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WELDABILITY STUDIES ON 12% AND 14% CHROMIUM STEELS

by

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TO MY WIFE LILI-MART

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Where is the wise man? Where is the scholar? Where is the philosopher of this age? Has not God made foolish the wisdom of the world? For since in the wisdom of God the world through its wisdom did not know Him, God was pleased through the foolishness of what was preached to save those who believe.

1 Corinthians 1:20-21 (NIV)

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Finally, to the living God who created everything through his Son, all praise and thanks.

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SYNOPSIS

This thesis is a detailed study of some important aspects of the weldability of the well-known 12% chromium steel, known as 3CR12, and a 14% chromium steel, designated 3CR14.

3CR12 is a duplex ferrite-tempered-martensite steel which was developed as a corrosion resistant steel, from the ferritic stainless steel AISI 409, for application in mildly corrosive environments in the South African coal and gold mines. 3CR14 is a new higher chromium steel which is presently being developed for application in more aggressive corrosive environments than 3CR12. Although it is reported in the literature that the weldability of 3CR12 is superior to that of AISI 409, there is an increasing concern about the actual weldability of 3CR12 in comparison to the steels (mild and low alloy steels) it is replacing. This is particulary the case since 3CR12 is now also specified for, and used in, more and more structural applications.

The following aspects of the weldability of 3CR12 and 3CR14 were studied:

1. A study of the fusion line fracture behaviour of welds on 6 mm 3CR12 and 3CR14 plate in the presence of a triaxial stress field. A new bead-on-plate bend test was developed for measuring the fracture toughness of the narrow (0.25 mm - 0.35 mm) high-temperature (HT) weld heat-affected zone (HAZ) adjacent to the fusion line. The influence of factors like chemical composition, phase composition of the HT HAZ and loading rate on the HT HAZ fracture toughness, was studied.

2. A study was undertaken into the influence of weld metal and base metal mechanical properties on the fusion line fracture behaviour of highly restrained welds. A new fusion line notch fracture toughness test was developed to compare the suitability of different filler metals for welding 12 mm 3CR12 plate.

3. The mechanism of splitting in transverse Charpy specimens was studied and the relationship was established between splitting and the phenomenon of lamellar tearing which sometimes attends welding.

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The experimental results are successfully explained in terms of two fracture mechanics theories.

The fracture toughness values measured in this thesis for the duplex ferrite-martensite HT HAZ of both 3CR12 and 3CR14 are much lower than the values reported in the literature. The HT HAZ ductile-brittle transition temperature of, e.g., 3CR12 is higher than 100°C, while values of below room temperature was reported in the literature. It is shown that the conventional Charpy V-notch test may not be used to measure reliably the toughness of the narrow HT HAZ. It is concluded that the weldability of 3CR12 is not really superior to that of AISI 409 and that the steel should not be used for structural applications in plate thicknesses above 3 mm if adequate joint toughness is required.

The HT HAZ fracture toughness of both 3CR12 and 3CR14 was found to be nearly independent of grain size and phase composition.

A type AISI 309L filler metal is recommended for welding 3CR12. The recently developed E3CR12 filler metal is not recommended due to its detrimental effect on the fusion line notch fracture toughness.

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SAMEVATTING

Sekere belangrike sweisbaarheidsaspekte van die bekende 12% chroomstaal (3CR12) en 'n 14% chroomstaal (3CR14) is in detail bestudeer.

3CR12 is 'n sweisbare, dupleks ferriet-getemperde-martensietstaal wat ontwikkel is vanuit die ferritiese roesvrye staal AISI 409, vir aanwending in matige korrosiewe omgewings in Suid-Afrikaanse steenkool- en goudmyne. 3CR14 is 'n nuwe staal wat tans ontwikkel word vir toepassing in meer aggressiewe korrosiewe omgewings. Alhoewel daar in onlangse publikasies beweer word dat 3CR12 'n baie beter sweisbaarheid het as AISI 409, heers daar tans heelwat onsekerheid ten opsigte van die sweisbaarheid van 3CR12, aangesien die staal nou ook gespesifiseer word vir strukturele toepassings.

Die volgende aspekte van die sweisbaarheid van 3CR12 en 3CR14 is ondersoek:

1. Die smeltlynbreukgedrag van sweislasse in 6 mm 3CR12 en 3CR14 plaat in die teenwoordigheid van 'n triaksiale spanningsveld. 'n Nuwe toetsmetode is ontwikkel vir die meting van die breuktaaiheid van die nou (0.25 mm - 0.35 mm) hoë temperatuur (HT) sone in die sweis hitte-geaffekteerde-sone (HAS). Die invloed van faktore soos chemiese samestelling, fasesamestelling van die HT HAS en belastingstempo op die breuktaaiheid van die HT HAS is bestudeer.

2. Die invloed van die sweismetaal en basismetaal meganiese eienskappe op die breukgedrag van ingeklemde sweislasse. 'n Nuwe smeltlynbreuktaai-heidstoetstegniek is ontwikkel vir die toetsing van verskillende tipes sweiselektrodes vir die sweising van 12 mm 3CR12 plaat.

3. Die meganisme van delaminering in transversale Charpymonsters. Ondersoek is ingestel om te bepaal of hierdie verskynsel nie moontlik 'n aanduiding is van die vatbaarheid van 3CR12 vir lamellare skeuring gedurende en na sweising nie.

Die eksperimentele resultate word suksesvol verklaar aan die hand van twee breukmeganikateorieë.

Die breuktaaiheidswaardes wat in hierdie studie bepaal is vir die HT HAS

van 3CR12 sowel as 3CR14, is baie laer as die gepubliseerde waardes. Die HT HAS brosoorgangstemperatuur van 3CR12 is bv. hoër as 100°C terwyl waardes laer as 20°C gepubliseer is. Daar word aangetoon dat die taaiheid van die HT HAS nie akkuraat m.b.v. die konvensionele Charpytoets bepaal kan word nie. Die eksperimentele resultate dui daarop dat die sweisbaarheid van 3CR12 nie beter is as die van AISI 409 nie. Vir strukturele toepassings waar aanvaarbare sweislastaaiheid 'n vereiste is, word 3CR12 gevolglik nie aanbeveel vir plaatdiktes dikker as 3 mm nie.

Die breuktaaiheid van die HT HAS van beide 3CR12 en 3CR14 word nie noemenswaardig deur die korrelgroote en fasesamestelling van die sone beïnvloed nie.

'n Tipe AISI 309L sweiselektrode word aanbeveel vir die sweising van 3CR12 terwyl die nuwe E3CR12 sweiselektrode glad nie aanbeveel word nie as gevolg van die nadelige effek van die E3CR12 sweismetaal op die smeltlynbreuk-taaiheid.

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