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Skrajševanje tehnološkega postopka od taline do žice

Shortenings of Technological Procedures from Melt to Wire

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Novi materiali in materiali z izboljšanimi uporabnimi lastnostmi, ki so v ospredju strateških usmeritev razvojnih programov, zahtevajo nove ali pa spremenjene in izboljšane tehnologije z ekstremno racionalizacijo procesov, zmanjševanjem specifične porabe energije in zagotavljanjem maksimalnega materialnega izkoristka. Pojavljajo se pomembne in prav revolucionarne spremembe celo v osnovnih konceptih tehnoloških postopkov s težnjo k skrajševanju tehnoloških poti. Odločilnega pomena je optimalna kombinacija specializacije in hitre prilagodljivosti tržnim in razvojnim potrebam.

V članku je podrobneje opisan razvoj pilotne proizvodnje z vakuumsko indukcijsko pečjo ter horizontalno kontilivno napravo za žico in palice v dimenzijskem območju ∅ 3 do ∅ 40 mm.

1. UVOD

Novi materiali so danes po vsem svetu v središču pozornosti strateških usmeritev razvoja. Za proizvodnjo in zagotavljanje kakovosti teh materialov je potrebna nova ali boljša tehnologija.

Spremembe tehnoloških procesov prinašajo izboljšanje materialnega izkoristka, zmanjšanje specifične porabe energije in optimalno ekonomiko proizvodnje.

Odločilnega pomena je pri tem optimalni odnos specilizacije in fleksibilnosti zaradi sposobnosti hitrega prilagajanja razmeram na trgu in zahtevam razvoja.

Pomembno novost v tehnološkem razvoju predstavlja horizontalno neprekinjeno litje drobnih dimenzij, žic in palic, ki je povezano tudi z novostmi v razvoju novih, tehnološko in energetsko racionalnejših procesov vroče predelave.

Razvoj pilotne proizvodnje na Metalurškem inštitutu v Ljubljani (1) je z mednarodnim sodelovanjem prinesel nekaj izvirnih novosti za nadaljnji razvoj tehnologije tega področja in novih materialov, tako da specifičnosti te nove tehnologije niso več zanimive samo za proizvajalce specialnih konstrukcijskih in orodnih jekel ter superzlitin, ampak tudi za proizvajalce manj legiranih jekel.

Izkazalo se je, da je danes že možno v proizvodni praksi uresničiti nekdanje futuristične želje po neprekinjeni proizvodnji od taline do končnega izdelka — palice ali žice v toplotno obdelanem stanju.

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New materials and materials with improved properties which are in the forefront of strategic orientation of development programmes demand new or modified and improved technologies with extreme process rationalization, reduction in specific energy consumption and higher material yield. New important and revolutionary changes have appeared even in basic technological concepts with the aim of shortening technological procedures. The optimum combination of specialization and quick adaptation to market and development demands are of decisive importance.

The development of pilot plant consisting of vacuum induction furnace and horizontal continuous casting machine for wire and rods within 3—40 mm diameter range is described.

1. INTRODUCTION

Today new materials are in the focus of strategic orientation of development all over the world. The production and quality requirements of these new materials require new or better technologies.

Changes in technological procedures result in higher yield of material, reduction of specific energy consumption and optimal economy of production.

The optimal ratio between specialisation and flexibility has a decisive role due to the need for quick adaptation to market conditions and development requirements.

Horizontal continuous casting of small section rods and wires is an important innovation of technological development associated with new achievements in the development of new from energetic and technological viewpoint more rational hot working processes.

The development of pilot production at Metallurgical Institute in Ljubljana (1) with international cooperation has brought forth some original innovations for further development of this technology and new materials so that this specific technology becomes interesting not only for the producers of special constructional and tool steels, and superalloys but for the producers of low alloyed steels as well.

It has been shown that today it is possible to realize old wishes for a continuous technological process from melt to the final product — rod or wire in heat treated state.

njenem tehnološkem postopku od taline do končnega izdelka — palice ali žice v toplotno obdelanem stanju.

Pilotna proizvodnja je tesno povezana z matematičnim simuliranjem procesov in tako v razvoju nove tehnologije ter zagotavljanja »zanesljive ekonomske kakovosti« prevzema pomembo razvojno vlogo.

Asortiment izdelkov pilotne proizvodnje omogoča tudi ustrezno uveljavitev na tržišču, nakar ga je v polni meri treba prenesti v industrijsko proizvodnjo — učinkovito in hitro!

Prva faza razvoja pilotne proizvodnje slovenskih železarn na Metalurškem inštitutu v Ljubljani obsega vakuumsko indukcijsko peč z napravo za horizontalno neprekinjeno litje, napravo za električno pretaljevanje pod žlindro, naprave za vlečenje v hladnem in toplem stanju ter toplotno obdelavo, klasično, v vakuumu in v lebdečem sloju. Poleg tako imenovane pilotne vloge za uvajanje novih tehnoloških procesov in materialov v industrijsko proizvodnjo, bodo te naprave zadovoljevale tudi potrebe po manjših količinah posebnih materialov, katerih proizvodnja je v industrijskih pogojih ekonomsko nesprejemljiva.

2. HORIZONTALNO NEPREKINJENO LITJE ŽICE, OKROGLIH IN KVADRATNIH PALIC TER DROBNIH PLOŠČATIH PRESEKOV

Leta 1972 je firma CSE (Steel Casting Engineering) izdelala prvo napravo (2) za horizontalno neprekinjeno litje žic **(Slika 1)**. Najpomembnejše je, da je na taki napravi možno izdelati tanke palice, premera 3 do 15 mm in dolžine ca. 6 ali tudi več metrov, iz nepredelavnih materialov na bazi kobalta in drugih zlitin za dodajne materiale pri postopkih varjenja oziroma navarjanja, katere je bilo doslej mogoče izdelovati samo z dragimi postopki sesanja v kvarčne cevke, dolžine največ do 600 mm. Z razvojem novega postopka neprekinjenega litja se je odprlo tudi novo področje tehnologije, ki je zaenkrat še omejeno na asortiment avstenitnih nerjavnih jekel in nekaterih supezlitin. Lito žico nekaterih vrst jekel in zlitin je namreč mogoče vleči v hladnem ali toplem, in to neposredno po litju, v nekaterih primerih celo brez kakršne koli predhodne toplotne obdelave. Za razvoj te tehnologije bo potrebno še veliko raziskovalno-razvojnega dela, predvsem na področju orodnih in nekaterih posebnih jekel, za ka-

Pilot production is closely bound with mathematical modelling and computer simulation of processes which enables it to undertake an important role in the development of new technological procedures and obtaining "reliable economic quality".

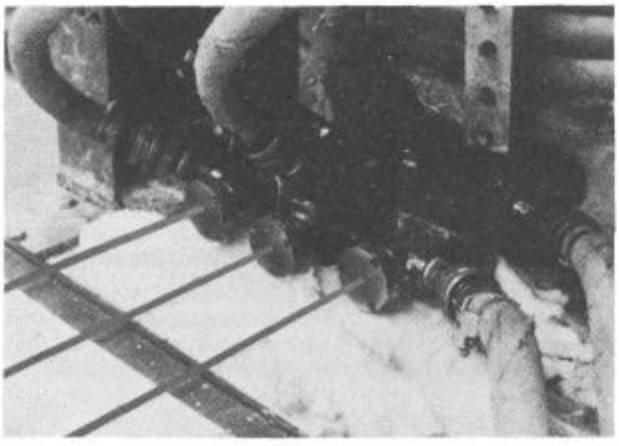
The production program of the pilot production makes it possible to reach corresponding market effect which should be followed by a quick and efficient transfer in industrial production!

The first phase of development of the pilot production of Slovenske železarne (Slovenian Ironworks) at the Metallurgical Institute in Ljubljana is made up of a vacuum induction furnace with horizontal continuous casting machine, electro-slag remelting unit, hot and cold drawing machines, and the equipment for vacuum heat treatment, classic heat treatment and heat treatment in fluidized bed. The pilot plant composed in this way will besides its development role satisfy also market demands for smaller quantities of special materials which can not be produced economicaly in an industrial plant.

2. HORIZONTAL CONTINUOUS CASTING OF WIRE, ROUNDED AND SQUARE BARS AND SMALL FLAT CROSS SECTIONS

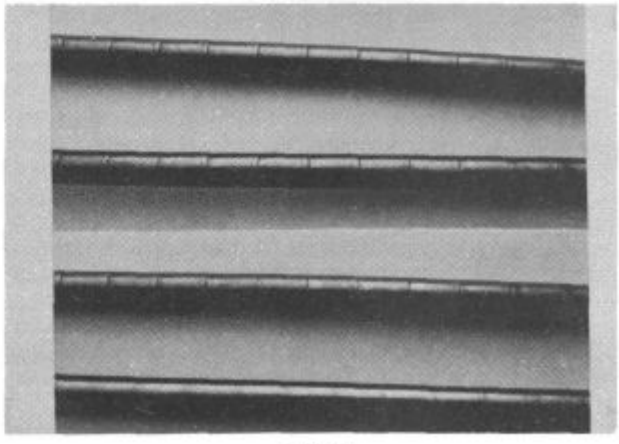
*In 1972 SCE (Steel Casting Engineering) built the world's first (2) horizontal continuous wire casting machine **(fig. 1)***

The most important is that such a caster can produce 3—15 mm diameter rods of ca 6 m or longer length from practically nonworkable materials such as cobalt based and similar alloys for welding rods which up to the present had to be produced by expensive vacuum sucking into quartz glass tubes of utmost 600 mm length. The development of the new continuous casting process opened up new field of technology also which is at present limited to austenitic stainless steel and some superaloys. Continuously casted wire of some steels and alloys can be subjected to hot or cold drawing immediately after the casting and in certain cases even without any heat treatment. The development of this technology specially for tool steel and some specialty steel will demand a lot of additional research work. However, the obtained experience confirm its feasibility and



Slika 1
Izhodni del trožilne naprave za horizontalno neprekinjeno litje žice

Fig. 1
Outgoing side of a three strand horizontal continuous wire caster



Slika 2
Površina žice kobaltove zlitine ob frekvenci oscilacij 200, 250, 300 in 800 impulzov na minuto (od zgoraj navzdol)

Fig. 2
Surface of cobalt based wire. Stroking rates from above: 200, 250, 300 and 800 strokes per minute.

tera tehnologija še ni osvojena, izkušnje pa kažejo, da je prav gotovo možna in za kakovost zelo perspektivna. Firma SCE je tudi dobavitelj pilotnih naprav Metalurškega inštituta v Ljubljani.

Tehnološki parametri litja (1, 2) vplivajo na izoblikovanje oziroma odpravo lunkerjev in na kakovost površine **(Slika 2)**. Pri optimalnih pogojih je danes, ne glede na veliko hitrost litja, že mogoče zanesljivo izdelati z neprekinjenim litjem žico brez lunkerjev **(Slika 3)**. Uvedba vmesne ponovce v izvedbi in vlogi dogrevalne ali celo talilne peči (3), ki deluje pod tlakom in ima možnost prepihovanja taline z argonom, omogoča vzdrževanje optimalnega in nespremenljivega ferostatičnega pritiska v kristalizatorju **(Slika 4)**.

Z razvojem horizontalnega neprekinjenega litja valjavskih gredic in žice je povezan tudi razvoj horizontalnega neprekinjenega litja palic končnih dimenzij za razrez pri postopku utopnega ali prostega kovanja in polizdelkov za nadaljnje valjanje. To so palice v območju premerov 20—50 mm, ki v zadnjem času postajajo vse bolj interesanten vložek za nadaljnjo predelavo.

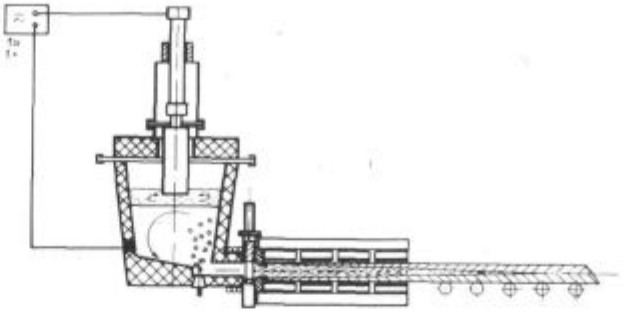
Izdelki iz te naprave za horizontalno neprekinjeno litje so zelo perspektivni v nadaljnjem razvoju predelave z vročim valjanjem specialnih jekel in zlitin, izdelkov in oblik, ki so v določenih primerih tudi vložek za vroče, poltoplo ali hladno kovanje. Kot primer lahko omenimo ventile, obroče krogličnih ležajev in številne druge izdelke.

Neprekinjeno litje palic v območju premerov 20—50 mm za nadaljnjo vročo plastično predelavo se je izkazalo kot zelo pomembno, predvsem pri materialih, ki se težko plastično preoblikujejo. Z manjšim vhodnim presekom je mogoče vhodno hitrost pri valjanju optimalno prilagoditi najprimernejši izhodni hitrosti ter z uravnavanjem stopenj deformacije pri posameznih prehodih zagotavljati izotermalno predelavo v ozkem temperaturnem intervalu. Tako je mogoče valjati z novo kovaško valjavsko linijo (4) tudi jekla in zlitine, ki so doslej veljale skoraj kot nesposobne za vročo plastično predelavo. Posebej je treba poudariti, da je interes za neprekinjeno vlivanje takih polizdelkov v obliki drobnih palic odprl nove probleme in zahteval nove tehnološke rešitve v tehnologiji neprekinjega litja.

Matematično modeliranje za optimiranje tehnoloških pogojev (5, 7) daje velik prispevek k pospeševanju napredka na področjih litja in predelave.

Slika 3
Vzdolžni prerez neprekinjeno lite žice nerjavnega jekla tipa 18 % Cr-11 % Ni ob izvlačenju žice s frekvenco 800 impulzov na minuto

Fig. 3
Longitudinal section of continubusly cast stainless steel (18 % Cr-11 % Ni) wire. Stroking rate 800 strokes/min.



Slika 4
Tlačna vmesna ponovca, ogrevanje z električnim pretaljevanjem pod žlindro ali induktivno ogrevanje ponovce in izlivka, prepihovanje z argonom in drsno zapiralo za horizontalno neprekinjeno litje

Fig. 4
Scheme of an HCC with Electroslag Heating, Ar-purging and constant gas pressure above the bath

promissing prospect regarding quality improvement. The mentioned equipment of the pilot plant of Metallurgical Institute is to be supplied by SCE.

*Technological parameters of casting (1, 2) influence the internal shrinkage and surface quality **(fig. 2)**. At optimum conditions it is possible to produce internally sound wire **(fig. 3)** with horizontal continuous casting irrespective of great casting rate.*

*The introduction of heating or even smelting type tundish (3) operating at constant gas pressure above the bath and equipped with argon purging helps to maintain optimal and constant ferrostatic pressure in the mould **(fig. 4)**.*

The development of horizontal continuous casting of bars of final dimensions and cutting for die or free forging and semi products for subsequent rolling is also asociated with the development of horizontal continuous casting of billets and wire. These bars of 20—50 mm diameter for further subsequent working have recently become very interesting. The products of horizontal continuous caster are very interesting for further development of hot rolling of special steels and alloys as well as profiles and shapes which in certain cases serve as semiproducts for subsequent hot, semi hot or cold forging. As an example valves and ball bearing rings should be mentioned.

Continuous casting of rods of 20—50 mm diameter for further hot working has been found as very important particularly for materials of poor workability. The use of smaller section makes it possible to select the most appropriate input rolling rate to suit the optimal exit rate and to ensure practically isothermal working within a narrow temperature range by the control of deformation degree in particular rolling passes. The new combined forging-rolling procedure (4) makes it possible to process the steels and alloys which up to now were considered as practically nonworkable. However, it should be underlined that continuous casting of such semi products in the form of small size rods opened up new problems and started the search for new innovations of the continuous casting technology.

Mathematical modelling as a tool for optimization of technological conditions (5, 7) have a significant share in the acceleration of progress in the field of casting and plastic deformation.

The productivity of these machines is quite good today also, e.g. a three strand horizontal continuous caster of wire can produce

Tudi produktivnost teh naprav je danes že kar pomembna, saj na primer horizontalna kontilivna naprava za žico s tremi žilami omogoča letno proizvodnjo.

— pri Ø 3 mm . . . ca. 200—250 t/leto
— pri Ø 5 mm . . . ca. 400—500 t/leto
— nad Ø 8 mm . . . nad 850 t/leto,

kar je odvisno od deleža sekvenčnega ali individualnega litja.

Enožilna naprava za palice, premera 50 mm, pa daje možnost proizvodnje od 10.000 do 20.000 ton letno, kar predstavlja dandanes najekonomičnejši postopek proizvodnje nekaterih izdelkov v določenem dimenzijskem območju.

V fazi razvoja je tudi naprava za neprekinjeno litje ploščatih presekov (3) z debelino 10 mm—15 mm in širino 150 mm—350 mm. Ta razvoj je namenjen optimiranju tehnologije za proizvodnjo nerjavnih varjenih cevi. Posebno za te namene prirejena valjavska linija se v kombinaciji z napravo za neprekinjeno litje pojavlja kot zelo resen konkurent konvencionalnemu proizvodnemu postopku za varjenje cevi.

3. NOVE PERSPEKTIVE RAZVOJA NA PODROČJU VALJANJA SPECIJALNIH JEKEL IN ZLITIN

Današnjo stopnjo razvoja je mogoče opredeliti z optimalno kombinacijo horizontalnega neprekinjenega litja z neprekinjeno kovaško valjavsko linijo za predelavo v vročem, ki ima prehodni kovaški stroj povezan s kontinuirno valjavsko progo (1). Taka kombinacija z regulirnim natančnim indukcijskim dogrevanjem pred vstopom v progo zagotavlja proizvodnjo homogenih in po vsem preseku zdravih izdelkov — žic in palic. Pri taki specialni liniji že stopnja predelave neprekinjeno litih polizdelkov z redukcijo 3,5:1 povsem zadošča (4).

Sekvenčno litje žice že pri majhni napravi omogoča izdelavo kolobarjev celo do dveh ton.

Vroča predelava v eni vročini od dobave vročega vložka iz jeklarne do končnega izdelka predelave, ki predstavlja normalni tehnološki postopek na področju konstrukcijskih jekel, je vsekakor ekonomsko tehnični cilj razvoja tudi na področju specialnih jekel in zlitin, orodnih jekel in superzlitin, kakor tudi visokotrdnih in ognjeodpornih, težko predelavnih materialov, kar pri današnjih standardnih pogojih ni izvedljivo.

V središču pozornosti je zato danes nov postopek vroče predelave z napravami, ki omogočajo učinkovitejšo plastično deformacijo in že pri manjši stopnji redukcije zagotavljajo zdrav presek tudi pri uporabi neprekinjeno litih gredic ali palic, zaradi optimirane porazdelitve deformacij, ki omogočajo učinkovito zapiranje lunkerjev in zgoščevanje centralne pozornosti (7).

Na osnovi praktičnih izkušenj valjanja je znano, da vhodna hitrost ne sme ali pa ne more biti manjša od 0,1 m/sek. Končna izhodna hitrost pri valjanju pa je omejena z značilnimi lastnostmi valjanega materiala.

Danes končna izhodna hitrost 50 m/sek pri premeru 6 mm ni več nikakršna posebnost in ne predstavlja tehničnih problemov valjanja. Seveda pa je ta hitrost dopustna pri običajnih konstrukcijskih jeklih, od nelegiranih do srednjelegiranih in pri malolegiranih orodnih jeklih. Pri brzoreznih jeklih ta hitrost v splošnem ne sme presegati 30 m/sek. Pri kobaltovih brzoreznih jeklih je ta hitrost omejena na maksimum 25 m/sek, a pri nekaterih superzlitinah celo na maksimum 20 m/sek.

Če upoštevamo te omejitve, lahko takoj ugotovimo, da klasično valjanje neprekinjeno litih gredic v eni vročini pri mnogih vrstah specialnih in orodnih jekel ter superzlitin sploh ni izvedljivo.

at 3 mm diameter . . . ca 200—250 t/year
at 5 mm diameter . . . ca 400—500 t/year
over 8 mm diameter . . . over 850 t/year.

which depends on the share of sequential casting.

Single strand caster for rods of 50 mm diameter can produce 10,000 to 20,000 tons per year, which today represents the most economic production process for some products of certain dimension range. Research work is continuing on a development programme to cast flats (3) in sizes of 10—15 mm by 150—350 mm. This development programme is aimed at the optimization of the manufacture of welded stainless steel tubes. Specially adapted rolling mill combined with continuous caster appears as very serious contester with conventional manufacturing of welded tubes.

3. NEW OUTLOOK FOR DEVELOPMENT IN ROLLING OF SPECIAL STEELS AND ALLOYS

The present stage of development can be defined with the optimal combination of horizontal continuous casting with a continuous forging-rolling mill for hot working with continuous forging machine coupled with continuous rolling mill. Such a combination with accurately controlled induction heating at the start ensures a reliable manufacture of homogeneous and over all section sound rods and wires. The degree of deformation for continuously casted semi products of 3.5:1 is already sufficient (4) for such a combined production line. Sequential continuous casting makes it possible to produce even 2 ton coils already with a small caster. Hot working of hot stock as supplied by steelworks without any intermediate reheating to the end of processing, which is a normal procedure for constructional steel, is by all means the economic and technical aim of development also in the field of special steels and alloys as well as for tool steels, superalloys, hardfacing and refractory materials of poor plasticity which at present standard conditions is still impossible.

Today the activity is focused in the new hot processing method which makes it possible to perform more effective plastic deformation and ensures sound crosssection of continuously cast billets or rods already at lower degree of deformation because of the optimum distribution of deformation which helps to eliminate center line porosity (7).

Experience obtained in rolling has shown that input speed may not or can not be lower than 0.1 m/s whereas the final exit rolling speed is limited by material properties.

Today's exit speed of 50 m/s at 6 mm diameter is almost routine and does not cause technical rolling problems. Of course, such final speed is permissible for common construction al steel from unalloyed to medium alloyed grade and for low alloyed tool steel. The speed for high speed tool steel is limited to 30 m/s. For high speed tool steel containing Co the maximum rolling speed is 25 m/s whereas it is utmost 20 m/s for some super alloys.

Taking into account these limitations it can easily be concluded that conventional rolling of continuous cast billets without intermediate reheating is not possible for numerous special and tool steels and superalloys. The key for the solving of hot working problem when dealing with such a production programme lies in the radical changes of first technological phase of plastic working as brought forth by the development of new GFM forging-rolling process which has been described elsewhere (1, 4, 6).

Ključ za rešitev problemov vroče predelave na področju teh asortimentov proizvodnega programa je v zagotavljanju radikalnih sprememb v prvi tehnološki fazi plastične predelave, kakršne je prinesel razvoj novega kovaško-valjavskega postopka GFM, ki je podrobneje opisan v (1, 4, 6).

4. NADALJNJI RAZVOJ

Nadaljnji razvoj prinaša bistvene novosti na področju specialnih jekel in zlitin z inovacijo nove moderne visoke tehnologije, ki se razvija z namenom izboljševanja materialnega izkoristka in zmanjševanja specifične porabe energije.

V proizvodnji specialnih jekel in superzlitin drobnih dimenzij je zaradi težav pri plastičnem preoblikovanju, ki so povezane z izkoristkom vloženega dela in materiala, a tudi zaradi splošne specifične porabe energije nesmiselno začeti predelavo s preseki vložnih materialov, ki so večji od nujno potrebnih. Dosedanje izkušnje s kovaško-valjavskim postopkom kažejo, da je pri tovrstnem plastičnem preoblikovanju že z zmanjšanjem premera vhodnega materiala na polovico mogoče zagotoviti zdravo strukturo po vsem preseku tudi pri uporabi kontinuirno vlitega vložka.

To pomeni, da neprekinjeno litje v območju dimenzij 20—40 mm danes že predstavlja interes v industrijski uporabi in ustreza smernicam razvoja najsodobnejše vrhunske tehnologije v svetu.

Spomnimo se, da je dosedanji razvoj neprekinjenega litja gredic potekal v dveh fazah. Najprej je bila izražena težnja k čimvečjim presekom neprekinjeno litih gredic, da bi s klasičnim valjanjem dosegli zdrav presek pri čimvečjih dimenzijah končnih izdelkov. Z novim kombiniranim razvojem tehnologije neprekinjenega vlivanja in intenzivnejše ter optimirane plastične predelave z novimi postopki so težnje razvoja usmerjene k zmanjševanju preseka neprekinjeno ulitih gredic, ki naj bi še zagotavljale ustrezno kakovost končnih izdelkov v čimširšem dimenzijskem območju do največjih potrebnih in tehnično ekonomsko sprejemljivih premerov. Nadaljnji razvoj je vse bolj usmerjen na področje horizontalnega neprekinjenega litja in predelave manjših dimenzij palic in žice.

Ta tehnologija daje široke možnosti intenzivni racionalizaciji proizvodnje, predvsem na področju materialov iz asortimenta specialnih visokolegiranih konstrukcijskih jekel, orodnih jekel, jekel s posebnimi lastnostmi, specialnih zlitin in superzlitin — materialov, od katerih se zahtevajo posebne lastnosti na najvišjem nivoju.

Znano je, da prinaša že dosedanje klasično in neprekinjeno litje v primerjavi s tradicionalnim litjem ingotov izboljšanje materialnega izkoristka za 10—20 %, odvisno od vrste jekla. Zmanjševanje stopnje predelave na minimalno neobhodno potrebno redukcijo omogoča posebno pri težko predelavnih materialih pomembno dodatno povečanje izkoristka, vezanega na tehnološko fazo predelave.

Skrajševanje verige celotnega tehnološkega postopka, ki predstavlja prevladujočo idejo v današnjih razvojnih prizadevanjih racionalizacije, prinaša zelo pomembne prihranke v specifični porabi energije (8).

Na današnji stopnji tehnološkega razvoja moramo posebej poudariti, da se že zelo približujemo industrijsko sprejemljivi realizaciji ideje neprekinjenega proizvodnega procesa od taline do končnih dimenzij palic ali žice v kolobarjih, kar je dolgo predstavljalo neuresničljive želje (1).

Za določeno dimenzijsko območje je mogoče razmeroma veliko hitrost neprekinjenega litja prilagoditi razme-

4. FUTURE DEVELOPMENT

Further development will result in essential innovations and advancements of high technology in the field of specialty steel and superalloys which is aimed at higher material yield and energy saving.

In the production of special steel and super alloys of small cross-section the input stock should have as small cross-section as possible because of well-known difficulties in plastic deformation which are joined with corresponding poor yield of material and high specific energy consumption. The obtained experience in forging-rolling process has shown that 50 % reduction in stock diameter already can ensure soundness over all cross section of continuous cast stock also.

This means that continuous casting of products within 20—40 mm section size range is today already interesting for industrial use and well compatible with development trend of the most advanced technology in the world.

The development of continuous casting of billets has proceeded in the two stages. The first trend was to develop continuous casting of billets of maximum possible section size to produce by conventional rolling completely sound cross-section at highest possible section size of finished products. With new combined development of continuous casting technology, with more intensive and optimum new plastic working processes the trend has changed to the reduction of cross section of continuously cast billets which should yet suffice for the corresponding quality of finished product of the widest possible dimension range up to the utmost needed and techno-economically acceptable diameters. Further development is even more oriented to horizontal continuous casting and processing of small sized rod and wire.

This technology offers wide possibilities for intensive rationalization of manufacturing particularly in the field of special high alloyed construction al steel, tool steel, steel with special properties, special alloys and super alloys of top level properties.

It is well known that transition from ingot casting to conventional continuous casting resulted in 10—20 % increase in material yield depending on steel grade. The reduction in the degree of deformation to the lowest necessary amount brings forth a significant additional increase in yield particularly of material with poor workability.

The shortening of over-all technological process which is the predominant idea lying in the background of present development trend and rationalization efforts results in very important reduction of specific energy consumption (8).

It should be emphasized that today's development level is very close to the industrially acceptable continuous production process from molten steel to the final product i.e., wire coil or rod of finite dimension which has long been unrealistic wish only (1).

For a definite dimension range comparatively great rate of continuous casting can be adapted to relatively small input rate of the continuous forging-rolling line.

For a part of production programme the production line composed in this way can reach optimal techno-economic results with the minimum energy consumption, the highest yield of material and generally, the lowest production cost.

This idea of the continuous production line which has not yet been realized has become feasible thanks to the new concept. Of course, it requires the determina-

roma majhni vhodni hitrosti v kovaško-valjavsko preoblikovalno linijo.

S proizvodno linijo, ki jo oblikujemo na tak način, je mogoče za določen del programa proizvodnje dejansko doseči optimalne tehničnoekonomske rezultate z minimalno porabo energije in maksimalnim izkoristkom materiala ter v splošnem doseči minimalne možne proizvodne stroške.

Ta, doslej še ne izpolnjena ideja tehnološkega postopka, ima z novim konceptom realno možnost uresničenja z zagotavljanjem optimalnih parametrov. Pilotna proizvodnja Metalurškega inštituta v Ljubljani ima pri tem važno vlogo (1).

5. RAZVOJNE RAZISKAVE IN PILOTNA PROIZVODNJA (1, 8)

V sodobni visoko produktivni proizvodnji se izvajanje raziskav prenaša iz laboratorijskih na pilotne naprave, ki se po osnovnih karakteristikah približujejo pogojem industrijske proizvodnje. Take pilotne naprave so predrage, da bi jih izkoriščali samo za raziskave, zato morajo dajati tudi določen delež neposredne proizvodnje, s katerim je po možnosti treba pokrivati vsaj lastne stroške delovanja pilotne proizvodnje. Informacije in rezultati raziskav ter meritve na napravah pilotne proizvodnje so velikega pomena za hitrejši nadaljnji razvoj. Na ta način z izkoriščanjem pilotnih naprav ne motimo redne proizvodnje z eksperimentiranjem, ampak v njej samo občasno preverjamo modele. Poleg raziskovalnega pomena ima pilotna proizvodnja tudi velik pomen za razvoj in osvajanje tržišča, saj daje normalne proizvode v manjših količinah za neposredno uporabo. Ko količina proizvodov iz pilotnih naprav ne zadošča več potrebam, se z vsemi izkušnjami ta proizvodnja prenese v industrijske obrate.

Take usmeritve razvojnih raziskav so povsem razumljive in pilotna proizvodnja je v današnjih pogojih za učinkovit napredek neobhodno potrebna!

Pilotna proizvodnja slovenskih železarn na Metalurškem inštitutu v Ljubljani neposredno povezuje v celovit sistem naprav vakuumsko indukcijsko peč in napravo za horizontalno neprekinjeno litje žice ali palic. To je izredno fleksibilen sistem, ki omogoča najrazličnejše kombinacije tehnoloških postopkov tudi v povezavi z električnim pretaljevanjem pod žlindro, kovanjem, valjanjem, vlečenjem v hladnem ali pri povišanih temperaturah in toplotno obdelavo vseh vrst, od klasične do vakuumske. Ta koncept pilotne proizvodnje odpira široke možnosti neposredne proizvodnje določenih specialnih izdelkov v ustreznih količinah, za katere je zagotovljen plasman na tržišču. Po drugi strani pa tak sistem omogoča v povezavi s posebnimi meritvami in laboratorijskim preizkušnjem ter raziskovanjem lastnosti izvajanje programov vrhunskih aplikativnih in znanstvenih raziskav, katerih rezultati se preko simulacij z matematičnimi metodami modeliranja učinkovito prenašajo v razvoj industrijske proizvodne tehnologije. Če tovrstno pilotno proizvodnjo gledamo kot mini tovarno s potrebami prav vseh normalnih aktivnosti, od raziskav in razvoja do organiziranja proizvodnje in plasmaja na tržišču, je tak celovit sistem odlična priložnost za sistematično vzgojo mladih kadrov in za dopolnilno usposabljanje strokovnjakov — tehnologov, organizatorjev, kontrolorjev, raziskovalcev in ekonomistov.

Naprava za horizontalno neprekinjeno litje žice ima tri žile za premer žice v območju od 3—12 mm in na njej se lahko izdelujejo palice dolžine do 6 m ali pa v primeru sekvenčnega litja kolobarji do 1000 kg.

Z zamenjavo izhodnega bloka vmesne ponovce je možno napravo prilagoditi za neprekinjeno litje palic,

tion of optimum technological parameters. The pilot production of Metallurgical Institute has an important role in respect to this task (1).

5. DEVELOPMENT RESEARCH AND PILOT PRODUCTION (1, 8)

In modern production with top level productivity research and development work is transferred from laboratory to pilot plant which is by its characteristics very close to industrial works. However, such a pilot plant is expensive therefore it must be partly market-oriented to cover pilot plant production costs at least. The informations measurements and research results obtained in pilot production are very important for the rate of development. In this way research and development work do not distub normal production which is temporarily used only for checking elaborated models. Besides this role the pilot production is very important for market development also sonce it offers smaller quantities of new products directly to the market. When the market demands surpasses the pilot production capacity the production moves to industrial scale together with overall experience obtained.

Such orientation of development is quite understandable. Under today's conditions pilot production is absolutely necessary for efficient progress!

The pilot production of Slovenian Ironworks at Metallurgical Institute in Ljubljana is an integral system composed of vacuum induction furnace and a horizontal continuous caster for rod and wire. This is a very flexible system which can be combined with electro-slag remelting unit, forging and rolling mills, cold drawing or drawing at higher temperatures including all sorts of heat treatment from the conventional one to the vacuum treatment. This pilot production concept opens up new possibilities for direct manufacture of certain special products in adequate quantities to satisfy the existing market demands. On the other side pilot plant in connection with special measurements and laboratory research makes it possible to carry out the most advanced scientific and applied research programme the results of which are used for mathematical modelling and computer simulation and finally utilized for development of industrial technology. The pilot plant can be considered as a mini factory including all necessary activities from research and development to the production planning and marketing so it is quite clear that such an integrated system offers excellent opportunities for systematic education of young workers and supplemental education of professionals like technologists, planners, foremen, supervisors, research workers, economists. etc.

Horizontal continuous caster is of three strand type for casting wire of 3—12 mm diameter range in coils and can be used for casting rods up to 6 m length also. In the case of sequential casting it can produce wire coils up to one tone weight.

By replacement of the exit block of tundish and puller system the caster can be adapted to single strand continuous casting of 20—40 mm diameter rods. Similar replacement of drawing mechanism can adapt it to cast flat section products.

The continuous manufacturing process from melt to wire can be connected with further cold drawing or drawing at higher temperatures.

The mentioned flexibility includes also vacuum or open-air casting of 300 kg ingots for subsequent forging on GFM machine in Ironworks Ravne. Of course, smaller experimental ingots can also be cast. Electrodes for

premera 20—40 mm, z eno žilo. Če zamenjamo vlečne mehanizme, je s to napravo mogoče vlivati tudi ploščate preseke.

Neprekinjen tehnološki postopek od tekoče kovine do žice lahko neposredno povežemo z nadaljnjo predelavo z vlečenjem v hladnem ali pri povišanih temperaturah.

K že omenjeni prilagodljivosti tega sistema pilotnih naprav naj omenimo, da je mogoče vlivati ingote, teže 300 kg, prosto na zraku ali v vakuumu za normalno predelavo na kovaškem stroju GFM v Železarni Ravne ali pa manjše eksperimentalne ingote. Prav tako je mogoče vlivati elektrode za električno pretaljevanje pod žlindro in ulitke v kovinske, croning ali precizijske forme, in to en ulitek maksimalne teže 300 kg ali pa več manjših ulitkov ali grozdov pri precizijskem litju.

Horizontalna naprava za neprekinjeno litje žice je predvsem pomembna za osvajanje novih vrst dodajnih materialov pri postopkih varjenja in navarjanja. Največkrat je mogoče proizvesti kar celotne potrebne količine nekaterih specialnih materialov. Pomembno je to, da se v določenih primerih lahko uporabi kar kontinuirno ulita žica, kar omogoča tudi izdelavo elektrod iz nepredelavnih materialov.

Na ta način razvoj pilotne proizvodnje lahko ocenjujemo z dveh gledišč, enkrat kot nujno potrebno in racionalno osvajanje novih materialov, drugič pa kot proizvodnjo mini količin, ki v normalnem industrijskem procesu ne morejo biti sprejemljive in ekonomične.

Horizontalno neprekinjeno litje predstavlja potencialno zelo velik interes za področje proizvodnje brzoreznih in ledeburitnih orodnih jekel ter specialnih zlitin, za katere pa tehnološki parametri litja še niso osvojeni. Ta interes je vezan predvsem na finozrnato strjevanje in na skrajševanje procesov, ki je danes v splošnem v ospredju tehnološkega razvoja predelave kovin. Na teh področjih pričakujemo od raziskav v naslednjem obdobju velik pomen in številne aktivnosti zaradi široke mednarodne aktualnosti tega razvoja.

6. MOŽNOSTI ZMANJŠANJA SPECIFIČNE PORABE ENERGIJE

V okviru investicijskega projekta pilotne proizvodnje na Metalurškem inštitutu v Ljubljani smo podrobno analizirali specifično porabo energije s primerjavo različnih postopkov opisanega tehnološkega razvoja (8).

Pri tem smo upoštevali za primerjavo dva značilna tehnološka postopka klasične tehnologije in tri variante nove tehnologije. Naslednja shema na **sliki 5** nazorno prikazuje specifičnosti teh petih tehnoloških postopkov. V glavnem nas zanima primerjava specifične porabe energije v procesu vroče predelave, kajti specifična poraba energije za taljenje jekla je pri vseh variantah v bistvu enaka in se ji ne moremo izogniti.

1. varianta tehnološkega postopka se uporablja danes za zahtevnejše vrste orodnih, specialnih in visokolegiranih konstrukcijskih jekel. Specifična poraba energije za tehnološko fazo vroče predelave, približno 1500 kWh/tono, predstavlja . . . indeks 100.

2. varianta tehnološkega postopka predstavlja klasični standardni tehnološki postopek. Specifična poraba energije, približno 1350 kWh/tono, predstavlja . . . indeks 90.

3. varianta tehnološkega postopka predstavlja tehnologijo za standardni del proizvodnega programa dobro predelavnih jekel. Specifična poraba energije, približno 500 kWh/tono, predstavlja . . . indeks 33.

electro-slag remelting can also be produced as well as castings made by metall mould, shell mould or precision wax cluster proces. Casting limited to a 300 kg piece or several pieces of smaller weight is possible.

Horizontal continuous wire caster is particularly significant for development of new materials for welding electrodes. Frequently it is possible to produce the required quantity of special materials. Sometimes continuously cast wire can be directly used for welding electrodes from nonworkable materials.

Thus the development of pilot production can be estimated from the two view points. First as absolutely necessary for rational research and development of new materials and second as mini production unit for small lot production which can not be accepted by normal industrial works.

The horizontal continuous casting is potentially very interesting for high-speed tool steel, ledeburitic tool steels and special alloys. Technological parameters for continuous casting of these materials have not yet been developed. Special interest is devoted to grain refinement and shortening of technological procedures which is generally in the forefront of development of metal working. Numerous development activities can be expected in these fields because of their's importance and universal actuality.

6. POSSIBILITIES FOR ENERGY SAVINGS

Within the investment project of pilot production plant at Metallurgical Institute an analysis of specific energy consumption has been made involving the comparison of different ways of the technological development described (8).

Two characteristical procedures of conventional technology and three variants of the new technology were taken into account. The sketch on ***fig. 5*** *display specific characteristics of the five procedures.*

Specific energy consumption for melting is naturally the same for all the five variants, therefore it is interesting to find out the differences in hot working stage.

1. variant *has been used for high quality tool, special and high alloyed constructional steel. Specific energy consumption for hot working phase of technology amounts to 1500 kWh/ton and sderves as a basis for comparison, i.e.*
Index 100

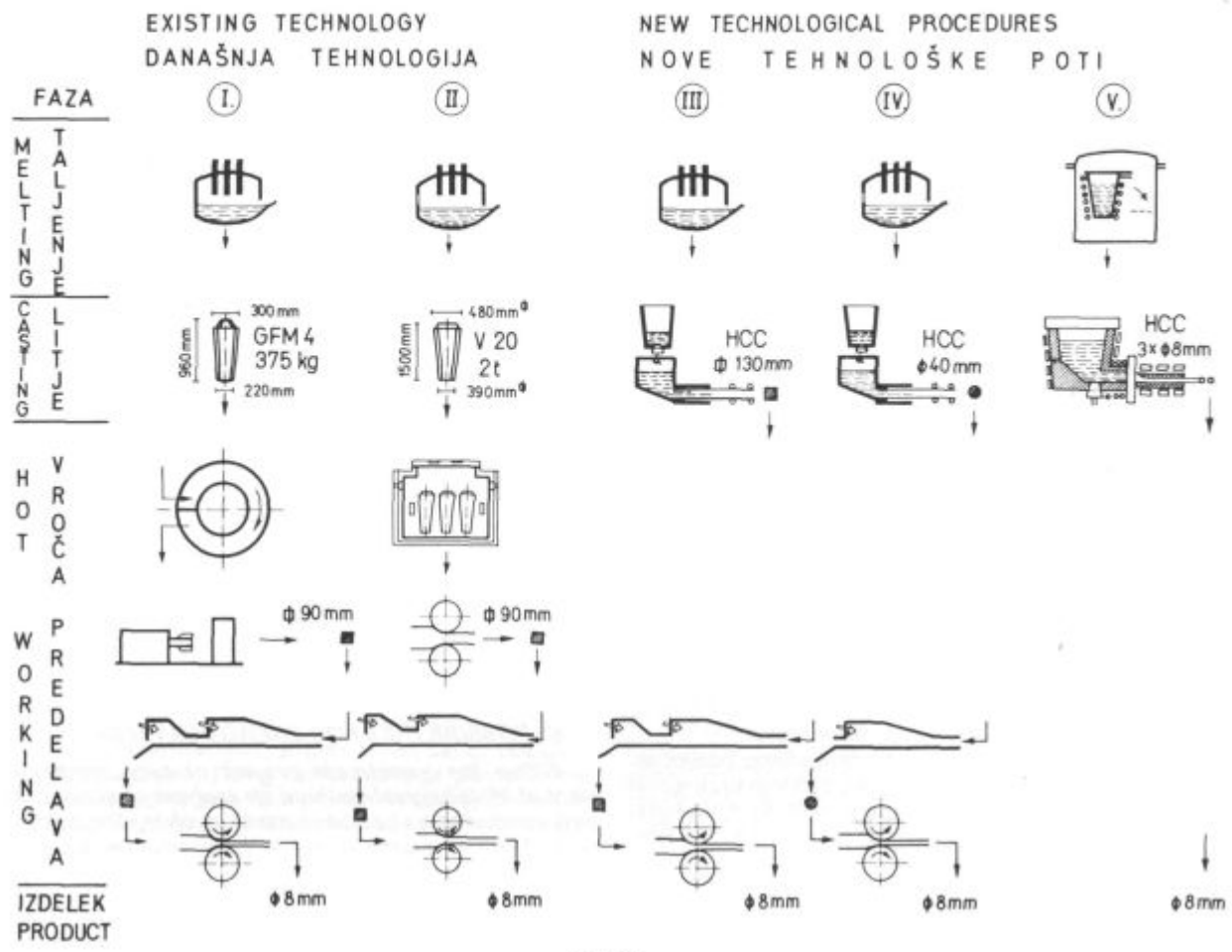
2. variant *is the standard technological procedure. Specific energy consumption is 1350 kWh/ton.*
Index 90

3. variant *represents the technology for standard part of production programme consisting of steel with good workability. Specific energy consumption is 500 kWh/ton i.e.*
Index 33

4. variant *covers dimension range under 20 mm and is suited to the stels of poor workability belonging to constructional, special and tool steel group as well as to special alloys and super alloys wherein it is desired to obviate problematic hot working. Specific energy consumption is approx. 400 kWh/ton.*
Index 27

5. variant *represents horizontal continuous casting of 3—12 mm diameter wire. This technology completely discard hot working stage.*
Index 0

It is specially interesting for the two fields of production programme:



Slika 5
Primerjava dveh klasičnih in treh novih tehnoloških postopkov za specifično porabo energije v procesu vroče predelave

Fig. 5
Comparison of specific energy consumption of hot working for two conventional and three new technological procedures.

4. varianta tehnološkega postopka naj bi pokrivala dimenzijski asortiment pod 20 mm in je posebej primerna za težko predelavna konstrukcijska jekla, specialna in orodna jekla, specialne zlitine in superzlitine, pri katerih se želimo predvsem izogniti nepotrebnemu delu problematične vroče predelave. Specifična poraba energije, približno 400 kWh/tono, predstavlja . . . indeks 27.

5. varianta tehnološkega postopka predstavlja postopek horizontalnega neprekinjenega litja žice s premerom 3—12 mm. Ta tehnologija, pri kateri vroča predelava sploh odpade (indeks 0) je interesantna predvsem za dve področji proizvodnega programa:

— za vse materiale, ki se uporabljajo v tem dimenzijskem območju in so praktično nepredelavni. Razumljivo je, da je ta tehnologija zanimiva predvsem za vse vrste dodajnih materialov za elektrode v postopkih varjenja, ker se s tem postopkom lahko popolnoma izognemo klasični predelavi, četudi bi bila izvedljiva. To prinaša pomembne ekonomske učinke v prihranku materiala, dela in porabe energije, kar končno omogoča maksimalno možno ekonomiko in izkoristek blizu 100 %;

— za vse materiale, ki so primerni za nadaljnjo predelavo z vlečenjem v hladnem ali vročem stanju. Za nekatere materiale, kot so na primer nerjavna in ognjeodporna jekla avstenitnega tipa, nekatera ventilska jekla in nekatere specialne zlitine, je postopek že v celoti osvojen in preizkušen, mnogo pa je takih jekel, za katere je

— for all practically non workable materials of the mentioned dimension range. Of course this technology is particularly interesting for welding electrodes. This brings forth considerable savings in material, work and energy making it possible to minimize the production costs and to reach almost 100 % yield.

— for all materials suitable for cold or hot drawing. For some materials of this group like austenitic stainless steels, heat resisting steels, some valve steels and special alloys the technology has been fully developed. However, the techology for numerous steel grades remain to be developed. The growing interest for this task is noted.

7. CONCLUSIONS

Technological process of continuous casting of steels and alloys in the shape of wire and rod brings forth significant quality and economic benefits as compared to conventional technology. Reduction in specific energy consumption is of great importance particularly in the field of heating and intermediate reheating in hot working.

The energy saving increases with reducing section size of the finished products.

In the field of expensive and hardly workable materials increase in yield is of particular importance. Con-

treba tehnologijo še raziskati in optimirati, interes za take rešitve pa je vse večji.

7. ZAKLJUČKI

Tehnološki postopek neprekinjenega litja jekel in zlitin v obliki palic in žice prinaša pomembne kakovostne in ekonomske prednosti v primerjavi s klasičnimi tehnološkimi postopki. Ekonomika specifične porabe energije ima velik pomen, posebno v območju ogrevanja in dogrevanja pri procesih vroče predelave. Ta ekonomika se izboljšuje z zmanjševanjem preseka gotovih izdelkov.

Pri asortimentu razmeroma dragih in težko predelavnih materialov je še posebno pomembna vloga izboljševanja izkoristkov materiala, ki že pri uvedbi klasičnega neprekinjenega litja gredic prinese 10—20 % v primerjavi s klasičnim postopkom litja v ingote, zaradi rezanja glav in nog ingotov. Velik je tudi vpliv, ki ga prinaša zmanjševanje investicijskih stroškov na področjih litja in predelave. V odvisnosti od vrste materialov ocenjujemo z novo tehnologijo možne prihranke materialov z boljšimi izkoristki 5—30 %, odvisno od sposobnosti materiala za plastično preoblikovanje v vročem. Tudi izgube s škajanjem so v primerih nove tehnologije znatno manjše.

S fizikalno-metalurškega gledišča ima jeklo, izdelano s postopkom neprekinjenega litja drobnih presekov, bistvene kakovostne prednosti, ki so povezane s hitrejšim strjevanjem.

ventional continuous casting results in 10—20 % increase in yield in comparison to ingot casting already. Highly important is a reduction in investment costs for casting and working also. Depending on hot workability of the material possible material savings through increased yield resulting from the new technology can be estimated as 5—30 %. Scale losses are also reduced as compared to the conventional technology.

From physico-metallurgical viewpoint the steel produced by horizontal continuous casting of small section size has essential quality advantages associated with increased rate of solidification.

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