R. RUDOLF[1], T. RAVLAN[2], G. LOJEN[1], I. ANŽEL[1], A. IVANIČ[3], J. MELE[4], E. HUDRAP[2]
[1]Univerza v Mariboru, Fakulteta za strojništvo / University of Maribor, Faculty of Mechanical Engineering, Slovenia, [2]SIJ Ravne Systems d.o.o, Ravne na Koroškem, Slovenia, [3]CPPE d.o.o., Celje, Slovenia
[4]Univerza v Mariboru, Fakulteta za gradbeništvo, prometno inženirstvo in arhitekturo, University of Maribor, Faculty of Civil Engineering, Transportation Engineering and Architecture, Slovenia

Razvoj naprednega orodnega jekla za najzahtevnejše aplikacije v industriji

Development of an Advanced Steel Tool for the Most Demanding Applications in Industry

Povzetek

V članku je predstavljen potek razvoja naprednega orodnega jekla za najzahtevnejše aplikacije v industriji, ki se izvaja v podjetju SIJ Ravne Systems v povezavi z Univerzo v Mariboru in partnerji Bosio d.o.o. ter CPPE d.o.o. Razvoj je na eni strani povezan z identifikacijo ključnih lastnosti orodnega jekla, ki predstavljajo konkurenčno prednost v primerjavi z ostalimi konvencionalnimi jekli. To so: žilavost, trdota, trdnost in rezilna sposobnost. Po drugi strani pa razvoj predstavlja vpeljavo ustrezne tehnologije izdelave in naknadne toplotne oziroma mehanske obdelave, kar omogoča doseganje ključnih lastnosti naprednega orodnega jekla.

Ključne besede: razvoj, orodno jeklo za delo v hladnem, lastnosti, toplotna in mehanska obdelava, karakterizacija

Abstract

In the lecture, we will present the development of an advanced steel tool for the most demanding applications in industry, implemented by SIJ Ravne Systems in conjunction with the University of Maribor, and partners Bosio d.o.o. and CPPE d.o.o. Development is, on the one hand, related to the identification of key properties of the steel tool which represent a competitive advantage compared to other conventional steel tools, which are: impact strength, hardness, tensile strength and cutting ability. On the other hand, the development represents the introduction of an appropriate production technology and subsequent heat or mechanical treatment, which enables the achievement of key properties of advanced steel.

Key words: cold-work tool steel, properties, heat and mechanical treatment

1 Uvod

Osrednji cilj razvoja naprednega orodnega jekla je okrepiti položaj in vlogo podjetja SIJ Ravne Systems (SRS) oziroma slovenske jeklarske industrije na področju posebnih orodnih jekel. Na ta način želimo vzpostavite pogoje, da bo lahko podjetje SRS prešlo iz standardnega v razvojnega dobavitelja teh jekel, in to ne samo v mednarodnih verigah,

1 Introduction

The main goal of the development is to strengthen the position and role of the company SIJ Ravne Systems (SRS) and the Slovenian steel industry in the field of special tool steels. In this way, we want to establish conditions so that the company SRS will be able to transit from a standard to a development supplier of these steels, not

ampak tudi v drugih mrežah vrednosti, kar bo omogočilo dvig konkurenčnosti SRS na globalnem trgu. Razvojne aktivnosti so povezane z operativnim programom za izvajanje Evropske kohezijske politike v obdobju 2014-2020 in predvidevajo večjo osredotočenost na ciljne trge ter manjšo razdrobljenost znanstvenega in tehnološkega razvoja v Sloveniji. Slovenska industrija jekla je ključna za mnoga izvozno usmerjena podjetja, ki so poddobavitelji vodilnih evropskih in svetovnih proizvajalcev avtomobilov, strojev, itn.

Podjetje SRS je eno izmed vodilnih svetovnih podjetij na področju proizvodnje industrijskih nožev, kjer se odvija velika tekma za prevlado na trgu orodnih jekel. Ena izmed pomembnih tržnih niš je industrija furnirja. Podjetje SRS že danes izdeluje nože za rezanje za furnirsko industrijo - luščenje ter obrezovanje furnirja. S poznavanjem kakovosti obstoječih orodnih jekel ter na osnovi obvladovanja tehnologije izdelave obvladuje praktično vse branže v furnirski industriji, razen področja rezanja mehkega lesa. Za to področje tudi svetovna konkurenca nima tehnoloških rešitev oziroma znanj za takšno orodno hitrorezno jeklo, ki bi imelo kombinacijo lastnosti, kot sta visoka trdota in hkrati udarna žilavost. Zato je opisan razvoj zahteven projekt, ki poteka na več ravneh, in sicer od določitve nove kemijske sestave, tehnologije izdelave jekla (z inovativnimi in naprednimi pristopi), karakterizacije mikrostrukture in identifikacije lastnosti, do razvoja tehnoloških postopkov obdelave, ki bodo omogočali izdelovanje nožev iz novega orodnega jekla. Daljša življenjska doba nožev pri visokih hitrostih rezanja je povezana z ustrezno mikrostrukturo materiala rezila. Prav tako morajo imeti ti noži visoko in konstantno trdoto, trdnost, žilavost ter visoko obrabno obstojnost in rezilnost. Pri tem je potrebno upoštevati tudi

only in international chains, but also in other value-added networks, which will enable SRS to become more competitive on the global market. Development activities are linked to the operational program for the implementation of the European Cohesion Policy for the period 2014-2020, and they foresee a greater focus on target markets and less fragmentation of scientific and technological development in Slovenia. The Slovenian steel industry is crucial for many export-oriented companies, which are sub-suppliers of the leading European and global manufacturers of cars, machinery, etc.

The SRS company is among the global leaders in the manufacture of industrial knives, involved in a big race to dominate the market of tool steels. The veneer industry is an important market niche. The SRS is already manufacturing industrial knives for slicing, peeling and trimming veneer. Thanks to the quality of existent tool steels and technology developed by our own staff and based on our own knowledge, we substantially control all branches of the veneer industry, with the exception of softwood cutting. This sector is plagued by a lack of technological solutions or skills, which not even the rest of our global competitors, are able to provide, for producing high-speed steel with a combination of properties offering high hardness and impact resistance at the same time. As a result, this is a developmentally challenging area, which requires a multi-layer approach consisting of determining a new chemical composition, steelmaking technologies (using advanced and innovative methods), microstructure characterization and identification of properties, as well as developing technologies for machining processes that will allow the manufacture of knives from the new type of tool steel. The requirements imposing a longer service

geometrijske zahteve, med katere spada zagotavljanje skoraj ničelne ukrivljenosti rezalne površine (±0,01% na 1 m).

Na podlagi preliminarno izdelanih vzorcev nožev iz obstoječega orodnega jekla in na osnovi izbranega referenčnega noža (stanje konkurence), predstavljamo smernice za izpeljavo postopkov razvoja novega noža, ki imajo temelj v karakterizaciji mikrostrukture in identifikaciji ključnih lastnosti.

2 Eksperimentalno delo

V eksperimentalnem testiranju smo za izdelavo vzorcev nožev uporabili obstoječe orodno jeklo z okvirno kemijsko sestavo: C 0,45-0,55 mas. % C; Si 0,9-1,2 mas. % C; Mn 0,3-0,6 mas. % C; Fmax 0,03 mas. % C; Smax 0,03 mas. % C; Cr 7,5-8,5 mas. % C; Mo 1,4-1,6 mas. % C; V 0,47-0,5 mas. % C; ostalo Fe (srednje ogljično malo legirano orodno jeklo s Cr, Mo in V). Za izvedbo raziskav in testiranj smo pripravili preliminarno izdelane vzorce nožev: (1) surovec, (2) toplotno obdelan in (3) referenčen nož. V tabeli 1 so predstavljene dimenzije vzorcev nožev. Toplotna obdelava vzorca noža (2) je vključevala postopek

Tabela 1. Dimenzije vzorcev nožev

Table 1. Dimensions of knife samples

Vzorci nožev / Knife samples		Mere [mm] / Dimensions [mm]		
		Debelina / Thickness	Širina / Width	Višina / Height
1. nož / knive	surovec / blank	645	155	23
2. nož / knive	toplotno obdelan / heat treated	653	183	18
3. nož / knive	referenca / refrence	688	200	16

life and the use of such knives in high-speed cutting applications are linked to a suitable microstructure, which is required for the functional contact surface (or cutting edge) of knives. Such knives must also possess a high and constant hardness, adequate level of mechanical properties (strength, resistance), high fatigue strength and cutting. In addition, blade geometry requirements for knives must also be taken into account, including providing the zero curvature of the cutting surface (±0.01% per 1 m).

On the basis of pre-fabricated knife samples from existing tool steel and on the basis of the selected reference knife (state of competition), we will present guidelines for the development of new knife development procedures, which have the basis in the characterization of the microstructure and in the identification of key characteristics.

2 Experimental work

In experimental testing, an existing tool steel with an indicative chemical composition was used to make knife samples: C 0.45-0.55 wt. % C; Si 0.9-1.2 wt. % C; Mn 0.3-0.6 wt. % C; Fmax 0.03 wt. % C; Smax 0.03 wt. % C; Cr 7.5-8.5 wt. % C; Mo 1,4-1,6 wt. % C; V 0.47-0.5 wt. % C; other Fe (medium carbon slightly alloyed tool steel with Cr, Mo and V). To carry out research and testing, we prepared prefabricated knife samples: (1) a blank, (2) a heat treated, and (3) a reference. Table 1 shows the dimensions of the knife samples. Heat treatment of the knife sample (2) involved the austenitization process at T_{aust} = 1010° C, quenching and two-step tempering at $T_{1.temp}$ = 520 ° C and $T_{2.temp}$ = 515 ° C.

ASTM A370 - 17a [1] and literature references [2-4] were used to carry out the mechanical properties of knife

avstenitizacije pri T_{avst}= 1010 °C, kaljenje ter popuščanje v dveh korakih pri $T_{1.pop}$= 520 °C in $T_{2.pop}$= 515 °C.

Za izvedbo testov mehanskih lastnosti vzorcev nožev smo uporabili standard ASTM A370 – 17a [1] in napotke iz literature [2-4]. Na osnovi zahtev smo pripravili navodila za ustrezno odkrivanje mikrostruktur ter pregled primernih jedkal za vzorce.

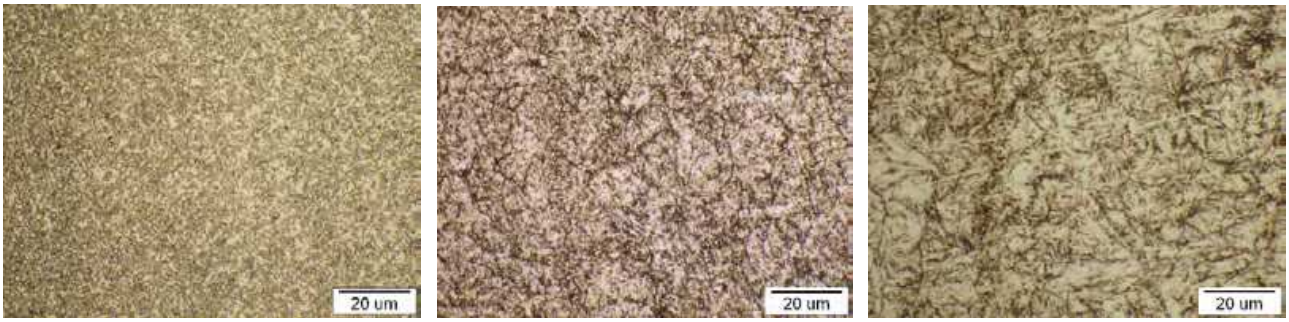
Sledila je izvedba preiskav in določitev ključnih lastnosti vzorcev nožev iz tabele 1: meritve trdote po standardu ISO-6507-1 [5], določitev natezne trdnosti po SIST EN ISO 6892-1 [6] ter udarne žilavosti po EN ISO 148-1 [7]. Za ta namen smo analizirali primernost različnih postopkov izdelave preizkušancev glede na trdoto materialov in ocenili, da je najprimernejši postopek za izdelavo preizkušancev iz kaljenih orodnih jekel za rezilna orodja žična erozija. Določili smo dimenzije preizkušancev in minimalno potrebno število posameznih tipov preizkušancev za zgoraj naštete preizkuse.

Analiza smiselnosti posameznih statičnih in dinamičnih mehanskih preizkusov, iz katerih je izdelan referenčni nož, je pomembna za razvoj novega orodnega jekla. Trdota je neposredno povezana z odpornostjo proti abrazivni obrabi, zato je ena od najpomembnejših karakteristik vsakega rezilnega orodja. Natezni preizkus je imel namen v pridobitvi podatkov o napetosti tečenja, natezni trdnosti in modulu elastičnosti obstoječega in referenčnega vzorca nožev. Ker so rezilna orodja obremenjena dinamično, udarne obremenitve niso izključene. V skrajnem primeru udarne obremenitve lahko pripeljejo do zloma orodja, preden je potrebna zamenjava zaradi obrabljenosti. Za preprečevanje predčasnega izpada orodja zaradi zloma, ki ga povzroči udarna obremenitev, je nujna zadostna udarna žilavost materiala. Zato so bili v raziskave vključeni tudi preizkusi udarne žilavosti.

samples. On the basis of requirements, we prepared instructions for proper detection of microstructures and a review of suitable etching agents.

It followed the implementation of the research and the determination of the key properties of the knife samples from Table 1: the measurement of hardness according to the ISO-6507-1 standard [5], the determination of the tensile strength according to SIST EN ISO 6892-1 [6] and impact toughness according to EN ISO 148-1 [7]. For this purpose, we analyzed the suitability of the different manufacturing processes of the test pieces in terms of the hardness of the materials and estimated that the most appropriate procedure for the preparation of test pieces from hardened tool steels for cutting tools by wire erosion. We determined the dimensions of the specimens and the minimum required number of individual types of test subjects for the above tests.

An analysis of the sensitivity of individual static and dynamic mechanical tests from which a reference knife is made is important for the development of a new tool steel. The hardness is directly related to the abrasion resistance, therefore it is one of the most important characteristics of each cutting tool. The tensile test had the purpose of obtaining data on the tension, tensile strength and elastic modulus of the existing and reference knife pattern. As the cutting tools are loaded dynamically, the impact loads are not excluded. In extreme cases, impact loads can lead to fracture of the tool before wear replacement is needed. To prevent early tool failure due to a fracture caused by a shock load, sufficient impact strength of the material is necessary. Therefore, tests of impact toughness were included in the research.



1a 1b 1c

Slika 1. Mikrostrukture treh vzorcev nožev

Figure 1. Microstructure of the three knife samples

3 Rezultati in diskusija

Na slikah 1a - 1c so prikazane karakteristične mikrostrukture vzorcev nožev od 1-3.

Na sliki 1a je prikazana mikrostruktura surovca pred toplotno obdelavo, ki kaže finozrnatost, zahtevano pred postopkom toplotne obdelave. Na slikah 1b in 1c pa je razvidna tipična mikrostruktura popuščnega martenzita, ki zahtevana za rezilna orodja.

Razvoj naprednega orodnega jekla je ciljno fokusiran na korekcijo kemijske sestave obstoječega orodnega jekla in toplotne obdelave, ki bo rezultirala v izboljšanih lastnosti orodnega jekla. Iz tega razloga je za primerjavo bil izbran referenčen nož, ki dosega najboljše rezultate.

Za doseganje zahtevanih lastnosti orodnih jekel se proizvajalci poslužujejo različnih tehnologij njihove izdelave in toplotne ter mehanske obdelave. Naš cilj je modifikacija kemijske sestave tako, da bodo izbrani mikrolegirni elementi stabilizirali popuščni martenzit, predvidena pa je tudi uvedba novih sistemov v finalizaciji izdelave s ciljem doseganja želene mikrostrukture. Tako bomo lahko zagotovili zahtevane končne lastnosti orodnega jekla in s tem nožev. Načrtovana je optimizacija avstenitizacije ter razvoj popolnoma novega kalilnega sistema. Predvidevamo, da bomo tako pri novem orodnem jeklu dosegli tako

3 Results and discussion

Figures 1a - 1c show the characteristic microstructure of the knife samples from 1-3.

Figure 1a shows the microstructure of the blank before the heat treatment, which has the fine-grained structure, which is required before the heat treatment process. In Figs. 1b and 1c, a typical microstructure of the tempering martensite, which is required for cutting tools. The development of advanced tool steel is targeted at the correction of the chemical composition of existing tool steel and heat treatment, which will result in improved properties of tool steel. For this reason, the reference knife was selected for comparison, which achieved the best results.

In order to achieve the required properties of tool steels, manufacturers use various technologies for their production and thermal and mechanical treatment. Our goal is to modify the chemical composition so that the selected micro-alloy elements stabilize the tempering martensite, and the introduction of new systems in the finalization of production with the aim of achieving the desired microstructure. This way, we will be able to provide the required final properties of the tool steel and thus the knives. The optimization of austenitization

dobre lastnosti, da bodo delovali zahtevano število ur (vsaj 10 h) v ekstremnih rezalnih pogojih. V članku so predstavljeni: študija kemijske sestave in nastanek mikrostrukture ter rezultati meritev trdot in trdnostnih lastnosti, kar bo osnova za doseganje konkurenčnih lastnosti referenčnega vzorca in ostalih proizvajalcev.

V članku smo obstoječe lastnosti orodnega jekla povezali s problematiko rezanja, kjer je potrebno izpostaviti dejstvo, da v primeru rezanja mehkih materialov (mehek les) delujeta dva načina odrezovanja, t.j. princip klina in princip ploščatega sekača. Za tak primer mora imeti material noža ustrezno trdoto in trdnostne lastnosti, da lahko nastanejo odrezki. Nož deluje na izbrani globini rezanja, kjer mora v strižni coni z dovolj veliko silo povzročiti striženje in cepljenje lesa, ki se spremeni v odrezek. Na stični površini imamo opravka z zelo visokimi pritiski in temperaturami (prevlada Coulombovega zakona trenja, koeficienti trenja nad 0,5). Mazanje in hlajenje lahko v tem primeru zanemarimo, medtem ko kemičen vpliv v strokovni literaturi še ni pojasnjen. Vsled mehanskih in toplotne obremenitve prihaja med rezanjem na dotikalni liniji nožev lokalno do nadaljnjega popuščanja, kar lahko povzroči nezaželeno fazno transformacijo popuščnega martenzita v mehkejše faze. V splošnem je za martenzit značilna velika trdota, ki jo v največji meri povzroča deformacija železove kristalne mreže zaradi prisotnosti prisilno raztopljenega ogljika, pomembni pa so tudi prispevki gostote dislokacij (deformacijsko utrjanje) oziroma dvojčičnih mej v posameznih ploščicah martenzita oziroma visoka gostota martenzitnih ploščic (utrjanje s kristalnimi mejami). Ob upoštevanju, da martenzitne ploščice nastanejo na dislokacijah v kristalnih zrnih in da se pri njihovem nastanku močno povečajo notranje napetosti, predstavlja

is planned and the development of a brand-new quenching system. It is assumed, that with this new tool steel, we will achieve such good properties that the required number of hours (at least 10 hours) will work in extreme cutting conditions. In the lecture, we will present a study of the chemical composition and the formation of a microstructure and the results of hardness and strength measurements, which will be the basis for achieving the competitive properties of the reference sample and other manufacturers.

In the lecture we will connect the existing properties of the tool steel with the problem of cutting, where it is necessary to emphasize the fact that in the case of cutting soft materials (soft wood), two methods of cutting are working, i.e. the principle of the wedge and the principle of a flat cutter. For this purpose, the material of the knife must have the appropriate hardness and strength properties so that clippings can be formed. The knife works at the selected cut depth, where it is necessary to cause shearing and splitting of the wood, which turns into a snippet, in the shearing zone with sufficient force. On the contact surface, very high pressures and temperatures are presented (the dominance of Coulomb‘s law of friction, coefficients of friction above 0.5). Lubrication and cooling can be neglected in this case, while the chemical influence in the professional literature has not yet been clarified. Due to the mechanical forces and heat of the load, during cutting at the touch line of the knives, it is local to further degradation, which can cause undesired phase transformation of the tempering martensite into the softer phase. In general, martensite is characterized by a high hardness, which is mostly caused by the deformation of the iron crystal net due to the presence of forced dissolved carbon, and the contributions of the density of the dislocations (deformation hardening) or

martenzit metastabilno fazo. To pomeni, da je po naravi težnja martenzita njegova fazna transformacija oziroma prehod v stabilno stanje (ferit in karbide). Če je ob tem prisotna zadostna gonilna sila, kot so v primeru rezanja mehanske sile in nastala toplota, se ta transformacija prej ali slej tudi zgodi. Posledica je poslabšanje mehanskih lastnosti rezila in hitrejša obraba. Zato bo potrebno razviti takšno mikrostrukturo martenzitnega orodnega jekla, ki bo dalj časa odporna - stabilna na mehanski in toplotni vpliv iz procesa rezanja, s čimer bo transformacija martenzita prestavljena na kasnejši čas.

4 Zaključki

V članku smo predstavili prve rezultate raziskav obstoječega in referenčnega orodnega jekla, ki bodo smernica za nadaljevanje razvojnega dela na področju nožev za najzahtevnejše aplikacije v hladnem. Raziskave so bile izvedene v okviru projekta Rano@steel (OP20.03523), kjer je koordinator podjetje Ravne Systems in ga financira Evropski sklad za regionalni razvoj in Ministrstvo za izobraževanje, znanost in šport Slovenija.

the twinning boundaries in the individual martensitic plates, or the high density of martensitic plates (hardening with crystalline boundaries). Taking into account that martensitic plates are formed on dislocations in crystalline grains and that their intrinsic tension increases greatly, martensite is a metastable phase. This means that, by nature, the martensitic tendency is its phase transformation or transition to a stable state (ferrite and carbide). If sufficient propulsion force is present, as in the case of cutting heat generated, this transformation sooner or later also occurs. The result is the deterioration of the mechanical properties of the blade and faster wear. Therefore, it will be necessary to develop such a microstructure of martensitic steel, which will be resistant for a long time - stable on the mechanical forces and heat effect from the cutting process, with which the martensite transformation will be postponed to a later time.

4 Conclusions

In the lecture we presented the first results of the research of the existing and reference tool steel, which will be a guide for the continuation of the development work in the field of knives for the most demanding applications in cold work. Research was carried out as part of the Rano@Steel project (OP20.03523), where the coordinator is Ravne Systems and is funded by the European Regional Development Fund and the Ministry of Education, Science and Sport Slovenia.

5 Reference / References

[1] ASTM A370 – 17a (Standard Test Methods and Definitions for Mechanical Testing of Steel Products).
[2] Wang, J., Shimada, K., Mizutani, M., Kuriyagawa T.; Tool wear mechanism and its relation to material removal in ultrasonic machining, Wear, 15 January 2018, 394-395:96-108.
[3] Xu, Q., Zhao, J., Ai, X.; Cutting performance of tools made of different materials in the machining of 42CrMo4 high-strength steel International Journal of Advanced Manufacturing Technology. Nov 2017, Vol. 93 Issue 5-8, p2061-2069.
[4] Roberts, G. A., Kennedy, R., Krauss, G.; Tool Steels (5th ed. Materials Park, 1998, OH: ASM International).
[5] ISO 6507-1:2018 Metallic materials -- Vickers hardness test -- Part 1: Test method.
[6] ISO 6892-1:2009, Metallic materials -- Tensile testing -- Part 1: Test method.
[7] ISO 148-1:2016, Metallic materials -- Charpy pendulum impact test -- Part 1: Test method.