

## Microstructural characterization and mechanical property evaluation of microalloyed steel

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### ABSTRACT

Experimental evaluation of microstructural and mechanical property of any material is very important for knowing their serviceability, various properties and behavior in different operational conditions. These parametric properties can be used to predict their proper utilization, life prediction, service reliability and operational safety in various condition. The material used in this investigation is a micro alloyed steel. The micro structural characterizations have been done through optical microscopy as well as SEM and various mechanical property evaluation were done through tensile test, hardness test and Charpy impact toughness tests in different orientations. The results have been used to predict the serviceability, and it is observed from this study that this steel contains good amount of ferrite-pearlite combination, and this material show the high tensile strength and better mechanical property for utilizing in the field of automotive and piping industry.

**Keywords:** EDS; Impact toughness; Micro alloyed steel; Microstructure; Mechanical properties; SEM.

### I. INTRODUCTION

Microalloyed steels are designed to provide better mechanical-metallurgical properties and superior resistance to atmospheric deterioration than conventional grade of carbon steels. It is not considered to be alloy steels in the usual sense because this is designed to encounter specific mechanical properties rather than a chemical composition. The chemical composition of a particular Microalloyed steel may be different for different product thicknesses to meet specific mechanical property requirements.

The Microalloyed steels in sheet or plate form have a low carbon content (0.05 to 0.25% C) in order to produce satisfactory mechanical properties such as formability and weldability, and they have manganese content up to 2.0%. Small quantities of chromium, nickel, molybdenum, copper, nitrogen, vanadium, niobium, titanium, and zirconium are used in various combinations [1].

Generally, the mechanical properties are improved by alloying. The different types of alloying methods are low-level, medium-level, high-level and micro-level alloying. Among these alloying techniques, microalloying [2-3] is one of the methods in which the alloying elements such as vanadium, niobium, titanium and zirconium are added individually up to 0.10%. These steels usually show a fine-grained microstructure that offers a superior combination of high strength and excellent

toughness. The room temperature microstructure of microalloyed steel plates depends on manufacturing technique and section thickness [4].

Now a days, these steels have found many applications in manufacturing, industrial parts such as offshore platform nodes, centrifugal cast pipes, machinery supports, nuclear reactor sustenance frames, natural gas compressor housing, ingot moulds and buckets which were all being produced by expensive manufacturing processes [5].

As the most of the parts made by this steel have to be heat treated in various conditions before being used, the effects of different heat treatment variables as well as the effects of prior homogenization, austenitizing time, temperature, cooling rate, inter-critical heat treatment, tempering time and temperature on the mechanical properties of micro alloyed steels have been the subject of many investigations [5-9]. However, the effects of micro alloying additions on the mechanical and micro structural properties of microalloyed steels in the as-received condition has not much investigated.

The objective of this study was to assess the influence of various micro constituent and micro alloying additions on the microstructure and mechanical properties of a microalloyed steel in the as-supplied condition for better utilizing of this steel and prediction of use of this steel in various fields.

### II. EXPERIMENTAL DETAILS

#### 2.1 Materials

The material selected for this research is a microalloyed steel, collected from the Rourkela steel plant, Rourkela, Odisha, India. The steel plates are found as half inch thickness. The chemical composition of the investigated steel is shown in table-1

## 2.2 Microstructural characterization

Micro structural examinations were done on as-received material samples prepared by standard metallographic techniques and etched with freshly prepared 2% nital solution. Well etched samples were studied using Carl Zeiss Microscopy, here all the three directions: L-T, L-S, and T-S orientation micro structure were taken. An Om nimet image analyzer was used to measure the area fraction of various micro constituent.

## 2.3 Mechanical properties

For evaluation of mechanical properties following test have been done as hardness, tensile, and standard room temperature Charpy impact test.

### 2.3.1 Hardness Evaluation

Hardness of the tested sample were examined in mutually three perpendicular orientation of polished surfaces such as L-T, L-S, and T-S surfaces with the help of a computerized Vickers hardness testing machine using a load of 5 kgf. The average hardness of each sample was reported from 10 measurements.

### 2.3.2 Tensile test

Three longitudinal and three transverse orientation tensile test specimens were prepared according to ASTM-E8-M [10] specification from as received material. A round bar specimens of diameter 6 mm and gauge length 30 mm are used for the test. The tests were conducted following the ASTM standard E8-M. All tests were conducted with the help of a computerized 100kN servo hydraulic Universal Testing Machine. During test using a 25 mm gauge length extensometer at room temperature, carried out at a constant displacement rate 1 mm/min. The true stress-strain was measured through 25 mm gauge length extensometer, mounted to the mid-section of the specimen length. The tensile test generated data after test were investigated to estimate the various mechanical properties of the material.

Table 1. Chemical composition of the investigated steel (in wt. %)

Element	C	Mn	Si	P	S	Al	V	Nb	Mo	Fe
(% wt.)	0.20	1.27	0.25	0.021	0.014	0.05	0.001	0.005	0.001	balance

Charpy impact toughness tests were conducted at room temperature. on L-T direction specimens with dimension 10mm X 10mm square cross section and 55mm length, provided 5mm deep U-notch in transverse direction at one side at midpoint of its length [11].

## III. RESULT AND DISCUSSION

### 3.1 Microstructural characterization

By typical SEM and optical micrographs of as-received material are illustrated in fig. 3.1 and fig. 3.2 respectively. The white portion of microstructure refers to the ferrite and light black portion refers to the pearlite. The dark black portion appears as martensite along with carbide precipitate throughout structure in this steel. By optical microscopy studies shows that all microstructures consisted of fine ferrite grains and pearlite. The ferrite matrix gives ductility and toughness to the investigated steel. This optical microstructure illustrates the arrangement and grain structures of the rolled plate in three mutually orthogonal directions. The microstructures of all three mutually perpendicular directions were obtained and shown in Fig. 3.2.

Scanning Electron Microscopy (SEM) studies conducted to illuminate the chemical composition of the material. In this plate, most of the ferrite is characterized by an equiaxed morphology. The equiaxed morphology of the ferrite is associated to the simple reduction in thickness during the final finish rolling.

The Energy Dispersive X-ray Spectroscopy (EDS) analysis of the microalloyed steel is shown in fig. 3.3. This investigation confirms the presence of the elements V, Nb, Mo and Mn in the microalloyed steel. Effects of microalloying elements in the steel are either to get fine grains or to form precipitates. The various factors contributing to the increase in hardness of the microalloyed steel are variations in the pearlite content, the ferrite grain size and the formation of fine carbonitride or inclusion precipitates. Among these factors, the increase in hardness and strength is mainly due to carbonitride precipitates. Based on earlier studies [12], carbonitride or inclusion precipitates form in the matrix. The micro-alloying element titanium and niobium precipitate at elevated temperatures [12–13] and generally, both elements form a precipitate in the

matrix.

### 2.3.3 Charpy impact toughness test

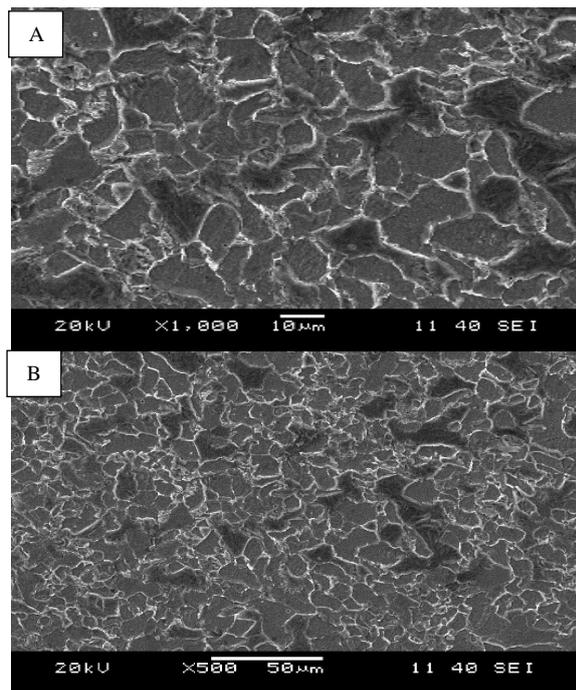


Fig. 3.1 SEM microstructure analysis of microalloyed steel; (A) at resolution 10 μm and (B) At resolution 50 μm

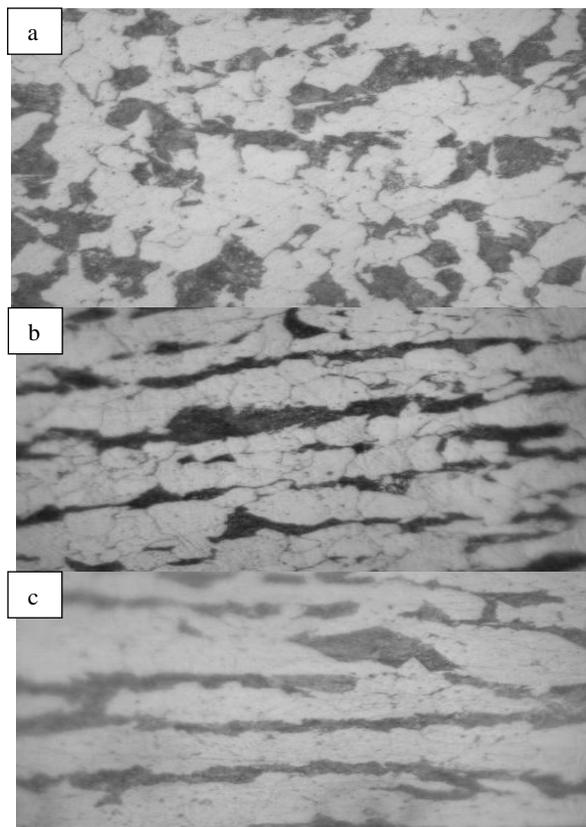


Fig. 3.2 Optical micrograph of as-received material, etched by 2% nital solution in different orientations at a resolution of 100 μm; (a) Longitudinal-Transverse (L-T), (b) Transverse- Short transverse (T-S), (c) Longitudinal- Short transverse (L-S)

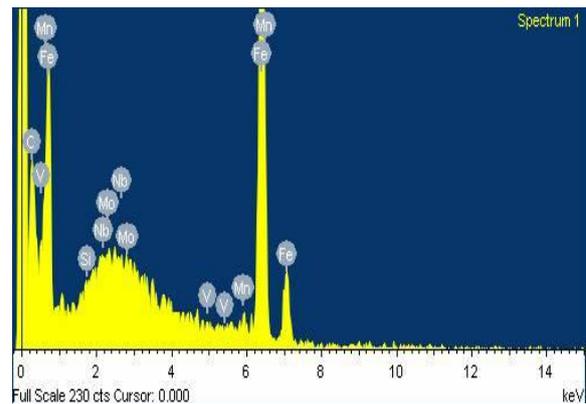


Fig. 3.3 EDS analysis of the microalloyed steel shows the various microalloyed elements

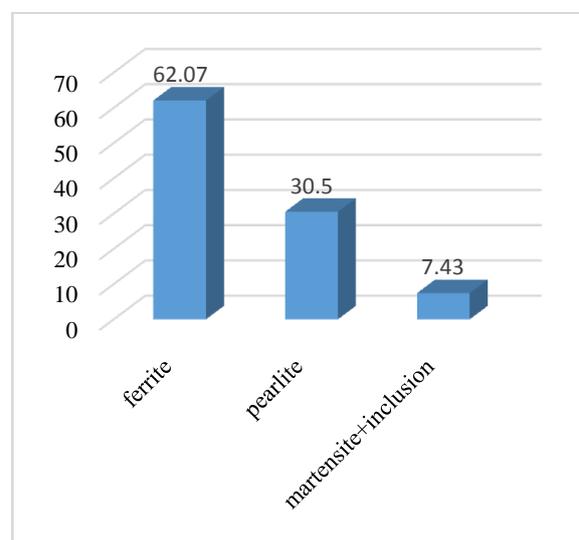


Fig. 3.4 Microconstituent analysis of microalloyed steel in per cent.

### 3.2 Basic mechanical property analysis

The results obtained from tensile, hardness, and Charpy impact tests are described in Table 2. Data presented in this table are the average properties of different testing specimens from different orientation within material sections. The mechanical properties as hardness, tensile strength, room-temperature impact energy percentage elongation and etc. given in Table 2.

#### 3.3.1 Hardness test

Hardness is measured as the resistance of a material to indentations and scratching. This is usually determined by forcing an indenter on to the surface. The resultant deformation in steel is both elastic and plastic. Here hardness values were measured in three mutually perpendicular directions, e.g., *L-T*, *L-S* and *T-S* surfaces with the help of a Vickers hardness testing machine applying a load of 5 kgf. The hardness data in all three orientations are shown in fig. 3.5

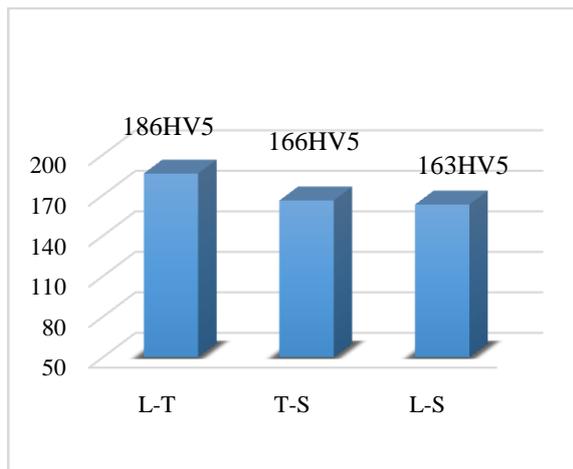


Fig. 3.5 Hardness values of investigated steel in three different orientations.

### 3.3.2 Tensile test

The stress-strain curve for steel is commonly obtained from a tensile test on standard specimens as shown in fig.3.7. The important parameters are the gauge length ( $L_0$ ) and the initial cross section area ( $A_0$ ). The loads are applied through the threaded or shouldered ends. The initial gauge length is taken as five times the diameter in the case of circular specimen.

A typical tensile test curves of the tensile test are shown in fig. 3.9 and fig 3.10 in which a sharp change in yield point followed by plastic strain is observed. After a definite amount of the plastic deformation of the material, due to a reorientation of the crystal structure an increase in load is observed with increase in strain. This range is called the strain-hardening range. After a little increase in load, the specimen ultimately fractures. After the failure it is seen that the fractured surface of the two pieces forms a cup and cone arrangement. This cup and cone fracture is considered to be an indication of ductile fracture.

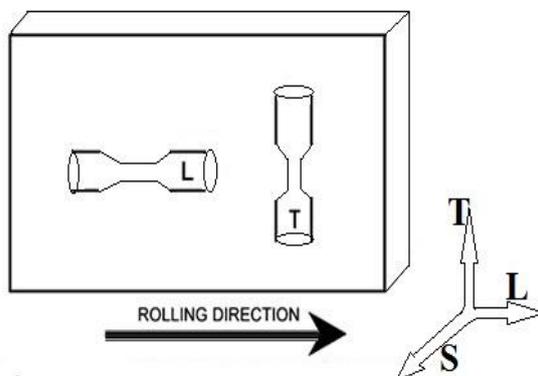


Fig.3.6 Specimen orientation relative to rolling direction. L- Longitudinal, T- Transverse, S- Short-Transverse.

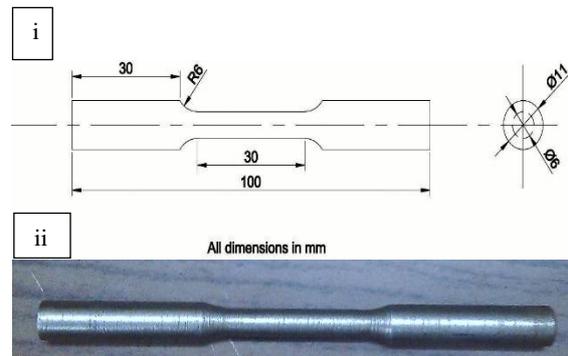


Fig. 3.7(i) Dimensional details of testing tensile specimen and (ii) Finished tensile specimen.



Fig. 3.8 Tested tensile specimen after the test.

Microalloyed steels, due to their specific microstructure, do not show a sharp yield point, but rather they yield continuously as shown in fig. 3.9 and fig 3.10. For such steels the yield stress is always taken as the stress at which a line at 0.2% strain, parallel to the elastic portion, intercepts the stress strain curve. The engineering stress is given by the applied load divided by the original cross section area. Similarly, the engineering strain is taken as the ratio of the change in length to the original length. Normally, these steels, irrespective of plate thickness, exhibit a higher YS/UTS ratio, thereby signifying a minimal strain hardening capability. The increase in the yield strength, UTS, and hardness of microalloyed steel can be recognised to several factors such as variations in pearlite content, and formation of fine-scale inclusion precipitates.

The tensile tests were conducted on BiSS UTM and the one of the load-displacement, engineering stress-strain and true stress-strain plot for each orientation are shown in fig. 3.9 and fig. 3.10 respectively. The tensile and Charpy impact test properties are summarized in Table 2. The tensile values are taken by the average of three tests for each orientation. The 0.2% yield stress and ultimate tensile stress values from the three tests are shown almost same with little deviation for both orientations. The high yield strength found because of ferrite-pearlite grain structure.

### 3.3.3 Charpy impact toughness

The amount of energy absorb is measured by impacting a notched specimen with a heavy pendulum as in Charpy tests. A typical test results were reported for both orientations in Table 2.

Table 2. Tensile and Charpy impact test properties of microalloyed steel

Specimen orientation	Yield strength ( $\sigma_{YS}$ ) in MPa	Yield load ( $P_{Yield}$ ) in kN	Ultimate tensile strength ( $\sigma_{UTS}$ ) in MPa	Peak load ( $P_{Peak}$ ) in kN	E in GPa	Poisson ratio ( $\nu$ )	Strain hardening coefficient (n)	% EL in 25mm gauge length	% RA	Charpy Impact energy (J) at room Temp.	Charpy Impact toughness $\left(\frac{kJ}{m^2}\right)$
Longitudinal	622.45 $\pm 10$	17.69 $\pm 2$	778.62 $\pm 10$	22.22 $\pm 2$	210	0.33	0.156	27 $\pm 2$	47.9 $\pm 2$	67.52 $\pm 5$	1125.31 $\pm 20$
Transvers	619.32 $\pm 10$	16.25 $\pm 2$	775.83 $\pm 10$	21.56 $\pm 2$	210	0.33	0.154	26.2 $\pm 2$	43.8 $\pm 2$	65.06 $\pm 5$	1015.63 $\pm 20$

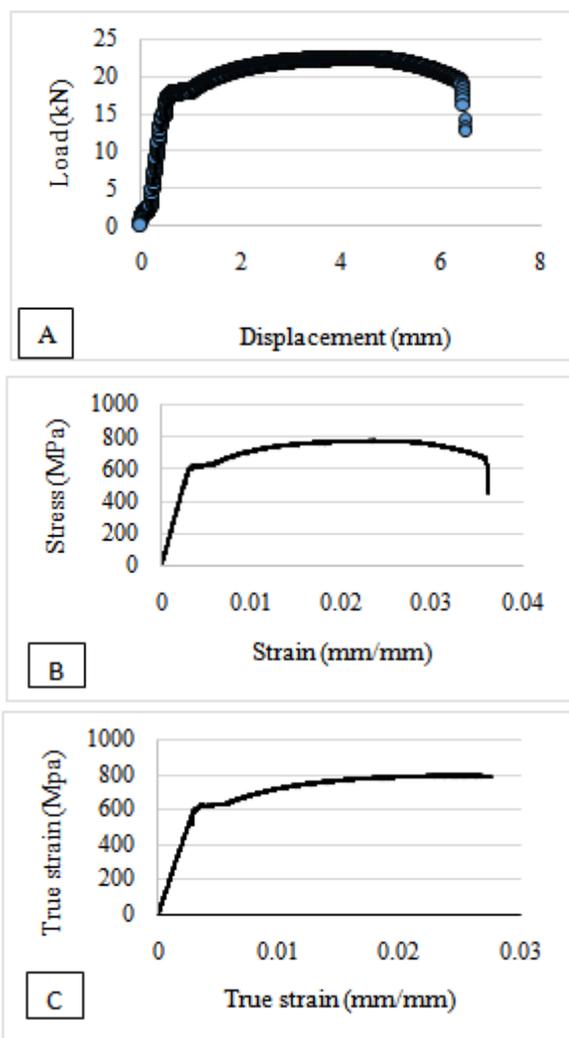


Fig. 3.9 Tensile test curves for longitudinal orientation (A) Load vs. displacement curve (B) Engineering stress vs. engineering strain curve (C) True stress vs. true strain curve

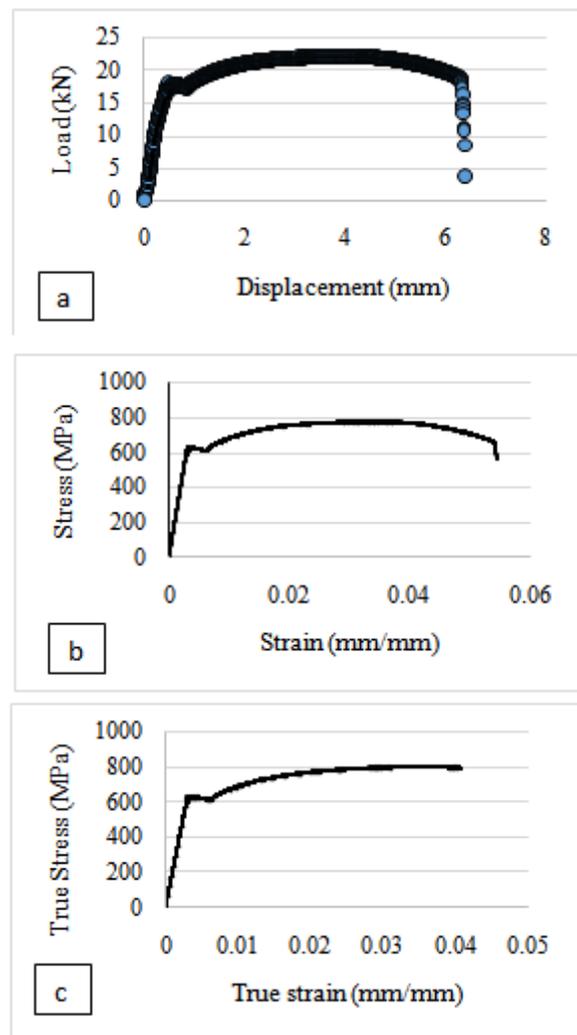


Fig. 3.10 Tensile test curves for transverse orientation (a) Load vs. displacement curve (b) Engineering stress vs. engineering strain curve (c) True stress vs. true strain curve.

#### IV. CONCLUSIONS

From the present study following conclusion have been found as:

- (1) Mechanical properties has higher values in the longitudinal direction rather than other directions. This could be clarified with the help of microstructure restricted orientation with rolling direction.
- (2) The higher tensile strength value found in these steel is related to the presence of martensite with inclusion precipitate in the matrix, and the refined grain of ferrite-perlite microconstituent in steel, however, shows higher yield strength, probably related to the fine grain structure of the steel.
- (3) Due to the presence of microalloying elements increase the yield strength, UTS, and hardness significantly. Based on the measurements, it seems that fine ferrite play a major role in increasing the strength and impact toughness of the microalloyed.
- (4) By optical microscopy studies, it shows that all microstructures consisted of fine ferrite grains and pearlite. The ferrite matrix gives good ductility and toughness to the investigated steel.
- (5) From the present analysis, it is found that this steel fulfilling the requirements of various mechanical properties for utilizing in the field of automotive and piping industry.

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