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Izdelava jekla 3Cr-3W s precizijskim litjem

Production of 3Cr-3W Steel by Investment Casting

Izvleček

V prispevku je prikazana izdelava jekla 3CrW z litjem. Jeklo je bilo legirano s Co in Ta. Preiskovali smo vpliv toplotne obdelave na mikrostrukturo in trdoto vzorcev. Ugotovili smo, da je toplotna obdelava pri različnih temperaturah spreminjala mikrostrukturo in trdoto materiala.

Abstract

In this study, 3CrW steel was produced by casting. 3CrW steel alloyed with Co and Ta. The effect of heat treatment on microstructure and hardness of samples was examined. It was observed that the heat treatments performed at different temperatures change the microstructure and hardness of the materials.

1 Uvod

Rafinerije nafte uporabljajo krom-molibdenova jekla pri procesih kemične industrije in v elektrarnah. Ta jekla imajo majhen razteznostni koeficient in so namenjena obratovanju, kjer je potrebna velika odpornost proti lezenju ter koroziji pri visokih temperaturah in tlakih. Lastnosti teh jekel nadzorujejo veliki dodatki karbidotvornih elementov, kot so Cr, Mo, W, V, Ti, in Nb. Kot pri vseh kovinskih materialih tudi pri jeklih Co-Mo prihaja do slabšanja mehanskih lastnosti, kadar so izpostavljena napetostim pri dolgotrajnem obratovanju pri visokih temperaturah. Glavni vzrok za poslabšanje lastnosti teh jekel pri visokotemperaturni uporabi je povezana z deformacijami zaradi lezenja (Fu in sodel., 2007, Fu in sodel., 2009, Sawada in sodel. 2009).

1 Introduction

Petroleum refineries utilize chromium-molybdenum (Cr-Mo) alloy steel in the manufacturing of chemical industry and power plants. These steels having low thermal expansion coefficient are designed for a higher creep and corrosion resistance to operate at high temperatures and pressure. The properties of these steels are controlled with the addition of powerful carbide forming elements such as Cr, Mo, W, V, Ti, and Nb. As is in all metallic materials, Cr-Mo steels display degradation for its mechanical properties by being exposed to stress under long term service temperature. The main reason for the degradation in the properties of these steels in high temperature applications is related with the creep deformation.(Fu et al., 2007, Fu et al., 2009, Sawada et al., 2009)

Za visokotemperaturno obratovanje elektrarn so potrebna jekla, ki so zelo učinkovita pri teh temperaturah, njihovi stroški izdelave so majhni in imajo dobre mehanske lastnosti, ker morajo obratovati pri visokih temperaturah ter velikih tlakih vodne pare. Te zahteve izpolnjujejo feritna jekla. Obratovanje pri višjih zahtevah je možno s povečanjem debeline sten. Vendar pa je možno obratovanje pri veliki učinkovitosti tudi pri manjši debelini sten, ker to omogoča legiranje in toplotna obdelava materialov. V zadnjem času je bilo objavljeno manjše število raziskav s Cr-W jekli, pri katerih se da doseči zelo dobre mehanske lastnosti. V literaturi so objavljene številne raziskave Cr-Mo jekel v razvoju (Abe in sodel., 1988, Bendick in sodel., 2007, Fu in sodel., 2009).

2 Eksperimentalno delo

Sestavo jekla, ki smo ga uporabili pri poskusih in je bilo izdelano s precizijskim litjem v keramične modele, prikazuje razpredelnica 1. Uliti vzorci so imeli približne dimenzije 270 mm x 25 mm x 15 mm. S svetlobno mikroskopijo in SEM smo preiskali ulite in toplotno obdelane vzorce ter izmerili njihovo trdoto. Vsi vzorci so bili avstenitno žarjeni 6 ur pri 1200 ºC in toplotno obdelani pri različnih časih ter temperaturah 1100 ºC, 710 ºC in 660 ºC.

V naši preiskavi smo lito jeklo 3CrW različno toplotno obdelali in ugotavljali učinek teh toplotnih obdelav z merjenjem

For the power plants operating at high temperature, the production of the steel operating with high efficiency at these temperatures, having low cost and exhibiting good mechanical properties is required. Low cost and high efficiency is possible to operate under high steam pressures and at high temperatures. These conditions have made the production of ferritic steels to operate under such requirements an obligation. Operating under higher conditions is possible with higher wall thickness. However, it is also possible to operate with high efficiency at low wall thickness thanks to the materials developed with alloying and heat treatments. That is why there are a limited number of researches on CrW steels being recently produced and having potential to exhibit high mechanical properties and, even though there are numerous studies in the literature on CrMo steels starting to be developed (Abe et al., 1988, Bendick et al., 2007, Fu et al., 2009).

2 Experimental Studies

The steel from the compound used in the experiment and stated in Table 1 was produced by using investment casting method in ceramic mould after its compound was set. The cast samples are approximately in dimensions of 270 mm x 25 mm x 15 mm. The optical microscope and SEM examinations of cast and heat treated samples were performed and their hardness measurements were taken. After all the materials were austenitized for 6 h at

Razpredelnica 1: Kemična sestava jekla, izdelanega s precizijskim litjem, v mas. %

Table 1: The Chemical composition of produced steel by investment casting (mass fraction, %)

C	Cr	W	V	Si	Mn	Co	P	S
0,023	2,916	3,504	0,191	0,049	0,194	3,182	0,014	0,009

trdote ter preiskavo mikrostrukture. Polirane obruse smo 30 s jedkali z jedkalom Viella.

3 Simulacije

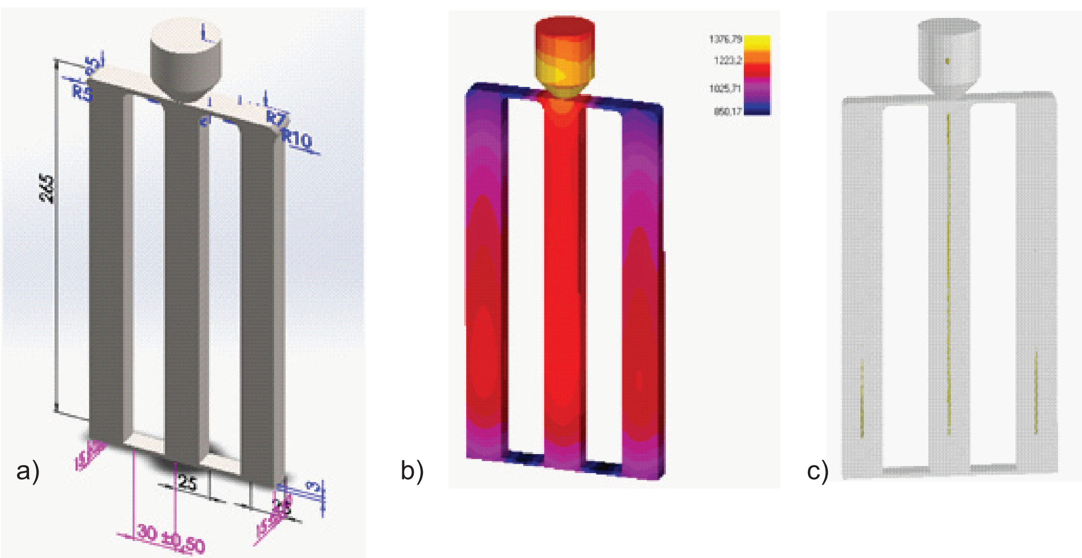
Narejena je bila simulacija litja na osnovi kemične sestave in dimenzij, opisanih v eksperimentalnem delu. 3D-risbo ulitega sestavnega dela smo pripravili s programsko opremo SolidWorks glede na dimenzije in konstrukcijo (slika 1a). Risbe so bile shranjene v STL-formatu, potem pa smo s programom SolidCast izdelali temperaturno porazdelitev in analizirali mikroporoznost. Sliko temperaturne porazdelitve ulite komponente prikazuje slika 1b. Kot se vidi na sliki 1b, se tanki prerezi med komponentami strdijo v kratkem času, kar lahko pripelje do napak predvsem v stranskih komponentah. Mikroporoznost ulitih delov, analizirana po kriteriju FCC

1200 °C, heat treatments were performed in different duration and temperatures as 1100 °C, 710 °C, and 660 °C'.

In this study, different heat treatments were performed on the 3CrW steel produced by using casting method and the effects of these heat treatments on hardness and microstructure were examined. The polished materials were etched by using Viella etching agent for 30 seconds.

3 Simulation Studies

The casting simulation was carried out for casting process that was performed in chemical composition and dimensions given in Experimental Procedure section. The component drawing was drawn on SolidWorks software as 3-D according to this dimensions and design (Figure 1a). Drawn components were saved as STL



Slika 1: a) 3D posnetek vzorca iz jekla 3Cr3W, b) analiza porazdelitve temperature med litjem, c) mikroporoznost ulitih delov, narejena po kriteriju FCC (FranCi Chiesa)

Figure 1: a) 3D figure of 3Cr3W steel b) temperature analyze during casting and c) The microporosity of cast parts, which was made according to FCC (FranCo Chiesa) criterion

(FranCo Chiesa) [Chiesa in Mammen], je prikazana na sliki 1c. Kot se vidi na tej sliki, je zelo majhna nevarnost nastanka mikroporoznosti v srednji komponenti, ker se le-ta strdi zadnja. Stranski komponenti se strdita prej.

4 Rezultati in razprava

Na osnovi faznih diagramov in CCT-krivulj iz literature smo pričakovali, da bo osnova iz feritne ali bainitne mikrostrukture. Slika 1a prikazuje lito mikrostrukturo ulitega materiala. Iz posnetkov svetlobne mikroskopije se vidi, da je lita mikrostruktura po litju nehomogena. Velika verjetnost je, da bo osnova imela feritno in bainitno mikrostrukturo, ker je bila talina ulita v keramično formo in je bilo zato njeno strjevanje počasnejše.

Ugotovili smo, da je postala prvotna nehomogena mikrostruktura po toplotni obdelavi bolj homogena in iz drobnejših zrn (slika 2 a-f). Pri ohlajanju na zraku s temperature avstenitnega žarjenja se je pričakovalo, da bo bainitna mikrostruktura odvisna od ohlajevalne hitrosti. Kot kažejo mikroposnetki, je bila mikrostruktura v glavnem sestavljena iz večjih bainitnih območij, čeprav ni bila 100 % bainitna. Pričakovalo se je, da bodo toplotne obdelave najprej zmanjšale, nato pa povečale delež bainita (Chen in sodel., 2004). Vidi se, da so mikrostrukture iz večjih zrn, čeprav imajo nekatere tudi drobnejša zrna. Drobnozrnate mikrostrukture smo zasledili v normaliziranih jeklih. Vendar pa so se velika zrna pojavila pri toplotnih obdelavah po normalizacijskem žarjenju. Vidi se, da so bila zrna bolj groba pri toplotni obdelavi pri 710 ºC v primerjavi s popuščanjem pri 660 ºC. Trdota po Brinellu se je merila po litju in po toplotni obdelavi. Vpliv toplotnih obdelav na trdoto jasno kaže slika 4. Vidi se, da se je trdota na zraku ohlajenih vzorcev

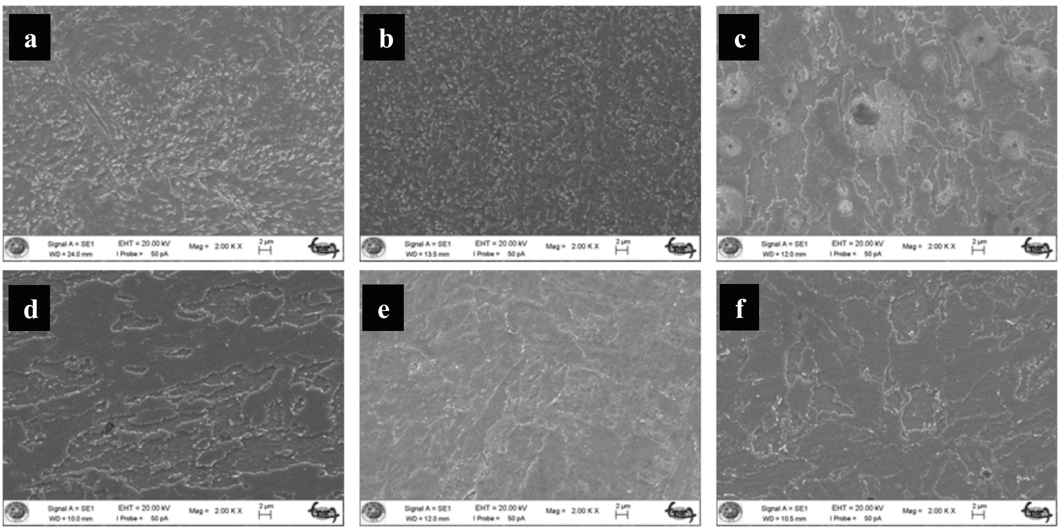
format and then temperature distribution and microporosity analysis was performed on SolidCast programme. The image of temperature distribution of cast component is shown in Figure 1 b. As seen in Figure 1b, thin connection sections between components solidify in a short time, which can cause to occur a failure especially in side components. The microporosity of cast parts, which was made according to FCC (FranCo Chiesa) criterion [Chiesa and Mammen] is given in Figure 1 c . As seen in Figure 1 c, because of the later solidification of the middle component than side components, there is very little risk of microporosity in middle component.

4 Experimental Results and Discussion

It is expected that the matrix is in the ferritic or bainitic structure as a result of examination of the phase diagrams and CCT curves upon the literature review as per the compound. Figure 1a illustrates the casting microstructure of the cast material. It can be understood that the casting structure had a non-homogenous microstructure from the optical microscope images taken after casting. There was a higher possibility that the matrix phase in the casting structure had a ferrite and bainite structure as a result of the fact that the casting was made into a ceramic mould and consequently the cooling rate was slower.

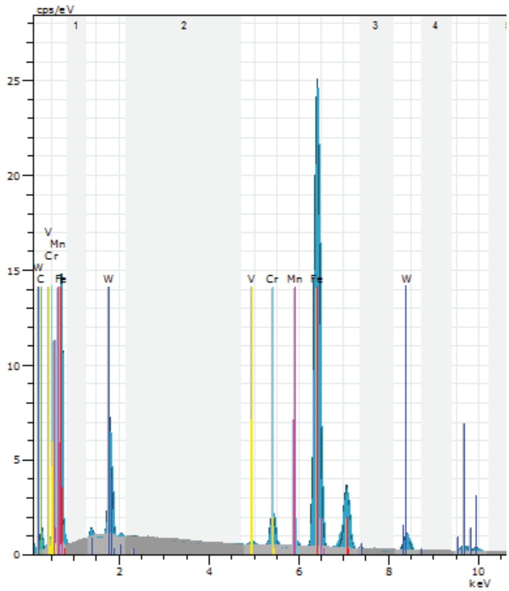
It was observed that after the heat treatments, the non-homogeneous casting microstructure became more homogeneous and had finer particles (Figure 2 a-f). In the air cooling processes carried out from austenite temperatures, bainitic microstructure is expected depending on cooling rate. As seen in the following microstructures, despite the fact that microstructures are not 100%, po avstenitizaciji (pri 1200 °C in 1100 °C) zmanjšala po popuščanju (pri 710 °C in 660 °C). Dejstvo, da je bila trdota po popuščanju pri 710 °C manjša kot pri popuščanju pri 660 °C, je bilo pričakovano. Znano je, da višje temperature popuščanja zmanjšujejo trdoto in povečujejo žilavost. Trdota po avstenitizacijski toplotni obdelavi je bila tudi višja kot po drugih toplotnih obdelavah. Različne izmerjene trdote so povezane z deležem bainitnih območij v mikrostrukturi materiala. Povečanje bainitnih območij vpliva na trdoto. EDS-analize smo naredili na vzorcu, ki je bil 6 ur homogeniziran pri 1200 °C in 1 uro normaliziran pri 1100 °C, potem pa 4 ure popuščan pri 710 °C.

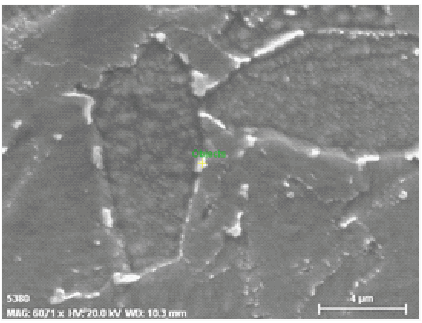
they were mostly comprised of a majority of bainite clusters. It is expected that the heat treatments will decrease and then increase the amount of bainite.(Chen et al., 2004) As is seen from the microstructures, while some microstructures had finer grains, some had larger grains. Fine grained bainitic structures were observed in the normalized steels. However, coarser bainite grains took place of finer bainite grains in the heat treatments after the normalization. It can be seen that the grains were coarser in the tempering process made at 710 °C compared to the tempering process made at 660 °C. Brinell hardness of the materials was taken after the casting structure and



Slika 2: SEM-mikroposnetki jekel a) lita mikrostruktura, b) homogenizirano 6 ur pri 1200 °C, nato popuščano 4 ure pri 660 °C, c) homogenizirano 6 ur pri 1200 °C, nato popuščano 4 ure pri 710 °C, d) homogenizirano 6 ur pri 1200 °C, nato normalizirano 1 uro pri 1100 °C, e) homogenizirano 6 ur pri 1200 °C, nato normalizirano 1 uro pri 1100 oC in popuščano 4 ure pri 660 °C, f) homogenizirano 6 ur pri 1200 °C, nato normalizirano 1 uro pri 1100 oC in popuščano 4 ure pri 710 °C

Figure 2: SEM microstructures of steels, a) Casting microstructure b) Homogenized at 1200 °C for 6 h and then tempering at 660 ° C for 4 h c) Homogenized at 1200 °C for 6 h and then tempering at 710 ° C for 4 h d) Homogenized at 1200 °C for 6 h and normalizing at 1100 °C for 1 h e) Homogenized at 1200 °C for 6 h and normalizing at 1100 °C for 1 h and then tempering at 660 ° C for 4 h f) Homogenized at 1200 °C for 6 h and normalizing at 1100 °C for 1 h and then tempering at 710 ° C for 4 h





Element	C norm.	C Atom.
	[m.f.,%]	[at.%]
Iron	77.43	82.62
Carbon	1.40	6.96
Tungsten	16.83	5.45
Chromium	3.47	3.97
Manganese	0.39	0.43
Vanadium	0.48	0.56
Total: 99.57	100.00	100.00

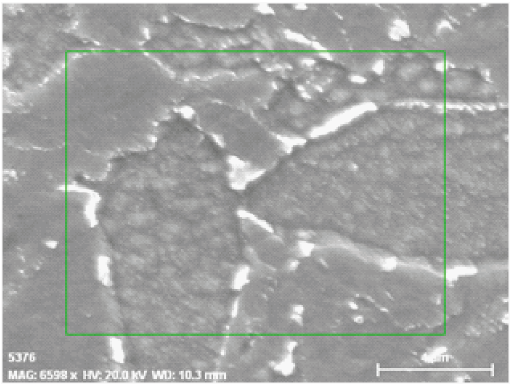
Slika 3: EDS-analiza delca v vzorcu, homogeniziranem 6 ur pri 1200 °C in normaliziranem 1 uro pri 1100 °C, nato popuščanem 4 ure pri 710 °C

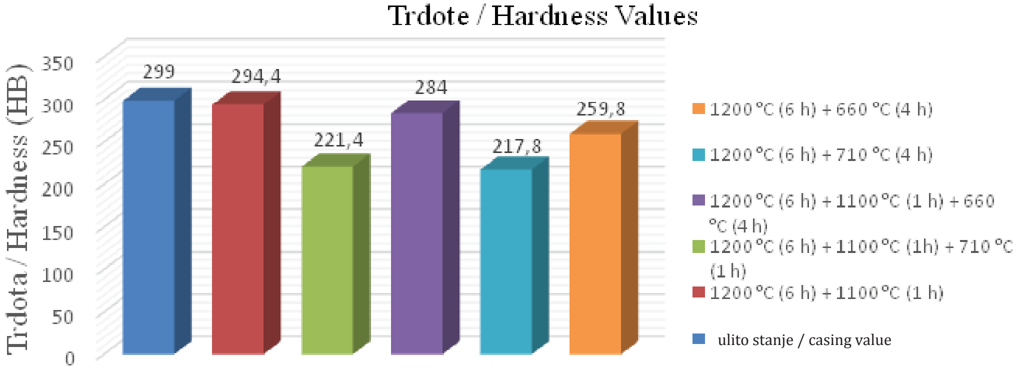
Figure 3: EDS result of a particle in the sample homogenized at 1200 °C for 6 h and normalized at 1100 °C for 1 h and then tempered at 710 ° C for 4 h

heat treatments. The effects of the heat treatments on the hardness can be seen clearly in Figure 4. It was observed that the hardness values obtained with air cooling after the austenitization (at 1200 °C and 1100 °C) decreased after the tempering (at 710 °C and 660 °C). The fact that the hardness value after the tempering process made at 710 °C is lower than the hardness value obtained following the tempering process made at 660 °C was an expected result. As it is known, high tempering temperature signifies low hardness and high toughness. The hardness value after the austenitizing heat treatment was also higher than the hardness value after the other heat treatments. Obtaining different hardness values can be related to the amount of bainite structure occurring in the structure of material. The increase in the bainitic structure affected the hardness EDS analysis was taken from the sample, which homogenized at 1200 °C for 6 h and normalized at 1100 °C for 1 h and then tempered at 710 ° C for 4 h. Also mapping analyses were performed in the same sample. As seen from the Figure 3 and 4, carbides, which were rich in Cr and Fe, were found in the sample homogenized at 1200 °C for 6 hours and normalized at 1100 °C for 1 hour and then tempered at 710 ° C for 4 hours.

5 Conclusion

As it can be understood from the microstructure images and hardness, the heat treatments performed at different temperatures change the microstructure and hardness of the material. Finer grains were obtained in the tempering process made at 660 °C for 4 hours compared to the tempering process made at 710 °C for





Slika 4: Trdote jekel

Figure 4: Hardness values of steels

5 Sklepi

Mikroposnetki in meritve trdot kažejo, da toplotne obdelave pri različnih temperaturah različno vplivajo na mikrostrukturo in trdoto materiala. 4-urno popuščanje pri 660 °C je dalo drobnejša zrna kot enako popuščanje pri 710 °C. Zato je bila trdota večja.

Iz mikroposnetkov se lahko sklepa, da ima material feritno-bainitno mikrostrukturo. Delež bainita se spreminja v odvisnosti od toplotne obdelave. Povečanje količine bainita povečuje trdoto. Trdota jekla z manjšimi bainitnimi območji je bila večja kot pri jeklih z bolj grobimi zrni.

4 hours, and consequently higher level of hardness was obtained.

It could be observed from the obtained microstructures that the material had a ferrite-bainite microstructure. The rate of bainite varied depending on the heat treatment. The fact that amount of bainite increased also increased the hardness. The hardness of the steel having finer bainite clusters was higher than the steel having coarse grains.

6 Zahvala

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AKTUALNO / ACTUAL

Koledar livarskih prireditev

Termin	Naziv dogodka	Kraj / država dogodka
03.-07.10.2016	Fond-Ex	Brno/Češka
25.-27.10.2016	Euromold	München/Nemčija
03.-04.11.2016	Metallurgie-Kolloquium 2016	Clausthal/Nemčija
01.-02.02.2017	9. VDI-Tagung „Giesstechnik im Motorenbau“	Magdeburg/Nemčija
16.-17.03.2017	Aachener Giesserei-Kolloquium	Aachen/Nemčija
27.-28.04.2017	61. Österreichische Giessereitagung	Gurten/Avstrija
17.-18.05.2017	Deutscher Giessereitag 2017	Düsseldorf/Nemčija