AN INVESTIGATION ON THE EFFECT OF STATIC TENSILE LOADING ON THE DUCTILE TO BRITTLE TRANSITION TEMPERATURE OF MILD STEEL

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Abstract: Low carbon steel or often called mild steel is extensively used for structural applications and in automobile industries due to its high strength and good ductility. The ductile to brittle transition (DBT) temperature for such material is determined by the Impact test, Charpy test or Izod test. However, in this work, the DBT is determined by the tensile loading at a low strain rate which shows lower DBT temperature under tensile load. Since the transition is a continuous and slow process; hence the failure probability is more perceptible when a component or a system is under static tensile loading. The test method adopted could preciously determine the DBT temperature. The brittleness factors determined by mechanical test are fully supported by the observed microstructure of the fractured samples.

Introduction: Mild steel is a type of carbon steel with a low amount of carbon – also known as low carbon steel and does not contain a large amount of other elements besides iron (Fe) due to which there are several properties that differentiate it from high carbon and alloy steels[1]. The venerable thermal properties enable this alloy to be economically rolled, extruded or forged into useful shapes Less carbon makes mild steel typically more ductile, machinable, and weldable than other steels, which means it cannot be hardened and strengthened through heating and quenching [2]. The less amount of carbon and other alloying elements which lead to block dislocations of the crystal structure, generally resulting in less tensile strength than high carbon and alloy steels. It has a high resistance power to breakage as opposed to high carbon steels, quite malleable, even when cold, which means it has high tensile and impact strength [3]. High carbon steels usually shatter or crack under stress, while mild steel bends or deforms.

Ductile to brittle transition (DBT) is an interesting property exhibited by some steels and other BCC materials. The estimation of DBT is done by a series of impact tests such as Charpy and/or

Izod [4]. These impact tests are of high strain rate tests, which do not suffice the usage of the material in practical applications [5-7]. In view of the above, there is a need for other tests for assessing the DBT regime of the material. The tensile test at slow strain rates is one of the solutions. Since the ductile and brittle fracture are two different offsetting mechanisms that result under tensile loading and finally leads to cleavage fracture. The ductile fracture exhibits a substantial plastic deformation with high energy absorption before fracture, while the brittle fracture exhibits a little or no plastic deformation with low energy absorption before fracture. [8,9].

Brittle fracture and ductile tearing are two offsetting mechanisms responsible for the ductile-to-brittle transition regime of different alloys like Steel. In this regime, the steel structure can withstand a significant amount of ductile tearing without substantial loss of its load-bearing capacity. However, many experiments show that stable crack growth by ductile tearing eventually gives way to catastrophic cleavage fracture. The latter appears to be the critical failure mechanism limiting the load-bearing capacity of the structure. Thus, it becomes important to estimate the cleavage failure probability of components operating at low temperatures or in irradiation environments (even if the temperature is in the ductile regime) [10].

Yield point, tensile strength, and elongation percent are the other measurements that determine the material properties. These measurements accurately identify the point at which the material will incur irreparable damage, the point where the material will fail, and the percentage difference between those two points.

Experimental Setup and Test Procedure: The basic test facility(Fig 1a)essentially includes a servo-hydraulic computer-controlled Universal Testing Machine (BiSS, Bangalore make), cryostat capable of maintaining temperature up to -150°C, cryo-can/ pressure vessel for holding & circulating liquid nitrogen, temperature controller cum indicator, specimen temperature indicator, nitrogen gas cylinder, laser extensometer, diametrical mechanical extensometer and so on. A typical photographic view of the test arrangement for testing grooved specimens is shown in (Figs. 1a. &1b). For carrying out tests, the specimens were fixed in position with the help of holders and diametrical extensometer gripped over the specimen gauge diameter suitably. Laser reflection tapes were fixed at the outer ends of the mechanical extensometer to serve as reference points for the laser extensometer to measure diametrical contraction. A chromel-alumel thermocouple (k-type) was placed in close contact with the specimen for measuring the specimen temperature during testing. Static load was applied gradually until the specimen is fractured. The tensile tests were carried out at the crosshead speeds of 0.03 mm per minute for grooved specimens with a gauge length of 2.5 mm, to maintain a strain rate of $2x10^{-4}$ s^{-1}. The diametrical contraction was measured through the laser and diametrical (mechanical) extensometers and recorded along with the corresponding load. The purpose of using both extensometers was to ensure the correctness of the measurement and to correct any discrepancy incurred in the recording due to ice deposition or drift of extensometer. This has helped in eliminating the repetition of any test due to the malfunctioning of any of the extensometers or fault in the recording. The plots of load as a function of diametrical contraction for the grooved specimens were directly displayed on the monitor.

Subzero temperatures are maintained in the cryo-chamber by passing liquid nitrogen vapor from the cryocan at positive atmospheric pressure. Pressurized nitrogen gas was passed through the cryocan at a controlled pressure and regulated flow rate for feeding the cryostat chamber with the required quantity of liquid nitrogen vapor. The controller in the cryo-chamber enabled to regulate the flow of the liquid nitrogen in the chamber to maintain the set temperature of the specimen within the accuracy of $\underline{+}1^{o}$C. The laser extensometer placed outside the cryostat chamber was focused on the two ends of the mechanical extensometer with the reflecting tape on its ends. A heating device (up to ~50^{o}C) was also placed near the window to remove fog/moisture deposition from outside on the window (Quartz glass) thereby enabling the laser extensometer to get the clearly reflected beam/signal back from the reference points (reflecting tapes) of the mechanical extensometer. Dimensions, like gauge diameter and length of the specimens, were measured prior to and after the tests. Diametrical contraction for grooved specimens is measured by the contact type (mechanical) and non-contact type (laser extensometer) during the tensile tests have been recorded as a function of the applied load.

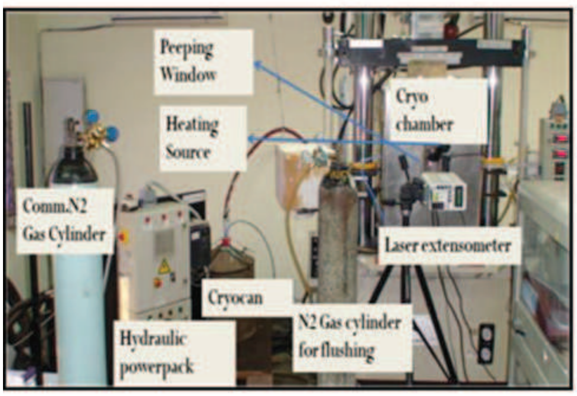


Fig 1a. Basic test facility along with accessories (Exterior view)

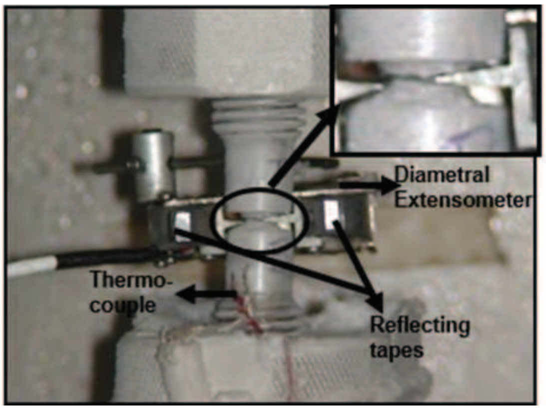


Fig 1b. Grooved specimens while testing at -500C (Interior view)

Results & Discussion: Tensile tests on grooved specimens have been carried out at three temperatures namely ambient, -10, and -50^{o}C. Diametrical contraction with respect to the peak & breaking load of specimens is recorded prior to failure at the test temperatures.

Comparisons of the load-diametrical contraction of the grooved specimens at different temperatures are shown in Fig.2awhich shows with the decreasing test temperature, an increasing trend in yield strength and tensile strength and a reducing trend in diametrical contraction prior to specimen failure resulting in ductile to the brittle transition of the specimens. Fig 2b represents the stress-strain plot of the grooved specimens tested at all three temperatures.

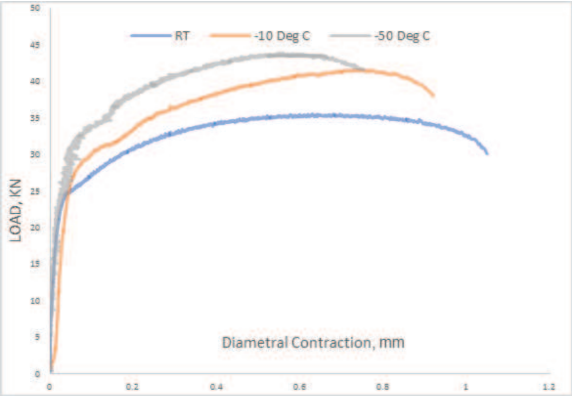


Fig 2a: Load- Diametral Contraction Curves

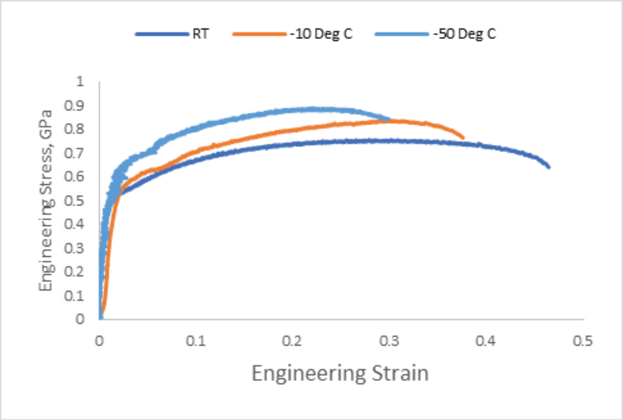
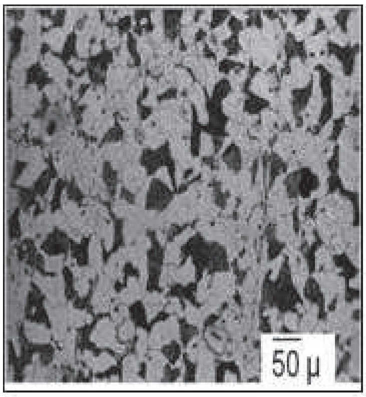


Fig 2b. Stress-Strain Curves

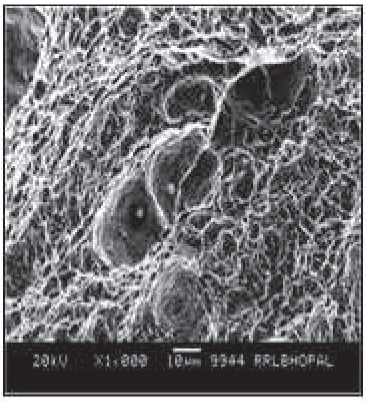
Fractography: Fig. 3 (a, b & c) shows the fractography of the specimens as received, tested at -10°C and -50°C respectively. Fig 5a shows the cup-cone fracture with nucleation point in its center which clearly shows a ductile fracture also confirmed by the % brittleness as shown in Fig.4a.

Fig.5b. shows cleavage fracture which confirms the brittle fracture as shown in Fig.4a. Cleavage generally takes place by the separation of atomic bonds along well-defined crystal planes. Ideally, a cleavage fracture would have perfectly matching faces and be completely flat and featureless.



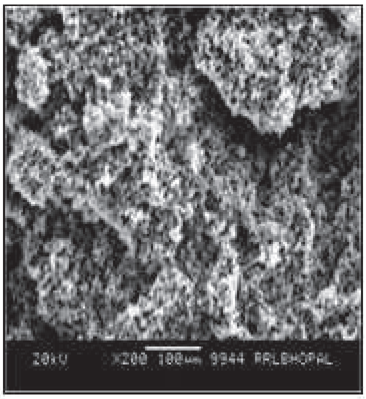
Mild Steel as received

Fig 3a



Mild Steel at -10˚C Ductile Fracture

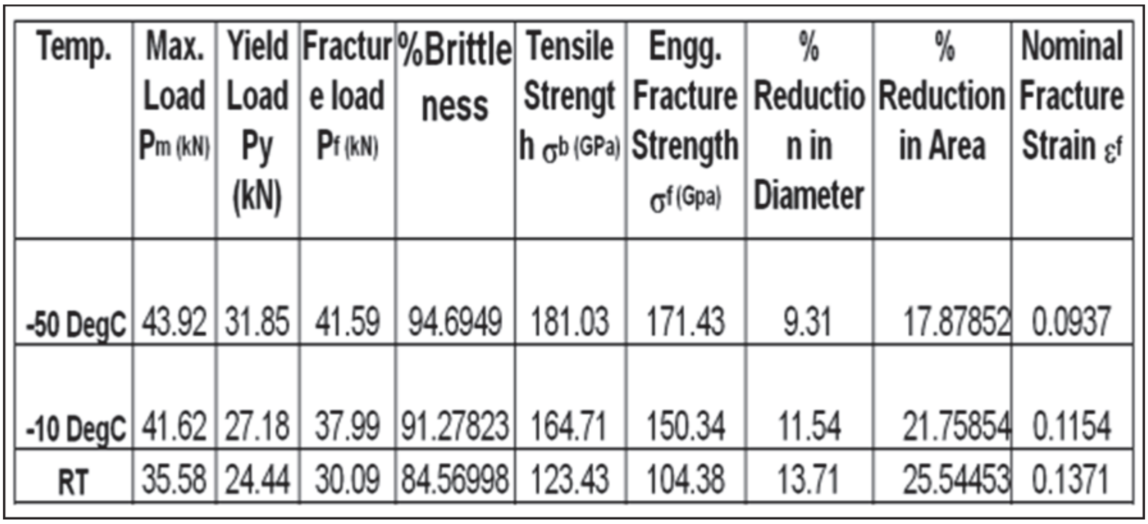
Fig 3b



Mild Steel at -50˚C Brittle Fracture

Fig 3c

Tensile Properties: The relative brittleness is measured as the ratio between the breaking load to peak load. Brittleness (%) does not have much difference at sub-zero temperatures, which clearly matches the load-axial extension curves. This may be due to the slow strain rate testing of the specimens or of microstructural defects of the specimen. Maximum load (P_m), Yield load (P_y) and Fracture load (P_f) increase with the decrease in temperature as shown in Fig 4b. While in, % reduction in diameter, % reduction in area and nominal fracture strain decreases with a decrease in temperature as shown in Fig. 4c. All the values are tabulated in Table.1.



Temp.	Max. Load P_m (kN)	Yield Load Py (kN)	Fracture load P_f (kN)	%Brittleness	Tensile Strength σ_b (GPa)	Engg. Fracture Strength σ_f (Gpa)	% Reduction in Diameter	% Reduction in Area	Nominal Fracture Strain ε_f
-50 DegC	43.92	31.85	41.59	94.6949	181.03	171.43	9.31	17.87852	0.0937
-10 DegC	41.62	27.18	37.99	91.27823	164.71	150.34	11.54	21.75854	0.1154
RT	35.58	24.44	30.09	84.56998	123.43	104.38	13.71	25.54453	0.1371

References:

1. T. Aldeeb, M. Abduelmula, "Fatigue Strength of S275 Mild Steel under Cyclic Loading", International Journal of Materials and Metallurgical Engineering, Vol:12, No:10, 2018, 564-570.
2. Hasan MF*, "Analysis of Mechanical Behavior and Microstructural Characteristics Change of ASTM A-36 Steel Applying Various Heat Treatment", J Material Sci Eng 2016, Vol 5(2): 227
3. J.F. Knott, C.A. English, D.R. Weaver, D.P.G. Lidbury, "Views of TAGSI on the effects of gamma irradiation on the mechanical properties of irradiated ferritic steel reactor pressure vessels", International Journal of Pressure Vessels and Piping. Vol. 82, 2005, pp. 929–940.
4. D. Bhattacharjee &J.F.Knott, " A critical shear strain criterion for the ductile brittle transition in HY100 steel under mixed mode I & II loading", 11 International Conference on Fracture, 2005.
5. Siewert, T. A., Manahan, M. P., McCowan, C. N., et al., The history and importance of impact testing in Pendulum impact testing: a century of progress, ASTM STP 1380, 2000, 3-16.
6. Xianqiao&Weisheng Lei, "Research into fracture behavior of mild steel in Charpy V-notch impact test", International Journal of fracture, 59, 1993, 7, 5-79.
7. S.J. Wu, C.L. Davis, A. Shterenlikht, And I.C. Howard, "Modelling the Ductile-Brittle Transition Behavior in Thermomechanically Controlled Rolled Steels", 36A, April 2005, Metallurgical and materials transactions A, 989-997.

8. Mateusz Stec · Jonas Faleskog, “Micromechanical modeling of grain boundary resistance to cleavage crack propagation in ferritic steels”, Int J Fract (2009) 160:151–167.
9. R. Thomson, “Brittle fracture in a ductile material with application to hydrogen embrittlement”, Journal of materials science, 13, 1978, 128-142.
10. SB Bhimavarapu, AK Maheshwari, D Bhargava, BK Dutta & SP Narayan, “An investigation on the effect of tensile loading on the ductile to brittle transition temperature of ferritic steel” SMiRT-21,Dec, 2011, Vol. 3, 2183-90.

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