Kaj prinaša nova tehnologija streljanja dodajnih materialov v jeklarsko prakso

Advance Technology in Steelmaking — Injection of Additions

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Opisana je nova metoda dodajanja različnih materialov v tekoče jeklo s streljanjem polne ali polnjene žice. Tehnika streljanja direktno v talino ima vrsto prednosti v primerjavi s klasičnimi načini, celo v primerjavi s tehniko vpihovanja materialov v talino. Predstavljena je metoda streljanja — žice v cilju izvajanja kontrolirane desoksidacije taline v ponvi in zagotavljanja ciljane vsebnosti aluminija, kar je danes osnovni pogoj za uspešno izvajanje ponovčne metalurgije.

Modern method of adding different materials by wire injection into molten steel is described. The method has numerous advantages over classic method of addition as well as over the pneumatic injection of powdered materials. The wire injection method for controlled deoxidation in ladle and attainment of prescribed final Al content of steel which is the main condition for successfull secondary metallurgy operations is described.

UVOD

Sodobna metoda streljanja ali injektiranja polne ali polnjene žice oziroma profila je našla široko področje aplikacij: **od tehnike dezoksidacije, legiranja, razžveplanja in nažveplanja do specialnih tehnik mikrolegiranja s B, Ti, Zr in dr.**

Njene osnovne prednosti v primerjavi s klasičnimi metodami so:

— visoka prilagodljivost različnim industrijskim napravam z neodvisnim spreminjanjem premera žice in hitrosti dodajanja,

— zelo zanesljiv način dodatka in visok izkoristek elementov,

— širok spekter dodajnih elementov in spojin,

— enostavna in relativno poceni naprava za dodajanje,

— idealna enota za avtomatizacijo procesov.

Čeprav smo na Metalurškem inštitutu v Ljubljani pričeli akcijo uvajanja te sodobne metode v naše jeklarne že leta 1980, večjega uspeha nismo imeli, predvsem zaradi togosti in ustaljenih navad, katere je zelo težko spremeniti.

Prvi prototip polindustrijske naprave, ki je bila izdelana v Železarni Ravne v letu 1983, je dal vzpodbudne rezultate na področju streljanja Al-žice v talino[1]. Zaradi težav z avtomatiko v industrijskih pogojih so ustavili nadaljevanje začetih poizkusov. Čeprav je bilo še nekaj akcij, da se začeto raziskovalno delo nadaljuje, večjih uspehov ni bilo.

INTRODUCTION

The modern wire or cored wire additions method has been widely applied for deoxidation, alloying, desulphurization or sulphur alloying, special microalloying with B, Ti, Zr, etc. Main advantages of the method as compared to classic methods are:

— high adaptability to different industrial devices with independent changes of wire diameter and feeding rate,

— high reliability and recovery of addition,

— wide spectra of added materials and compounds,

— simple and comparatively cheap device,

— ideal unit for process control and automation.

Although the work on introduction of the method into our steelworks started on Metallurgical Institute in 1980 there was no significant success mainly because of the well-known inertia of conservative-minded steelmakers. First prototype made on semiindustrial scale in Steelworks Ravne in 1983 showed encouraging results in the field of Al-wire addition.[1]. The tests were stoped due to difficulties met during development of an automated industrial device. There were some initiatives to continue with the work however, no significant success has been achieved.

Only at the end of 1986 first industrial tests on calcium wire additions started in Ironworks Jesenice. At last the wire addition method has arouse enough interest in our steelworks so the tests with commercial devices have finally started.

1. DEVELOPMENT OF INJECTION TECHNIQUES FOR ADDITIONS INTO MOLTEN STEEL

Modern steelmaking technology is based on combined use of a number of processes which makes it possible to reach optimum results and a high production

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Šele konec 1986. leta je prišlo v železarni Jesenice do prvih industrijskih poskusov streljanja Ca-žice v talino. Kot kaže, je metoda streljanja žice dokončno postala zanimiva tudi za naše jeklarne, ker trenutno potekajo poizkusi v vseh slovenskih železarnah s komercialno izdelanimi napravami.

1. RAZVOJ TEHNOLOGIJE STRELJANJA DODAJNIH MATERIALOV V TEKOČE JEKLO

Sodobna jeklarska tehnologija sloni na kombinaciji več postopkov, kar omogoča optimalno delo in visoko fleksibilnost proizvodnje.

Klasični postopki izdelave jekla v enem talilniškem agregatu so v razvitih državah večinoma že zgodovina.

Novi kombinirani postopki, kot je tehnološka linija:

EOP + VAD + CC ali IC*

oziroma

EOP + AOD + CC ali IC

so narekovali tudi delno zamenjavo konvencionalnih načinov dodajanja materialov, kot so: **manjši dodatki legur, dodatki dezoksidantov, posebni dodatki FeB, FeP, FeS itd, ki se pri standardni praksi dodajajo v talino ali curek ob prebodu.**

Zaradi vse večjih zahtev po večji točnosti zadevanja kemične analize in ožjih toleranc v predpisnih mejah, zlasti kar se tiče posebnih elementov, kot so: Ca, Ti, B, S, Al, N itd., so postale klasične metode dodatkov nezanesljive in neekonomične. Prišlo je do razvoja novih metod dodatka omenjenih materialov v talino, katere lahko razvrstimo v dve veliki skupini:

— vpihovanje drobnozrnatih materialov v talino,

— streljanje polnjene žice ali profilov direktno v talino (SPŽ — metoda)**.

Obe skupini postopkov sta našli hitro uporabo v jeklarski tehnologiji in tudi vsaka od omenjenih metod ima svoje pozitivne in negativne lastnosti. Za SPŽ — metodo kaže, da ima nekaj več prednosti in zato pridobiva številne zagovornike predvsem zaradi enostavnejše in cenejše aparaturne tehnike in nekaterih drugih ugodnosti, o katerih bo govor v naslednjih poglavjih.

2. OSNOVNE ZNAČILNOSTI METODE DIREKTNEGA STRELJAJA ŽICE V TEKOČE JEKLO

Naprave za direktno streljanje žice v tekoče jeklo sestojijo v glavnem iz dveh delov:

— gonilni mehanizem z več valjčnicami in enosmernim ali izmeničnim regulacijskim motorjem ter elektronsko regulacijo,

— odvijalna naprava, ki ima več variant — boben ali prosto odvijanje žice.

Na **sliki 1** vidimo tipično izvedbo postavitve naprave v bližini livne jame, s katero se izvaja obdelava taline s SPŽ-napravo.

Sodobne naprave za streljanje žice imajo poleg standardne opreme, tj. elektronske nastavitve hitrosti poda-

* EOP = električna obločna peč,
VAD = vakuumsko-obločno razogljičenje z možnostjo dogrevanja taline,
AOD = argonsko kisikovo razogljičenje,
CC = kontilitje jekla,
IC = litje jekla v ingote.

** S(P)Ž = streljanje (polnjene) žice ali profilov v talino (predlog)

flexibility. Classic steelmaking in single metallurgical furnace in developed countries mainly belong to the history. New combined process such as the technological lines

*EAF + VAD + CC or IC**

EAF + AOD + CC or IC

required also a partial change in the addition method in ***low alloying, deoxidation, special additions of FeB, FeP, FeS, etc. which were usually carried out at tapping.***

Due to ever increasing demands for higher reliability of achieving prescribed specifications and continuously closing tolerances especially for Ca, Ti, B, S, Al and N the standard method of additions into the stream or ladle became unsuccessfull and unreliable. Newly developed addition methods can be divided into the two groups:

— pneumatic injection of powdered material into the melt

*— direct feeding of wire or cored wire into the melt (SPŽ)**.*

Both the groups have soon find wide application in steelmaking. Each of the methods mentioned has its own advantages and shortcomings. SPŽ method seems to appear more convincing mainly because of a simple and cheap operation technique and certain other advantages yet to be mentioned.

2. *MAIN CHARACTERISTICS OF WIRE INJECTION METHOD*

Devices for direct wire injection into molten steel are mainly composed of the two parts:

— driving mechanism with a number of rollers and DC or AC electromotor with electronic control and

— despooling device of drum type.

A typical installation used for SPŽ injection is seen on ***fig. 1****. Modern units for wire injection beside electronic control of feeding rate (0—400 m/min) make it possible to preset the required length of wire, to control the wire end and internal temperature of device.*

Device operation is very simple and well adapted to the work conditions in smelting shop. The spool brake is flipped off (modern devices are equiped with remote controls) and unwind sufficient length of wire to reach driving mechanism. The roller adjustment in the beginning is set in dependence on wire diameter and the depth of melt in ladle. During the operation it automatically changes to fit eventual minor changes in wire or profile diameter.

All necessary preparation take only few minutes which ***is very helpful for convincing workers to accept the new technique as a routine method.***

Recently advanced devices with two or thee strand mechanism (ODERMATH STAHLWERSTECHNIK Gmbh) which enable simultaneous injection of two different materials (e. g. Al wire and Ca-Si wire). Special devices can be made on byuers request to suit the user requirements, of course.

* *EAF — Electric Arc Furnace*
VAD — Vacuum Arc Decarburisation (with additional heating)
AOD — Argon Oxygen Decarburisation
CC — Continuous Casting
IC — Ingot Casting

** *SPŽ — Shooting of wire or cored wire into melt (proposition).*

janja žice (0—400 m/min) tudi možnost nastavitve željene dolžine, kontrole konca žice po končani obdelavi, nadzor notranje temperature v napravi itd.

Posluževanje naprave je zelo enostavno in prilagojeno pogojem dela v topilnici:

Na odvijalnem bobnu sprostimo zavoro (novejše izvedbe npr. nudijo možnost delovanja zavore s komandnega pulta) in s koluta odvijemo zadostno količino žice, da premostimo razdaljo med odvijalnim bobnom in pogonskim delom naprave. Nastavitev valjev je pogojena s premerom žice in globino taline v ponovci, ki se potem avtomatsko prilagaja eventualnim manjšim spremembam profila žice.

Pripravo naprave za streljanje žice izvedemo v nekaj minutah, kar je zelo pomembno za **pripravljenost ljudi, da uporabljajo tovrstne naprave kot rutinske metode**.

V zadnjem času se razvijajo tudi naprave z dvo- in večžilnim krmilnim mehanizmom (ODERMATH STAHLWERKSTECHNIK Gmbh), ki omogočajo istočasno dodajanje dveh različnih materialov (npr. Al-žice in CaSi-žice). Možne so seveda tudi posebne izvedbe, ki se prilagajajo zahtevam kupcev.

3. SPLOŠNO O MATERIALIH ZA STRELJANJE V TEKOČE JEKLO

Prvotna ideja o streljanju dodajnih materialov v tekoče jeklo se je porodila iz naravnih omejitev, da imajo številni materiali, katere želimo dodati v talino, neprimerne fizikalne lastnosti za pogoje jeklarskih temperatur:

— gostota materiala je ponavadi znatno nižja od jekla,

— velika reaktivnost s kisikom in žveplom v talini in žlindri,

— visok parni tlak in zato dokaj slab izkoristek dodanega elementa,

— cena tovrstnih materialov je zelo visoka in vezana na uvoz,

— skladiščenje in manipuliranje ni enostavno in zahteva posebno skrb.

Kasneje je na razvoj vplivala tudi potreba po avtomatizaciji procesov in izboljšanju delovnih pogojev v jeklarnah. Vse skupaj pa je vplivalo na večjo zanesljivost zadevanja ciljanih načrtovanih želenih vrednosti, kot je končna vsebnost Al, uspešnost mikrolegiranja z B, S, Ti, V, uspešnost modifikacije nekovinskih vključkov in dr.

4. DODAJANJE Al-ŽICE V TEKOČE JEKLO (dezoksidacija + legiranje)

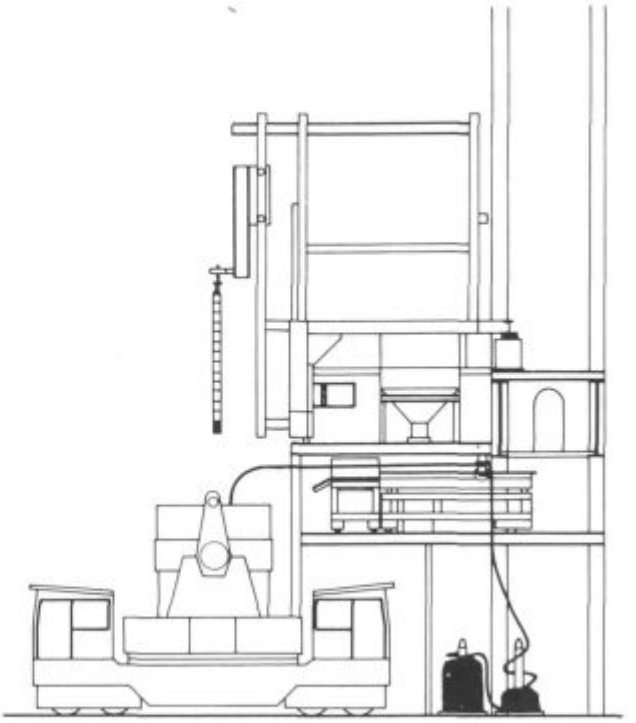
Osnovni cilj uporabe metode streljanja ali injektiranja aluminijeve žice je transport Al na čim večjo globino v tekoče jeklo, in sicer preden se začne njegova reakcija s kisikom v talini. S tem smo dosegli ključni pogoj, da tekoči Al reagira s kisikom v talini, pri čemer ferostatični tlak in mešanje taline s argonom skrbita, da reakcija poteka v celoti do meje topnosti.

Za doseg teh idealnih pogojev moramo zagotoviti nekaj pogojev:

— hitrost podajanja žice mora biti prilagojena debelini žice in globini taline v jeklarski ponovci,

— ob dodatku Al v talino moramo zagotoviti zadostno mešanje taline s plinskimi mediji, ker na ta način povečujemo homogenost taline in omogočimo lažjo porazdelitev dodanega aluminija.

Raziskave hitrega dodajanja Al-žice v tekoče jeklo so pokazale, da se Al-žica, npr. Ø12 mm, prvih 50—100 ns prevleče z jeklenim plaščem, nato se v naslednjem ča-



Slika 1
Postavitev naprave za streljanje žice v bližini livne jame

Fig. 1
Typical installment of wire injection unit in the vicinity of casting pit

3. MATERIALS FOR INJECTION INTO MOLTEN STEEL

The new injection methods have been developed due to the fact that physical properties of numerous materials used for addition are not suitable for the classic addition method:

— density is usually considerably lower than that of steel,

— high affinity to oxygen and sulphur in steel and slag

— high partial vapor pressure which means low yield of added element,

— materials are imported and prices are usually quit high and

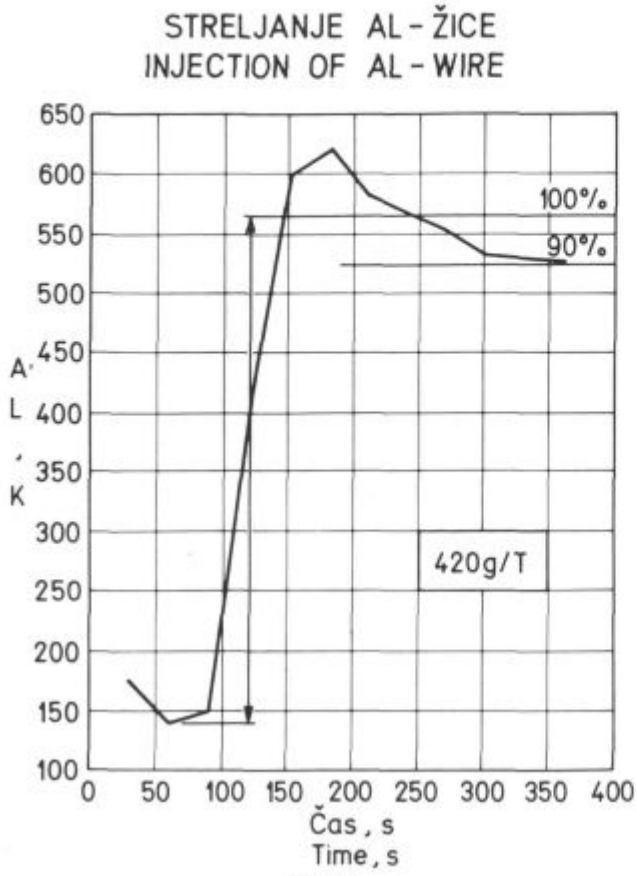
— storing and manipulation is not simple and require special care.

Later on the trend for process automation and improvement of working conditions have also contributed to the overall drive for change.

The general results obtained are mainly a higher reliability of achieving prescribed specifications such as final Al content, successful microalloying with B, S, Ti, V and modification of non-metallic inclusions, etc.

4. INJECTION OF Al WIRE (Deoxidation + alloying)

The main aim of Al wire injection is to transport Al to the higher possible depth of melt as quickly as possible to prevent it from reacting with oxygen in melt. This is of decisive influence to obtain the reaction of molten Al with oxygen dissolved in steel which supported by ferrostatic pressure and argon mixing proceeds completely i. e. to the solubility limit. This ideal result can be obtained by satisfying the following conditions:



Sljka 2
Izvajanje dezoksidacije v 190-tonski ponovci s streljanjem Al-žice v količini okoli 420 g/t

Fig. 2
Deoxidation of a 190 ton heat by 420 g/t Al-wir injection

sovnem obdobju 100—800 ns Al topi, pri čemer je debelina jeklenega plašča še vedno debela okrog 2 mm. Šele nato se začne taljenje jeklenega plašča in burna reakcija Al z kisikom[3].

Na **sliki 2** vidimo profil naraščanja Al v talini pri streljanju 420 g Al/t v 190—tonsko ponovco.

Ob uporabi kisikove sonde za točno ugotovitev vsebnosti kisika v talini pred pričetkom streljanja Al lahko dosežemo točnost zadevanja Al:

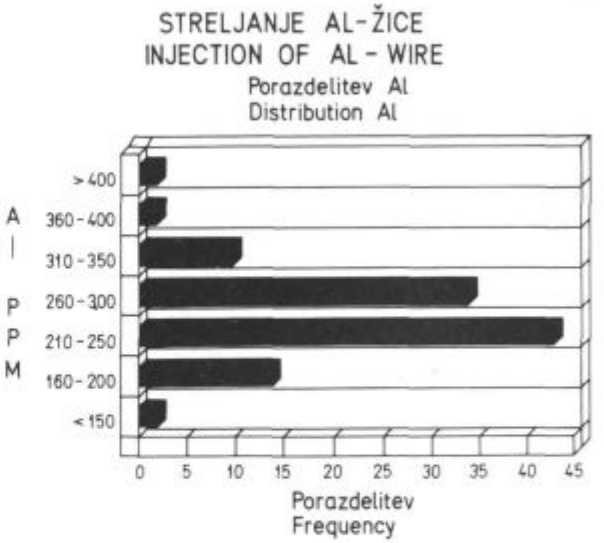
$$0.05 \pm 0.009\ \%\ Al_k,$$

kar je odvisno tudi od vsebnosti oksidov, zlasti (FeO+MnO) v žlindri, in vsebnosti kisika v talini pred streljanjem aluminija. Tipična porazdelitev Al pri izdelavi večjega števila šarž s metodo streljanja Al-žice kaže **slika 3**.

5. ZAKLJUČKI

V članku smo predstavili sodobno metodo, tako imenovano »streljanje« ali »injektiranje« polne ali polnjene žice v tekoče jeklo (SPŽ — metoda). Opisana metoda se uporablja v sodobnih jeklarnah več kot 10 let in je danes nenadomestljiva tehnika za izvajanje kontrolirane dezoksidacije in modifikacije oksidnih nekovinskih vključkov v ponovci pred litjem ali celo v medponovci pri kontolitju jekla. V zadnjih letih se uspešno uporablja tudi za mikrolegiranje jekel, kot so dodatki Ti, B, V, C, N in dr.

Naprave za avtomatsko dodajanje polne ali polnjene žice so danes komercialne izvedbe in ločimo dva tipa:



Slika 3
Porazdelitev aluminijev talini pri uporabi streljanja žice v talino

Fig. 3
Al distribution obtained by Al wire injection method

— appropriate feeding rate must be used depending on wire diameter and the depth of melt,

— sufficient argon flow for efficient mixing must be applied during wire injection in order to ensure the homogenity and easier distribution of added aluminium.

Investigation of aluminium wire injection at high feeding rate revelaed that Al wire of 12 mm diameter is covered with solidified steel during first 50—100 ns. Aluminium melts during the next 100—800 ns period, however the thickness of solidified steel layer is about 2 mm.[3]

Only afterwards steel layer starts to melt and vigorous reaction of Al and oxygen dissolved in steel takes place.

Increase in Al content of 190 ton steel melt during 420 g/t Al wire injection can be seen in ***fig. 2****.*

By the use of an oxygen probe for the measurement of active oxygen in steel immediately befor the injection it is possible to attain the accuracy of final Al content:

$$0.05 \pm 0.009\ \%\ Al_k$$

which depends also on the content of oxides especially (FeO+MnO) in slag and the oxygen content of steel before the injection. Typical Al distribution obtained by Al wire injection in a high number of heats can be seen in ***fig. 3****.*

5. CONCLUSIONS

Modern (SPŽ-method) method of Al-wire or cored wire injection into molten steel is described. The method has been used in steelworks for more than 10 years. To day it is the standard method for controlled deoxidation and modification of non-metallic inclusions in carried out in ladle before casting or even in tundish before continuous casting. Recently it has been successfully used for microalloying of steel with Ti, B, V, C, N etc also.

Commercial injection devices for addition of common or cored wire can be divided into the two groups: ***a) Devices with driven drum which serves as a spool for wire and b) devices with free unwinding of wire from the spool interior.***

a) **naprave s pogonom odvijalnega bobna, na katerem je navita žica in b) naprave s prostim odvijanjem žice iz notranjosti koluta.**

Dosedanje praktične izkušnje z metodo SPŽ so pokazale, da pri kombinaciji s kisikovo sondo, ki določi vsebnost aktivnega kisika, pred dodatkom žice dosežemo učinkovito in reproduktivno dezoksidacijo taline.

Točnost zadevanja Al je izredno visoka in znaša standardna napaka na nivoju Al = 0.05 ± 0.009 %. SPŽ — metoda je pokazala izredne rezultate tudi pri modifikaciji nekovinskih vključkov s streljanjem žice, polnjene s Ca-zlitinami, zlasti če predhodno uspešno izvedena dezoksidacija taline in vsebnost žvepla v talini ne presega 100 PPM.

Operational experience obtained with the injection method has shown that combined with the use of oxygen probe which determines the active oxygen content of steel before the Al wire injection the efficient and reproducible deoxidation of steel can be achieved.

The accuracy of attaining prescribed final Al content is very high. The standard error at the level of Al = 0.05 ± 0.009 %. SPŽ method has shown extraordinary results in modification of nonmetallic inclusions also by the injection of Ca alloy cored-wire especially in cases where previous deoxidation and desulfuration depressed the sulfur content under 100 ppm level.

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