Journal of Petroleum and Gas Exploration Research (ISSN 2276-6510) Vol. 1(2) pp. 072-079, December, 2011
Available online http://www.interesjournals.org/JPGER

Full Length Research Paper

Characterization of X-120M pipeline steel

Jai Dev Chandel, Nand Lal Singh

M S University of Baroda, Vadodara, India

Accepted 08 December, 2011

The metallurgical science has been used to develop new weldable high strength steel plates having strength and toughness of API-5L, X-120M for manufacturing line pipes for transportation of petroleum products. A pan cake type microstructure design has been used to ensure the strength level of X-120M and ductile fracture behavior at temperature down to -20 ºC. Ultra refined, lean micro-alloyed chemistry design and plate rolling through TMCP (thermomechanical control processing) in combination with AC (accelerated cooling) steel has been produced of lower transformation microstructure in the steel plates. The steel chemistry and TMCP and AC plate rolling designed in such a way that the plate should be of lower bainite and lower martensite to achieve the strength level of X-120M line pipe. The provision was made in the chemistry so to have minimum effect of welding heat input on the base metal or so called heat affected zone (HAZ) in the submerged arc welding of long seam weld of line pipe.

Keywords: TMCP, AC, HAZ, pan cake Microstructure, line pipe, API-5L, HSLA, lower transformation product.

INTRODUCTION

In view of the ever increasing length of pipe line networks and ever increasing operating pressure, it is very essential to develop high strength steel for manufacturing line pipes. The governing parameters of any pipe line project are project cost, operating cost and operating life. The variables affecting the project cost are mainly the tonnage of steel and the welding consumables used in any pipe line project. The development of high strength low alloy steel has a significant contribution to pipe line project cost reduction. Recent experiments Corbett et al (2003) show that X-100M steel could give investment cost savings of about 7% with respect to X-80M and by using X-100M instead of X-70M, the cost saving could be higher. When we use X-120M steel the cost saving may be much higher over X-70M material. In other words the clean fuel may be delivered at lower price to the end users in today's competitive market.

High-strength low alloy steel (Bhadeshia, 1989) was sometimes called acicular ferrite (AF) high strength low alloy (HSLA) steels. This is because they exhibited a microstructure of heavily dislocated laths, this microstructure is more like the low carbon bainite in which adjacent laths are in the same crystallographic orientation in space and it is probably not useful to call it an acicular ferrite (AF) microstructure. The microstructure and dislocation densities are playing a major role in the development of high strength pipeline steel (Hillenbrand et al., 2001; Graf et al., 1995). The bainite microstructure (Nakasugi et al., 1980; Bhadeshia, 1999) with ultralow carbon and carbon equivalent can meet the requirement of strength and toughness at low temperature. The strength of bainite is increased due to the carbide precipitation in the bainite and the defect introduced by plastic deformation on the kinetics. The (Koo et al., 2003) lower bainite and dual phase microstructure were shown to offer superior combination of strength and toughness in the steel plates and thus these are attractive for X-120M line pipe manufacturing. The control of raw materials and clean steel making practice and limited 'O' and 'S' contents up to 20 ppm while TMCP conditions produced domain of less than 2 µm. It was determined that 'B' addition of 5-15 ppm enables the use of very low 'C' lean chemistry design. The 'B' addition, lean chemistry provides sufficient hardenability, thus flexibility during plate processing and seam welding. The (Schwinn et al., 2004; Fabian et al., 2005) 'B' steel with 17ppm of 'B' along with alloying elements 'Cr', 'Ni', 'Mo' etc. and microalloying elements can achieve the strength and toughness level with, TMCP (thermomechanical control processing) process. Also (Heckmann et al., 2004) 'B'

*Corresponding author email: jaidev.chandel@jindalsaw.com

Table 1. Weight Percentage of Elements of X-120M Steel Plates

Element	C	Si	Mn	P	S	Cr	Ni	Mo	Al	Cu
Wt. (%)	0.065	0.290	1.950	0.012	0.005	0.170	0.040	0.130	0.042	0.021
Element	**Ti**	**V**	**Nb**	**Ca**	**N**	**B**	**Al/N**	**Nb+V+Ti**	**Pcm**	**CE**
Wt. (%)	0.012	0.001	0.042	0.001	0.002	0.004	21	0.055	0.211	0.454

containing steel has an advantage of having the wider window for rolling and cooling condition. The widening the operating window for rolling and cooling due to shifting the gamma-alpha (γ-α) transition curve by the addition of ‘B’ allows the formation of bainite microstructures even at low cooling rates. The effect of micro alloying elements (Hillenbrand and Kalwa, 2002) and effect of ‘B’ on the properties of line pipes will be enhanced if the addition of ‘B’ made in control way. The new (Funakawa et al., 2004; Siwecki et al., 1999) hot rolled high strength steel consisting of ferrite matrix and nanometer sized carbides achieved the strength level of 800 MPa (X-100M). By this route, by adding more ‘Ti’ as equal as ‘Mo’ we can achieve the high strength level of X-120M pipeline steel. By Schutz et al (2000); Schwinn et al (2002); Ouchi (2001) utilizing the new heavy accelerated cooling (HACC) technique the cost of the alloy for X-120M steel can further be reduced by using X-100M steel composition. This will further help to maintain the good toughness level in the weld as well as in the HAZ of the seam weld. The mechanical properties (Manohar et al., 1996; Manohar and Chandra, 1998; Hara et al., 2004) of the TMCP steel by combined addition of ‘Nb’ and ‘B’ or that of ‘Mo’ and ‘B’ in low carbon steel has been studied by the authors. The strength remarkably increased due to the combined addition of ‘Nb’ and ‘B’ or that ‘Mo’ and ‘B’ because gamma/alpha (γ/α) transformations is retarded and bainite transformation promoted. This caused by the increase in the segregated ‘B’ along the gamma (γ) grain boundary before gamma to alpha (γ-α) transformation. Thermodynamics and metallographic analysis (Yang et al 1995) show that the transformation of acicular ferrite and bennite are apparently similar with displacive characteristics.

MATERIALS AND EXPERIMENTAL METHODS

Experimental TMCP and AC steel plate specification has been formulated for grade as per API-5L, X-120M and Chemistry of experimental plate shown in table 1 respectively. The parameters Pcm and C_{EQ} are calculated as per formulae in terms of weight percent are as per equation (1) and (2) respectively:

$$Pcm = C + Ni / 60 + Si / 30 + (Mn + Cu + Cr) / 20 + Mo/15 + V / 10 + 5B \quad (1)$$

$$C_{EQ} = C + Mn/6 + (Cr+Mo+V)/5 + (Ni + Cu)/15. \quad (2)$$

The scanning electron microscopy (SEM) and transmission electron microscopy (TEM) has been performed on the experimental TMCP and AC steel.

Scanning Electron Microscopy (SEM)

The scanning electron microscopy on the plates has been performed on the samples drawn from the TMCP steel plate by using two percent nital solution as an etchant.

Transmission Electron Microscopy (TEM)

Transmission electron microscopy was carried out on thin foils prepared by cutting thin wafers from the steel samples of TMCP steel plate, and grinding to ~ 100 µm in thickness. Three millimeter discs were punched from the wafers and electropolished using a solution of ten percent perchloric acid in acetic acid electrolyte. Foils were examined by HITACHI 7600 TEM operated at 120 kV.

RESULTS

The results obtained from scanning electron microscopy and transmission electron microscopy are shown in figure 1 to 11 below. The two electron microscopy techniques are used to establish the microstructures obtained.

DISCUSSION

The electron microscopy was carried out on experimental TMCP and AC cooled steel plates. The micrograph obtained are shown in this paper with SEM in figure 1, shows pan cake type microstructure which confirms the predominant bainitic phase along with the second phase (Nakasugi et al., 1980; Matsumoto et al., 1986) or predominantly acicular structure (laths) and the pan-cakes (Koo et al.,2003) along the rolling direction. The white dotes within the laths are fine cementite are the characteristic of lower bainite. The SEM micrographs are having ultrafine lath like bainitic structure (Schwinn et al., 1984; Heckmann et al., 2004) and small island of coalesced bainite predominantly the

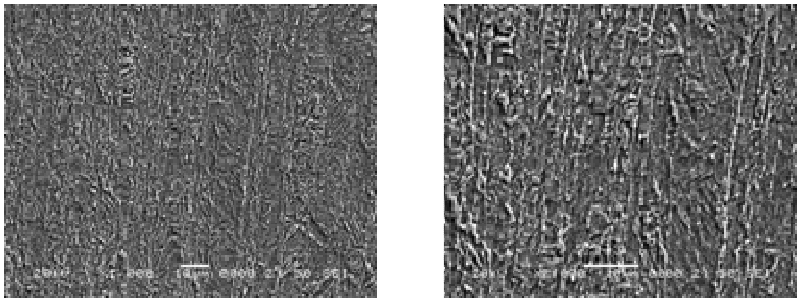

Figure 1a. SEM Micrograph of lath type and pancake along the rolling direction, typically bainitic structure at 1/4th thickness of base plate.

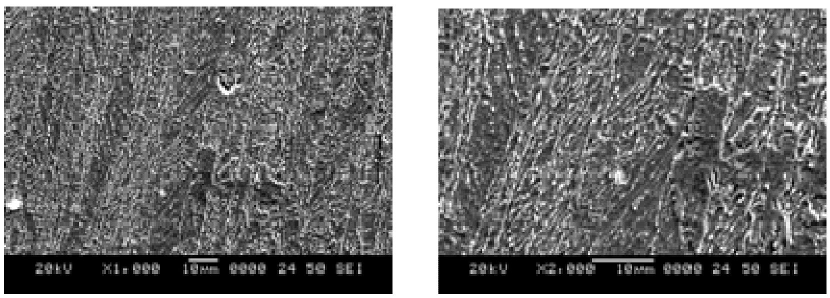

Figure 1b. SEM Micrograph of lath type and pancake along the rolling direction, typically bainitic structure at mid thickness of base plate.

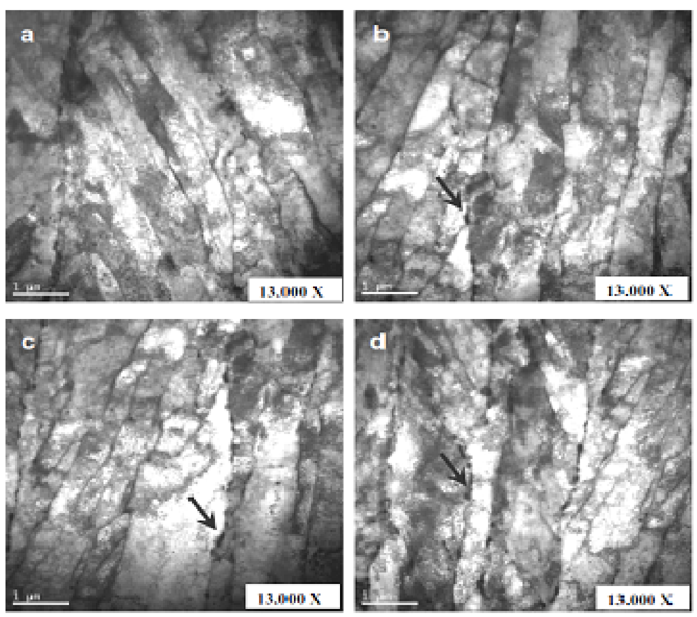

Figure 2. Bright field TEM micrographs showing lath-type and bainitic-type ferrite with high dislocation density. Interlath carbides are indicated with arrows.

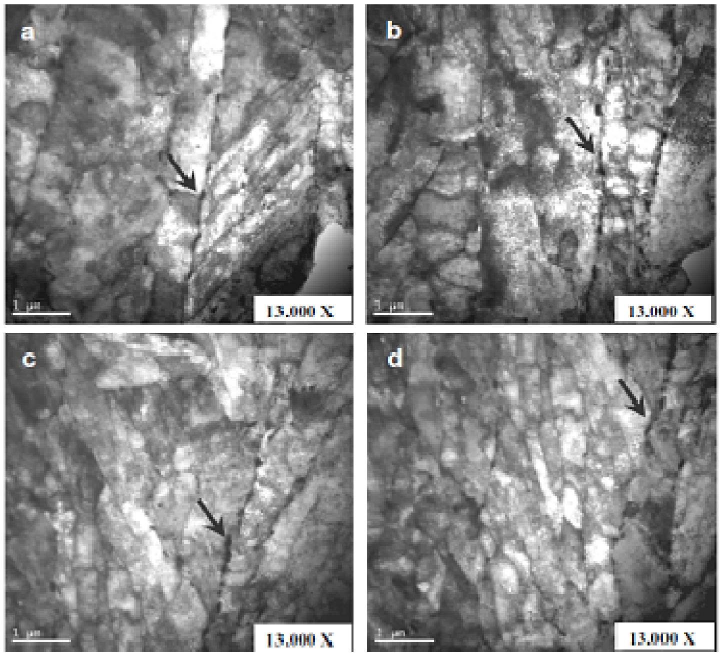

Figure 3. Bright field TEM micrographs showing lath-type and bainitic-type ferrite with high dislocation density. Interlath carbides are indicated with arrows.

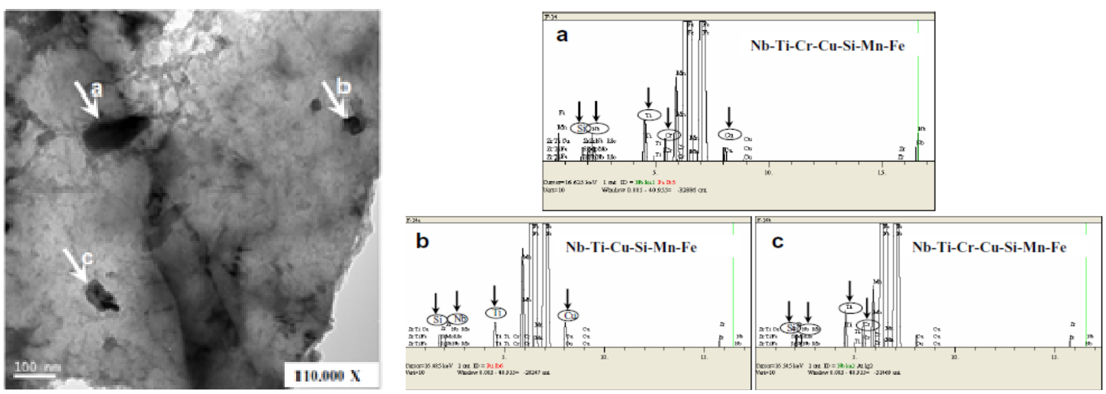

Figure 4. Bright field TEM micrograph showing coarse precipitates in ferrite matrix together with EDS analysis for precipitates identified as “a-c”.

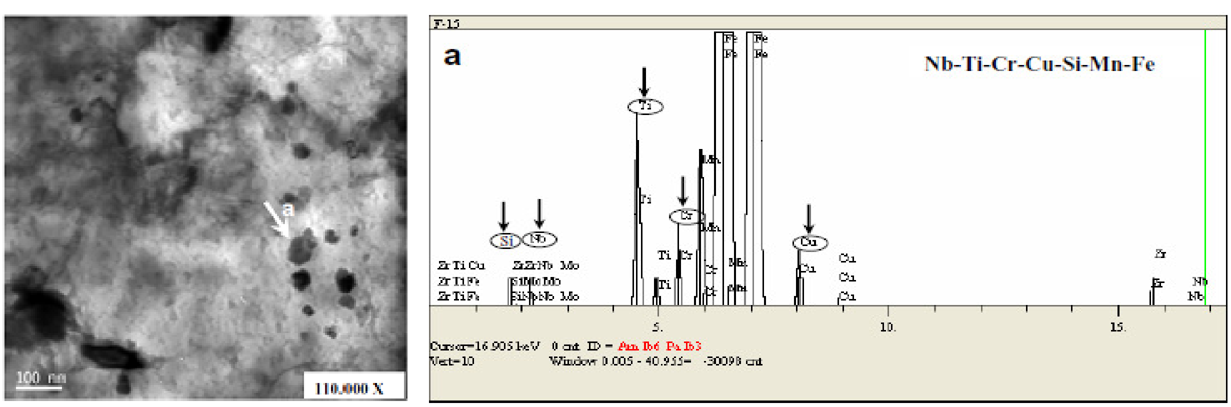

Figure 5. Bright field TEM micrograph showing coarse precipitates in ferrite matrix together with EDS analysis for precipitate shown.

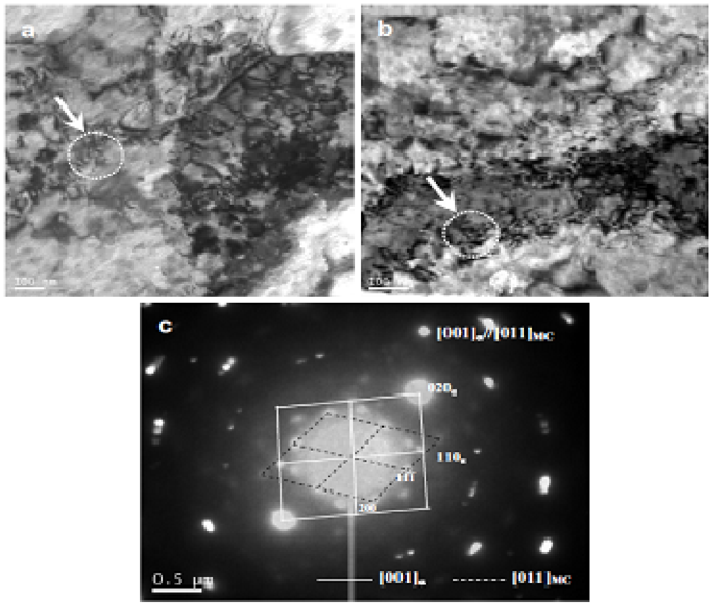

Figure 6. (a) and (b) Bright field TEM micrographs showing fine precipitates in ferrite matrix.(c) SAD pattern for the fine MC type carbides, where M = Nb or Ti.

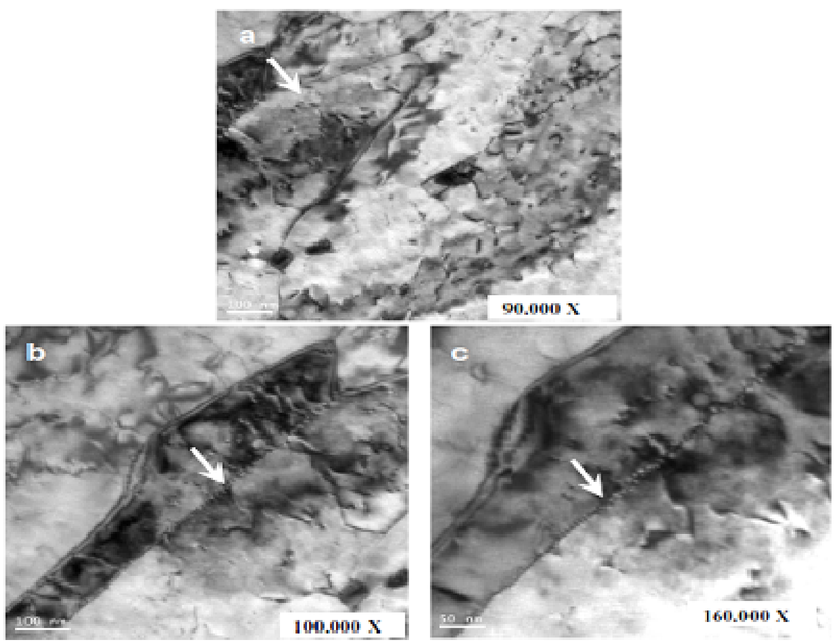

Figure 7. (a) Bright field TEM micrographs showing fine precipitates in ferrite matrix and grain boundaries.

martensite inside the island. These micrographs are typically bainitic microstructure (Asahi et al., 2003) of lower bainite with fine pancake like grains and dominated by lower bainite. The SEM micrographs are having a typical microstructure of TMCP (Hitoshi et al., 2004) steel with boron and low carbon lean chemistry of lower bainite which is capable to produce high strength and toughness values.

The transmission electron microscopy (TEM) micrograph shows the microstructure in TMCP and AC plate material is of predominantly lath type ferrite, lath type bainitic ferrite and non-polygonal ferrite along with martensite with high dislocation density as shown in figures -02, 03 (snaps taken at two different spots) 08 and 09. The coarse metallic carbide inclusions are of cubic structure are found in the microstructure shown in

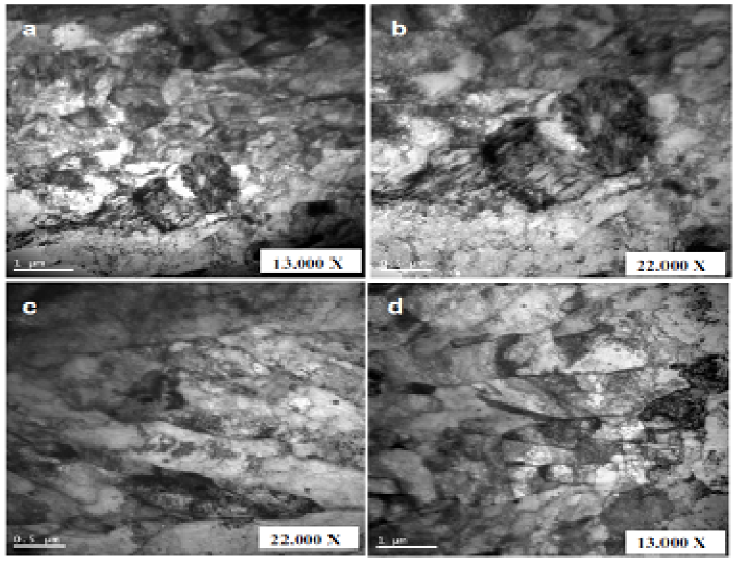

Figure 8. Bright field TEM micrographs showing non-polygonal ferrite and bainitic-type ferrite with high dislocation density.

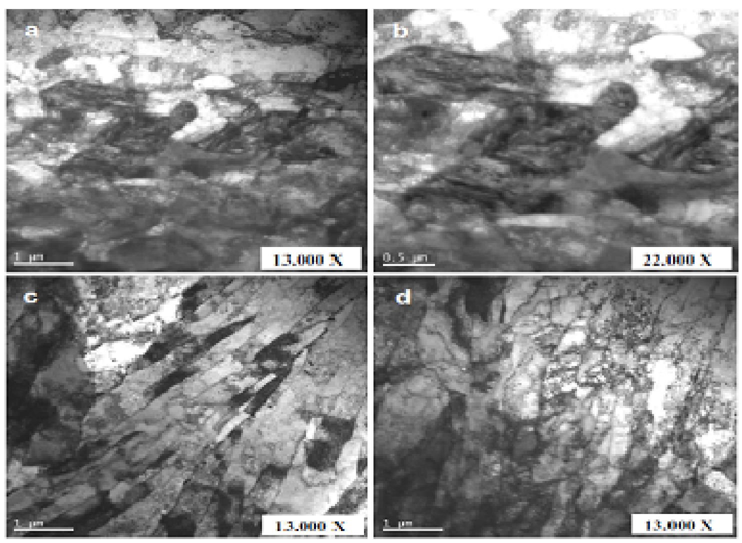

Figure 9. Bright field TEM micrographs showing lath-type and bainitic-type ferrite with high dislocation density.

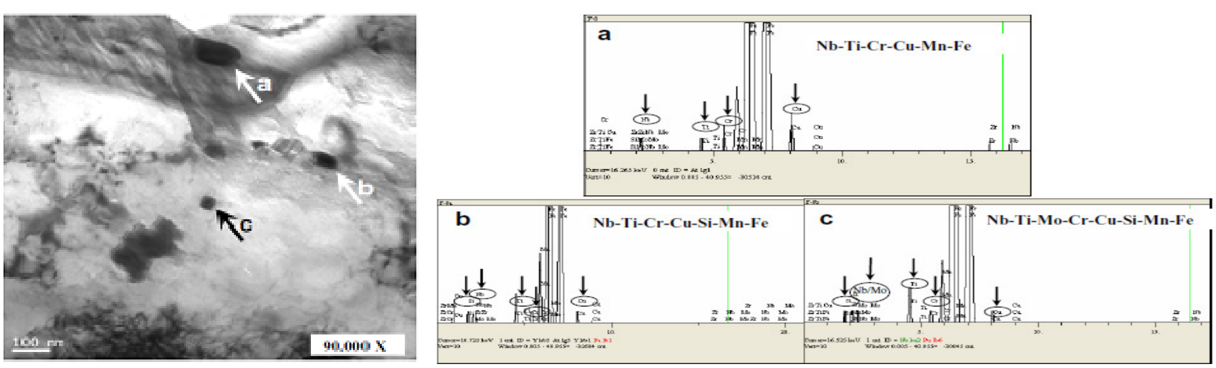

Figure 10. Bright field TEM micrograph showing coarse precipitates in ferrite matrix together with EDS analysis for precipitates identified as “a-c”.

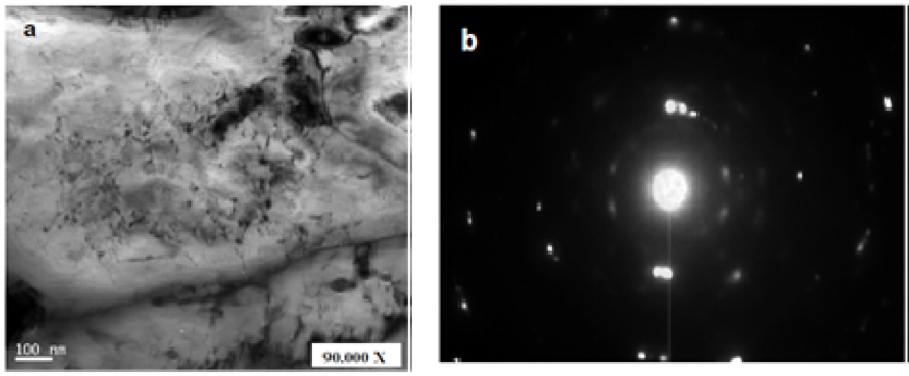

Figure 11. (a) Bright field TEM micrograph showing fine precipitates in ferrite matrix. (b) SAD pattern for the fine precipitates.

figures – 04 to 07 and 10 to 11. The results of test are shown in the figures 02 to 07 are base plate ¼th thickness from the surface approximately and figures 08 to 11 are base plate near mid thickness approximately.

The microstructure near plate surface is lath type, bainitic ferrite with high dislocation density and Interlath carbide as shown in figure 02 and 03. The precipitates in the ferrite matrix and along the grain boundaries are the metallic carbides are of cubic structure and these carbide are of Nb and Ti as shown in figures 04 to 07. The microstructure at mid thickness of the plate having lath type, bainitic type ferrite and non-polygonal ferrite with high dislocation density as shown in figure 08 and 09. The appearance of non-polygonal ferrite is due to the cooling rate difference during accelerated cooling as compared to the surface. The ferrite matrix having coarse precipitates as found in near surface of the plate microstructure.

The structures found in the scanning electron microscopy and transmission electron microscopy are predominantly the lower bainite and martensite with cubic precipitates of ‘Nb’ and ‘Ti’ carbides in the ferrite matrix. It is very difficult to obtain the high toughness at sub zero temperature at this strength level (minimum yield strength of 120 ksi) without having microstructure of lower bainite and martensite through TMCP and AC route. This is a well known fact that as the strength level increases the toughness starts decreasing. (Bhadeshia, 1989; Bhadeshia et al., 1980; Koo et al 2003) the microstructure obtained in the experimental steel can achieve the required strength and toughness at sub zero temperature.

ACKNOWLEDGEMENT

I am grateful to Prof. N L Singh (Department of Physics, M S University of Baroda - 392 002, India) for his endless support and encouragement during this study. I acknowledge the support from Welspun Gujarat Stahl Rohren Ltd. India.

CONCLUSION

Present Experimental TMCP and AC steel plate of API-5L, X-120M with Pcm of 0.211 and lower bainite and martensite with precipitates of Nb and Ti carbides having the capacity of producing good toughness values of X-120M pipeline steel below sub zero temperature. The development of high strength low alloy steel has a significant contribution to pipe line project cost reduction. Recent experiments (Corbett et al., 2003) show that X-100M steel could give investment cost savings of about 7% with respect to X-80M and by using X-100M. When we use X-120M steel the cost saving may be much higher over X-70M material. In other words the clean fuel may be delivered at lower price to the end users in today’s competitive market because of lower cost of a pipeline construction. In other words lower transportation cost.

REFERENCES

Corbett KT, Bowen RR, Petersen CW (2003). High Strength Steel Pipeline Economics. - Proceedings of the 13th International Offshore and Polar Engineering Conference Honolulu, Hawaii, USA.

Bhadeshia HKDH (1989). Production and Metallurgy of Advance Bainitic Steels. – Steel Technology International.

Hillenbrand HG, Graf M, Kalwa C (2001). Development and Production of High Strength Pipeline Steels. – Niobium, Orlando, Florida, USA.

Graf M, Hillenbrand HG, Zeislmair U (1995). Production of Longitudinally Welded Large Diameter Linepipe for Deep Water Applications. - Pipeline Technology Conference Ostende, Belgium.

Nakasugi H, Matsuda H, Tamehiro H (1980). Development of Controlled Rolled Ultra Low Carbon Bainitic Steel for Large Diameter Line pipe – Alloys for the eighties. - Proceedings of Conference, Ann Arbor, MI, USA.

Bhadeshia HKDH (1999). The Bainite Transformation: Unresolved Issues. - Material Science and Technology, Vol. A273-275.

Koo JY, Luton MJ, Bangaru NV, Petkovic RA, Fairchild DP, Petersen CW, Asahi H, Hara T, Terada Y, Sugiyama M, Tamehiro H, Komizo Y, Okaguchi S, Hamada M, Yamamoto A, Ikeda T, Takeuchi I (2003). Metallurgical Design of Ultra-High Strength Steel for Gas Pipeline. – Proceedings of the 13th International Offshore and

Polar Engineering Conference Honolulu, Hawaii, USA.
Schwinn V, Zajac S, Fluess P, Tacke K-H (2004). Bainitic Steel Plates for X100 and X120. - Pipeline Technology Proceedings, Conference, Ostend, Belgium.
Fabian G, Stefan M, Carl JH, Andre G (2005). Development, Production and Application of Heavy Plates in Grades up to X120. – 1st International Conference on Super-High Strength Steels Rome, Italy.
Heckmann CJ, Ormston D, Grimpe F, Hillenbrand HG, Jansen JP; (2004). Development of Low Carbon NbTiB Microalloyed Steels for high Strength Large DIAMETER Linepipe.–2nd International Conference on Thermomechanical Processing of Steels, Liege, Belgium.
Hillenbrand HG, Kalwa C (2002). Production and Service Behaviour of High Strength Large Diameter Pipe.– International Conference on Application and Evaluation of High Grade Linepipe in Hostile Environments, Yokohama, Japan.
Funakawa Y, Shiozaki T, Tomita K, Yamamoto T, Maeda E (2004). Development of High Strength Hot-Rolled Sheet Steel Consisting of Ferrite and Nanometer-Sized Carbides. - ISIJ International. 44 (11): ??Provide npage??
Siwecki T, Blaz L, Pettersson S (1999). The Effects of TMCP Parameters on the Strength Properties in Modified V-Nb-Mo Steels. – The ASM Material Solution Conference on Steel for Fabricated Structures, Ohio, USA.
Schutz W, Kirsch HJ, Fluss P, Schwinn V (2000). Extended Property Combinations in Thermomechanically Control Processed Steel Plates by Application of Advanced Rolling and Cooling Technology. - Proceedings of the Conference on Thermomechanical Processing of Steels, IOM London.
Schwinn V, Fluess P, Bauer J (2002). Production and Progress Work of Plates for Pipes with Strength Level of X80 and Above. – International Conference on Application and Evaluation of High Grade Linepipe in Hostile Environments, Yokohama, Japan.
Ouchi C (2001). Development of Steel Plates by Intensive Use of TMCP and Direct Quenching Processes. - ISIJ International, 41(6): ??Provide npage??
Manohar PA, Chandra T, Killmore CR (1996). Continuous Cooling Transformation Behaviour of Microalloyed Steels Containing Ti, Nb, Mn and Mo. - ISIJ International, 36 (12): ??Provide npage??
Manohar PA, Chandra T (1998). Continuous Cooling Transformation Behaviour of High Strength Microalloyed Steels for Linepipe Applications. - ISIJ International. 38(7): ??Provide npage??
Hara T, Asahi H, Uemori R, Tamehiro H (2004). Role of Combined Addition of Niobium and Boron and of Molybdenum and Boron on Hardenability in Low Carbon Steels. - ISIJ International. 44(8): ??Provide npage??
Yang JR, Huang CY, Chiou CS (1995). The Influence of Plastic Deformation and Cooling Rates on the Microstructural Constituents of an Ultra-Low Carbon Bainitic Steel. - ISIJ International. 35(8): ??Provide npage??
Matsumoto K, Akao K, Taira T, Arikata K, Niikura M, Naganawa Y (1986). Development of High Strength Line Pipe with Excellent Toughness and Superior Weldability - Nippon Kokan Technical Report- Overseas, No. 46-
Asahi H, Hara T, Sugiyama M, Maruyama N, Terada Y, Tamehiro H, Koyama K, Ohkita S, Morimoto H, Tomioka K, Doi N, Murata M, Ayukawa N, Akasaki H, Fairchild DP, Macia ML, Petersen CW, Koo JY, Bangaru NV, Luton MJ (2003). Development of Plate and Seam Welding Technology for X-120 Linepipe. – Proceedings of the 13th International Offshore and Polar Engineering Conference Honolulu, Hawaii, USA.
Hitoshi A, Takuya H, Eiji T, Yoshio T, Masaaki S, Naoki M, Hiroshi M, Koichi S, Kunio K, Masahiko M, Naoki D, Hideki M, Tatsuya Y, Naoshi A, Hiroo A (2004). The Metallurgical Design of High-Strength Steel and Development of X120 UOE Linepipe. - Pipeline Technology Proceedings, Conference, Ostend, Belgium.
Hitoshi A, Eiji T, Shigeru O, Naoki M, Kunio K, Hiroo A, Masahiko M, Hideki M, Takuya H, Hiroshi M, Masaaki S, Koichi S, Yoshio T, Naoshi A, Naoki D, Tatsuya Y (2004). Development of Ultra- High-Strength Line pipe, X120. – Nippon Steel Technical Report No. 90 (UDC 669.14.018.292-462.2:621.643.23)