THE MARINE TECHNOLOGY DIRECTORATE LIMITED

CURRENT AND POTENTIAL USE OF HIGH STRENGTH STEELS IN OFFSHORE STRUCTURES

J.Billingham, J.Healy and J.Spurrier

PUBLICATION 95/102

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The authors wish to acknowledge the sponsors of the Managed Programme of University Research, High Strength Steels in Offshore Engineering, 1992 - 94, at Cranfield University, for their permission to publish this document. Sponsors of the Programme include MTD Ltd acting on behalf of EPSRC, and AMEC, Amoco, BOC, BP, DRA, ESAB, HSE, NPD, Shell Expro, Texaco, Total.

We are also grateful to the following organisations for information contributed to this study and helpful discussions:
Billington Osborne-Moss Engineering Ltd, Maidenhead
British Steel Corporation
John Brown Engineers and Constructors Ltd, London
Dillinger Hüttenwerke
Fabrique de Fer de Charleroi S.A.
GTS Industries, Dunkerque
Kvaerner Earl and Wright, London
McDermott Engineering, London
SSAB Sweden
Sumitomo London
Swedish Steel UK Ltd

Published by MTD
The Marine Technology Directorate Limited

Registered in England
Registered Office
19 Buckingham Street
London WC2N 6EF

Registered as a Charity under the Charities Act 1980

Registered Charity No 295576

ISBN: 1 870553 24 1

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LIST OF ACRONYMS AND ABBREVIATIONS

AWS	American Welding Society
BOP	bead on plate
CE	carbon equivalent
CGHAZ	coarse-grained heat affected zone
CP	cathodic protection
CTOD	cracktip opening displacement
CTS	controlled thermal severity
CVN	Charpy vee notch
FCAW	flux cored arc welding
FE	finite element
HAZ	heat affected zone
HSLA	high strength low alloy
MAC	martensite, retained austenite and aligned carbides
PWHT	post weld heat treated
Q & T	quenched and tempered
SAW	submerged arc welding
SMYS	specified minimum yield strength
S - N curve	stress range plotted against number of cycles to failure
SRB	sulphate reducing bacteria
TMCP	thermomechanically controlled processing
TS	total sulphide
UTS	ultimate tensile strength
YR	yield ratio

Abbreviations of chemical elements

Al	aluminium
B	boron
C	carbon
Cr	chromium
Cu	copper
Mn	manganese
Mo	molybdenum
Ni	nickel
Nb	niobium
P	phosphorus
S	sulphur
Si	silicon
Ti	titanium
V	vanadium

NOTATION

a	crack length
a_{eff}	critical flaw parameter
B	thickness
CE_{IIW}	IIW carbon equivalent
Co	surface/absorbed hydrogen concentration
da/dN	crack propagation rate per cycle
F_u	ultimate tensile strength
F_y	yield strength
Hv	Vickers hardness
J_c	critical value of J-integral
K_c	apparent toughness, critical value of stress intensity factor
K_{IC}	plane strain fracture toughness
K_{th}	threshold stress intensity
m	magnification factor
R	ratio of minimum load/maximum load
W	width
δ_c	critical crack tip opening displacement
σ_{app}	applied stress
σ_y	yield stress
ΔK	applied stress intensity factor

1. GENERAL INTRODUCTION

High strength steels have been available for many years, but their use in offshore engineering has been severely restricted except in specialised applications. This is largely because, in general, satisfactory performance can be achieved with cheaper, more readily available, lower strength steels. Additionally, as strength increases, not only does the cost increase but the ductility and weldability generally decrease. In major structural applications such factors have significant influence. Thus most steels used in offshore structural applications have yield strengths in the range 250 to 350MPa. Indeed, there are restrictions in many codes which militate against using steels with yield strengths greater than 460MPa[1].

The major requirement offshore is for tubular construction practice which utilises steel plate as the raw material. The ferrite pearlite steels used must be readily available in tonnage quantities and in a range of thicknesses up to 100mm. The conventional steel production route is normalising in order to produce satisfactory properties in the thicker section components. A primary requirement for this production route is adequate weldability, which is provided by limiting the steel hardenability through compositional limitations usually imposed through restrictions in allowable carbon equivalent values[2]. This factor, combined with the need for good notch ductility, has led to a continual reduction in carbon levels in such steels over the past two decades[3].

In contrast, over the same period, the pipeline industry has successfully exploited large tonnages of higher strength steels in marine environments. Thus, X70 grade (480MPa) steels are commonly used in subsea pipelines. Such steels are ferrite pearlite steels which are micro-alloyed to produce a fine grain size, to give both strengthening and resistance to low temperature brittle fracture. They also have low carbon contents to ensure good weldability and toughness, and low levels of impurities to ensure resistance to ductile failure processes, which might occur in gas pipelines as a result of overpressurisation. Pipelines utilise much smaller section thicknesses (usually 19mm or less), and they can therefore take advantage of alternative steel production routes such as controlled rolling or TMCP to develop the necessary fine grained microstructure[4].

Even higher strength steels (700MPa yield strength) have been used for some time in jack-up platforms[5]. Such steels have usually had a relatively high carbon content, because good abrasive resistance is required in the jacking operation, and weldability is not a prime requirement[6]. Because of the periodic docking arrangements which allow easier inspection capabilities, fatigue is also not seen as a major design limitation. More recent proposals to use such structures on much longer term operational schedules have instigated a more widespread interest in the likely fatigue performance of the type of steels used[7].

Another traditional application for higher strength steels in marine environments has been submarines[8], where higher strength (700MPa) steels are utilised to reduce section thicknesses because of their excellent mechanical property combinations in terms of strength and toughness[9]. However, such steels are generally much more highly alloyed, making them more expensive and more difficult to weld. In turn, this often necessitates lengthy and costly pre-, and sometimes post-welding treatments, which extend and complicate fabrication procedures, and introduce considerable additional costs[10]. Similar steels have also been used in mooring applications such as the tethering attachments in tension leg platforms, where their high strength and good resistance to fatigue can be utilised. In this application, the steels are not usually used in the welded condition, screwed connectors being used for example, so that their excellent resistance to fatigue initiation or sudden overloads can be utilised[11]. However, a recent example used welded connections on a 38-mm thick lower strength X70 (485MPa) tether string for the Heidrun project[12].