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STRENGTHENING OF A COLD WORKED 17% CHROMIUM FERRITIC STAINLESS STEEL BY HEAT TREATMENT

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Abstract

Slat-band chains are used as conveyors by the food industry, breweries and bottling plants. The operating conditions require abrasion resistance and strength which are at the limit of the capabilities of the current material of choice, cold worked type 430. In an unconventional way of strengthening this material, Mintek developed a process in which the cold worked material is aged between 450°C and 500°C. The present work aims to elucidate the strengthening mechanism, using type 430 stainless steel containing 16.42% Cr and 0.036% C, in the cold-rolled condition (38% reduction in area), with and without prior solution heat treatment.

The Cr-rich precipitate α" may form in the 450°C to 500°C range (due to the miscibility gap in the Fe-Cr system), resulting in the increased hardness and lowered ductility. Mössbauer studies confirmed that the α", at this composition and temperature, forms through the process of nucleation and growth. Hardening due to α" precipitation was only observed after aging for 64 hours or more, however. After increasing the dissolved interstitial content by solution heat treatments (in the vicinity of 900°C), increases in Vickers hardness of 30-50 kg/mm^2 could be obtained after only 8 minutes at 475°C. This hardness increase corresponds to an increase in tensile strength of more than 100 MPa. The increased hardness does not appear to be caused by strain aging, and presumably results from fine carbide or nitride precipitation. Solution treatment at 930°C also introduced some martensite (α') into the microstructure, which raised the hardness of the unaged cold worked material.

Overaging of the carbide and nitride precipitates was observed at 475°C, but not at 450°C, probably due to the lower diffusion rates at the lower temperature. No overaging of the α" precipitates occurred, for aging times up to 2072 hours.

Samples aged for selected periods of time at 475°C had low impact strengths – even well before the formation of α" – and revealed predominantly cleavage fracture with some ductile fracture areas, mostly at grain boundaries. Both impact strength and lateral expansion

indicated that embrittlement accompanies the increased hardness obtained by aging. Calculation of critical crack lengths from the impact data, however, revealed that a maximum flaw length of 0.8 mm, for specimens solution treated at 880°C, could be tolerated before catastrophic failure. Since it is not expected that flaws of that size would exist in the as-manufactured links, fatigue will probably determine the lifetime of the chains, although the lower K_{Ic} values indicate that less crack propagation will be tolerated before brittle fracture.

During the aging treatment, the strength may be lowered by recrystallisation of the cold-worked material. Transmission electron microscopy (TEM) revealed the start of recovery, but no recrystallisation. Some large precipitates (around 1 μm in diameter) were present. These were identified, through their diffraction patterns, as $M_{23}C_6$; these carbides were present in both aged and unaged material and hence represent precipitates which had not dissolved during the initial solution treatments. The α" precipitates – and the presumed newly formed nitride and carbide precipitates – were too fine for detection by TEM.

Potentiodynamic testing of the treated material in a 0.5M H_2SO_4 solution indicated that, although the probable hardening mechanisms imply localised Cr depletion of the matrix, the general corrosion resistance and passivation behaviour were not affected.

It is concluded that the strength of the chain may be increased markedly by short-term heat treatments at 475°C, with lowered toughness, but with no decrease in corrosion resistance. Martensite, work hardening, and precipitation of carbides and nitrides all contribute to the final strength, with α" formation only becoming significant after longer aging times.

Keywords

slat-band chain

Type 430 ferritic stainless steel

475°C embrittlement

carbide and nitride precipitation

cold work

martensite

strengthening through heat treatment

corrosion resistance

alpha (double) prime

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Opsomming

Vervoerbandkettings word veral in die voedselbedryf, brouerye en bottelarye gebruik. Die gebruikstoestande vereis slytasieweerstand, sterkte en korrosiebestandheid. Tipe 430 ferritiese roesvrye staal word tans tot by sy sterktelimiet gebruik. 'n Onkonvensionele versterkingsproses is deur Mintek ontwikkel waarin die bestaande materiaal tussen 450°C en 500°C verouder word. Die doel van hierdie studie is om die moontlike versterkingsmeganismes wat betrokke is, te identifiseer deur van 'n 430 roesvrye staal, met 16.42% Cr en 0.036% C, gebruik te maak. Die materiaal is in die koudverwerkte toestand (38% reduksie in area) getoets, met en sonder voorafgaande oploshittebehandelings.

Die Cr-ryke presipitaat (α") vorm in die 450°C tot 500°C gebied (a.g.v. 'n onmengbaarheidsarea in die Fe-Cr fasediagram) en veroorsaak 'n toename in hardheid en afname in taaiheid. Dit is deur middel van Mössbauer-studies bevestig dat die α", by hierdie samestelling en temperatuur, vorm deur 'n proses van kernvorming en groei van partikels. Verharding deur die α"-presipitate is egter eers waargeneem na veroudering vir meer as 64 uur by 475°C. Nadat die opgeloste interstisiële inhoud verhoog is deur addisionele oploshittebehandelings (in die omgewing van 900°C), is gevind dat 'n toename in Vickershardheid van 30-50 kg/mm^2 verkry kan word binne 'n verouderingstyd van 8 minute. Dié toename stem ooreen met 'n verhoging in treksterkte van meer as 100 MPa. Dit blyk dat die verhoging nie die gevolg van rekveroudering is nie, maar wel waarskynlik toegeskryf kan word aan die presipitasie van fyn karbiede en nitriede. Oplosbehandeling by 930°C het ook die vorming van martensiet tot gevolg, wat die hardheid van die onverouderde materiaal verhoog.

Oorveroudering van die karbied- en nitriedpresipitate is by 475°C waargeneem, maar nie by 450°C nie, moontlik as gevolg van die laer diffusietempo's by die laer temperatuur. Geen oorveroudering van die α"-presipitate is waargeneem nie, selfs vir verouderingstye van tot 2072 uur.

Veroudering by 475°C het lae slagsterktes tot gevolg, selfs voor die vorming van α". Breukvlakke het hoofsaaklik uit splytingsvlakke bestaan, met smeebare breukareas meestal op korrelgrense. Beide die slagsterkte en die laterale uitsetting het getoon dat verbrossing gepaardgaan met die verhoging in hardheid wat verkry word deur veroudering. Die berekening van kritieke kraaklengtes uit die impakdata het egter getoon dat, vir oplosbehandelings by 880°C, die maksimum defekgrootte - voor katastrofiese faling - 0.8 mm is. Dit word nie verwag dat defekte van hierdie grootte in die soos-vervaardigde skakels teenwoordig sal wees nie, en daarom sal die leeftyd van die kettings waarskynlik deur vermoeidheid bepaal word. Die laer K_{Ic} waardes toon egter dat minder kraakvoortplanting plaas sal kan vind voor bros faling.

Tydens veroudering kan die sterkte van die materiaal moontlik weens herkristallisasie verlaag. Deur transmissie-elektronmikroskopie (TEM) is dit wel waargeneem dat herstel, maar geen herkristallisasie nie, plaasvind. Presipitate (van ongeveer 1 μm in diameter) is deur middel van hul diffraksiepatrone as $M_{23}C_6$ geëien, en aangesien die presipitate teenwoordig was in beide die verouderde en onverouderde materiaal, is dit waarskynlik dat die presipitate nie opgelos het tydens die oorspronklike oplosbehandelings nie. Die α" en nuutgevormde karbied- en nitriedpresipitate was te fyn om deur middel van TEM waargeneem te word.

Potensiodinamiese toetse in 'n 0.5M H_2SO_4 oplossing het getoon dat, alhoewel die waarskynlike versterkingsmeganismes gelokaliseerde chroomverarming tot gevolg het, die algemene korrosieweerstand en passiveringsgedrag nie deur die hittebehandelings beïnvloed word nie.

Dit kan gevolglik afgelei word dat die sterkte van die materiaal noemenswaardig verhoog kan word deur koue verwerking, en hittebehandeling by 475°C. Dit gaan gepaard met 'n afname in taaiheid, maar algemene korrosiebestandheid word nie beïnvloed nie. Martensiet, werksverharding en die presipitasie van fyn karbiede en nitriede dra by tot die finale sterkte, terwyl α" eers 'n invloed na langer verouderingsperiodes het.

Sleutelwoorde

vervoerbandkettings

Tipe 430 ferritiese roesvrye staal

475°C verbrossing

karbied- en nitriedpresipitasie

koue verwerking

martensiet

versterking deur hittebehandeling

korrosie weerstand

alfa (dubbel) aksent

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