNO KONTINUIRNO LITJE - HKL
HORIZONTAL CONTINUOUS CASTING - HCC

HCC PROGRAM "MILIT"

POSEBNE ZLITINE NA OSNOVI Co ZA LESNO INDUSTRIJO
SPECIAL Co-BASE ALLOYS FOR WOOD CUTTING

	MILIT 6H	MILIT 12H	MILIT 12WH	MILIT 1H	MILIT FH	MILIT 21H
C	1,2	1,4	1,6	2,5	1,8	0,3
Si	1	1	1,5	1	1	0,5
Mn	0,5	2,5	2,5	0,5	0,5	0,5
Cr	29	30	29	30	25	28
Ni	2	1,5	1,5	-	23	3
W	4,5	8	10	13	12	-
Mo	0,5	-	-	-	-	6
Co	60	54	53	50	35	60
HRC	**42**	**48**	**54**	**55**	**42**	**30**

OBLIKE FORMS	DIMENZIJE DIMENSIONS	DOLŽINE LENGTHS	DOBAVNO STANJE DELIVERY CONDITION
	2.0 mm ÷ 8.0 mm	L = 8 mm ÷ 16 mm 350 mm ÷ 4000 mm	lito ali brušeno as cast or grinded
	2.0 mm ÷ 6.5 mm	L = 8 mm ÷ 16 mm 1000 mm	brušeno - grinded
	F = 8 mm^2 ÷ 50 mm^2	L = 8 mm ÷ 16 mm 1000 mm	brušeno - grinded
	B = 2.7 mm ÷ 6.0 mm H = 2.5 mm ÷ 4.0 mm A = 3.2 mm ÷ 6.5 mm	L = 1000 mm	brušeno - grinded
	A = 4.0 mm ÷ 7.5 mm B = 3.0 mm ÷ 5.0 mm D = 2.8 mm ÷ 4.5 mm H = 3.5 mm ÷ 6.5 mm α = 30°	L = 1000 mm	brušeno - grinded
	D_1 = 11 mm D_2 = 5 mm α = 50°	L = 1000 mm	brušeno - grinded
	A = 4.0 mm ÷ 6.5 mm α = 60°	L = 1000 mm	brušeno - grinded