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A review on welding of high strength oil and gas pipeline steels

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ABSTRACT

Owing to the findings of new locations for crude oil and natural gas, the need of high strength materials that can be used for pipes and their joining has gained paramount importance. Welded pipes have to bear internal fluid pressure in addition to the adverse external conditions. Welding of high strength pipeline materials is also a challenge for engineers in construction of pipes as well as oil and gas transportation lines. To increase reliability and profitability in this industry, effective welding techniques are needed for these materials. To understand the issues related with the welding of these high strength steels, requirements of chemical composition and mechanical properties for these materials are discussed in detail. Through this review article, an attempt has been made to critically analyse the issues and challenges associated with the weldability of high strength pipeline materials. Status of current research for weld corrosion, hydrogen embrittlement, residual stress, weld repairing and deteriorated heat affected zone is also summarized. Current development trends are discussed with a view to envisage future directions. Findings of this review work emphasize the need to shift the research focus from currently used grades X65, X70 and X80 to the advanced grades X90, X100 and X120.

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1. Introduction

Population growth and industrial development in any country gives rise to the demand for petroleum products. Demand, which is more than supply, can be fulfilled either by finding of new resources location or export from any other surplus ones. With the increasing demand and findings of new crude oil and natural gas resource locations, their transportation has gained considerable attention of manufacturing industry. Sometimes the transportation has to be continuous for a long time which is only possible by pipeline. These pipelines may range from few kilometres to thousand kilometres, passing through different geographical and environmental conditions. Consequently, a need has arisen to emphasise on the development requirements of high strength materials which can withstand the onshore, offshore and underground conditions as large variation of ambient conditions. Thus, the increasing demand of oil and gas industry has motivated the use of these high strength materials (Mathias et al., 2013). The need of high pressure application of these materials makes job challenging for makers and welders of these pipes. To understand the issues related to the welding of these high strength low alloy (HSLA) steels, it is necessary to know about chemical composition as well as mechanical properties. This information will help us in selection of suitable welding process and accordingly welding consumables. With the knowledge of chemical composition and mechanical properties for a material, we can also estimate its weldability. It can also help in prediction of phase transformation in its heat affected zone (HAZ) during thermal cycle of welding and microstructure of weld metal. In this section, information about some popular designating standards, product specification levels, chemical compositions and mechanical properties of HSLA oil & gas pipeline steels are presented. The weldability issue of these materials, welding processes suitably used for production of pipes from these steels are also discussed and tabulated in this section.

1.1. High strength low alloy oil & gas pipeline steels

The materials that are best suited to the requirements of oil & gas pipeline industry are HSLA steels. Specifications regarding chemical composition, mechanical properties and other important issues like welding, cutting, manufacturing etc. of oil & gas pipeline materials are specified by American Petroleum Institute (API), International Organisation for Standards (ISO) and other national agencies. API standards are generally taken as reference by many national agencies for setting their own specifications for these materials. API specifications are accepted and popularly used worldwide. Table 1a shows the year of invention for each grade of high strength pipeline steel (Trench and Kiefner, 2001). A comparative list of high strength pipeline materials' names given by some organizations and agencies are presented in Table 1b

As specified by API, pipeline materials are manufactured or provided with two product specification levels known as PSL 1 and PSL 2. According to API 5L specifications, PSL 1 pipes are supplied in Grades A25, A25P, A, B, X42, X46, X52, X56, X60, X65 and X70 whereas PSL 2 pipes are supplied in Grades B, X42, X46, X52, X56, X60, X65, X70, X80, X90, X100 and X120. Difference between PSL 1 and PSL 2 is that PSL 2 has mandatory requirements for carbon equivalent and notch toughness in addition to the minimum as well as maximum limit for yield strength and tensile strength whereas PSL1 has minimum limits/specifications only for notch toughness, yield strength and tensile strength. It is also worth noting that no limit is specified about carbon equivalent for PSL 1 grade pipes. Other major difference is based on the type of pipe ends. PSL 1 pipes can be manufactured and supplied with plain-end, threaded-end, belled-end and as special coupling pipe whereas PSL 2 pipes are manufactured with plain-ends only.

In this paper, information about chemical compositions, mechanical properties and pipe manufacturing techniques used is listed for X42 through X120 pipeline steel. The starting grades A25, A25P, A and B are left from the main frame of discussion because these grades are considered as medium strength materials. According to American Society for metals (ASM), low alloy steel showing yield strength of minimum 290 MPa is considered in the category of high strength steel (ASM Metals Handbook, 1994). Knowledge about chemical composition and mechanical properties of these pipes is necessary to understand the weldability and other issues for welding of these pipes. For this purpose, Table 2a provides the detail about mechanical properties of API grade pipe steel and Table 2b gives an insight about the chemical composition of PSL 1 & PSL 2 oil and gas pipeline HSLA steels (American Pertoleum Institute, 2012).

1.2. Weldability of line pipe steels

Carbon equivalent (CE) term is used to indicate hardenability or crack susceptibility in steel weld. CE helps in estimating the combined effect of all important alloying elements on microstructure (formation of martensite structure) during welding of steel because it is the change in microstructure of steel that decides its properties and behaviour after welding. So lower value of CE is always preferred which indicates good weldability. American Petroleum Institute has adopted two formulae (CE_{IIW} & CE_{Pcm}) to specify the limit of carbon equivalent for API PSL 2 grade pipe steel. CEIIW formula is given by International Institute of Welding (IIW doc,

Table 1a
High strength pipeline steels with their year of invention.

Steel Grade	(X42)	(X46)	(X52)	(X56)	(X60)	(X65)	(X70)	(X80)	(X90)	(X100)	(X120)
Year of Invention	1948	1953	1953	–	1966	1967	1973	1985	1985	1985	1998

Table 1b
Comparative names list for high strength pipeline materials.

Organisation/Country	Specification no.	Material Name (equivalent to)								
		(X52)	(X56)	(X60)	(X65)	(X70)	(X80)	(X90)	(X100)	(X120)
API	API 5L	X52	X56	X60	X65	X70	X80	X90	X100	X120
ISO	ISO 3183	L360	L390	L415	L450	L485	L555	L625	L690	L830
EN (Euro-norms)	EN 10208	L360	L390	L415	L450	L 485	L 555	L625	L690	L830
DIN (Japan)	DIN 17172	StE 360.7 TM	StE 385.7 TM	StE 415.7 TM	StE 445.7 TM	StE 480.7 TM	StE 550.7 TM	–	–	–
BIS (India)	ICS NO. 75.200; 77.140.75	YSt 359	YSt 386	YSt 414	YSt 448	YSt 483	YSt 552	–	–	–
Russia	–	–	–	–	–	K60	K65	K70	K80	K90