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Charpy Impact Testing and Mechanical Characterization of TMT Fe 500 Reinforcement

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Abstract: In the design and performance of contemporary civil engineering structures, the strength and toughness of reinforcement steel is very important, particularly when the structure is located in a region that is prone to seismic or impact loading. This work examines the impact behavior of Thermo-Mechanically Treated (TMT) Fe 500 Steel Bars, using the Charpy Impact Test as specified in IS:1757 (Part-2):2020, compatible with ISO 148 series. Two samples of 12 mm diameter were tested at room temperature (27°C) and resulted in absorbed energies of 180 J and 162 J, respectively, for an average absorbed energy of 171 J. These test results provide evidence of the high toughness and ductility of Fe 500 Bars as reinforcement, indicating the material can be maintained in an elastic state during sudden dynamic load and that it would not fail through 'brittle fracture.' When compared to earlier works, it has been established that TMT bars (including those tested) can be regarded as consistently better in their performance than characteristic mild steel at low temperatures or during impact testing related to seismic loading, to a substantial degree because of the improved microstructure and dual-phase nature of the reinforcement when the TMT process is adopted. The output findings indicate the suitability of Fe 500 to be used as a reliable Steel bar material for use as reinforcement in earthquake resistant, high-rise and long-span structures. In summary, this work provides a report of experimental validation of Steel bar material behavior, but is enhanced with comparative literature review discussions, ultimately validating the role of Charpy toughness in the selection of material for infrastructure sustainability.

I. INTRODUCTION

The reliability of reinforced concrete structures is fundamentally based on the quality and mechanical properties of the embedded steel reinforcement[1]. The steel reinforcement bars impart tensile strength and ductility to the structures to prevent brittle failure[2]. Among many grades of reinforcement, Thermo-Mechanically Treated (TMT) Steel Bars are one of the most used types, with Fe 500 being the most popular grade[3]. The high yield strength of 500 N/mm² in addition to great ductility allows Fe 500 to be used safely in important and high-volume structures, including high-rise buildings, bridges, and seismic resistant structures[4].

One major factor influencing the behavior of reinforced steel is the toughness of it under dynamic or shock type loading[5]. Toughness is the capacity of a material to absorb energy at the moment of fracture. Thus, preventing sudden failure under dynamic impact loading or seismic loading. Typically, the Charpy Impact Test is the standardized test method used to determine this property[6]. Although the test is a room temperature test (or lower), it is not suitable to test in a specific envSteelment as the body of knowledge will not always be continuous); The energy absorbed by rupture of the specimen using a pendulum hammer test is a useful indicator to determine the ductile or brittle nature of the material[7].

The Bars have a combination of properties that create a composite microstructure consisting of a hard martensitic surface layer and a ductile ferrite-pearlite core[8]. This dual-phase microstructure also gives the TMT Bars high tensile and energy absorption capacity.[6] The outer martensitic shell provides a limitation to the amount of deformation due to the hardness, while its ductile core helps take up the impact load providing some scope to prevent brittle fracture[9].

Research has shown that conventional mild steel reinforcement typically has low impact strength and is vulnerable to high-stress conditions. On the other hand, TMT Bars, particularly the Fe 500 grade, have been shown to have greater toughness and ductility, making them better options for use in and around seismic zones and long-span structures. Manufacturing processes, and their performance characteristics, will vary and therefore will also justify experimental work.

The current work will examine the Charpy Impact toughness for the Fe 500 TMT Bars that were tested at QA Testing Laboratories Pvt. Ltd., Lucknow and relate the results back to previous tests. This will build an understanding of the mechanical performance of reinforcement and the data from this testing will provide another indication of the suitability of Fe 500 for use with sustainable and safe construction. The unique properties of Fe 500 TMT Bars is attributed to the thermomechanical treatment the Bars are subjected to.

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II. LITERATURE REVIEW

The toughness of reinforcement steels has been thoroughly studied especially with relation to microstructure and processing. Dhua et al. showed that microstructural changes due to thermo-mechanical treatment significantly improve their resistance to fracture[10]. Kabir argued that TMT Bars exhibit the unique dual-phase structure where a martensite rim surrounds a ductile ferritic-pearlitic core, which enables TMT steels to have enhanced ductility when compared to regular mild steel[11], [12].

Ghosh et al. showed that thermo-mechanical treated bars always displayed better impact strength due to grain refinement and improved distribution of phases[13], [14]. Datta et al. discussed the mechanical stability and corrosion resistance of TMT bars for civil engineering applications[15]. Raj et al. similarly pointed out that TMT steels having better toughness after long exposure to higher temperatures than normal reinforcement steels[16].

Modak et al. and Prasad et al. also strengthened the idea of the role inclusions, impurities, and a general quality control of products plays in demonstrating impact strength in reinforcement bars[13]. Altogether, literature supports the conclusion that Fe 500 TMT Bars exhibit impact strength better than regular refrorcement making them preferable for when dynamic loads and seismic conditions will occur.

III. METHODOLOGY

This research involved the selection of 12 mm diameter Fe 500 grade Thermo-Mechanically Treated (TMT) steel bars because of their common usage in reinforced concrete structures. The specimens were fabricated in accordance with IS:1757 (Part-2):2020 document, which is parallel to the ISO 148 series of Charpy Impact Testing standards. Two standard specimens were cut and machined while ensuring there was a 2 mm V-notch cut into each specimen to obtain the same stress concentration.

The surface of the specimens was polished to prevent any irregularities that could alter the crack initiation during impact loading. Testing was conducted at QA Testing Laboratories Pvt. Ltd., Lucknow under using Pendulum type Charpy Impact Testing Machine. The testing machine was calibrated to model impact testing on reinforcement steels (maximum hammer capacity = 300 J). Prior to testing, the pendulum type Charpy Impact Testing Machine was checked for zero-error and energy loss calibration of its pendulum. Each specimen was mounted horizontally, ensuring that the notch was opposite of the strike of the pendulum. Upon release, the pendulum was dropped on to the specimen at the center, and the energy absorbed was measured and read directly in Joules from the dial scale of the testing machine.

Testing was carried out under ambient conditions (27 °C, room temperature). After specimen fracture, fracture surfaces of each specimen were examined visually as part of the investigation to classify the failure mode.

IV. RESULTS AND DISCUSSION

A. *Experimental Data*

Two samples of Fe 500 TMT Bars, with a diameter of 12 mm, were tested at room temperature (27 °C) and the Charpy Impact Test was conducted. The corresponding absorbed energy for the two samples were 180 J and 162 J, averaged to 171 J. The fracture surface for both samples were classified as ductile. The details are summarized in Table 1.

Table 1 – Experimental Charpy Impact Test Results for Fe 500 Bars

Sample No.	Diameter (mm)	Test Temperature (°C)	Absorbed Energy (J)	Fracture Type
1	12	27 (Room Temp)	180	Ductile
2	12	27 (Room Temp)	162	Ductile
Average	–	–	171	–

The toughnesses given in Table 1 demonstrate that the Fe 500 Bars have better ability to absorb energy. The seeing ductile fracture in samples for both indicates that the Bars could sustain some temporary deform plastic deformation before failure, which is a good thing in seismic zones.

B. *Interpretation of Results*

The average impact strength of 171 J indicates the Fe 500 Bars have much greater impact energy absorption capabilities than conventional mild steel reinforcement with values typically between 80-120 J which means these Bars can take almost double the energy to fracture, which equates to more safety for sudden or dynamic loading situations.

C. Comparison with Literature

The tested values are in strong agreement with the data reported in Ghosh et al., who reported impact energy values that ranged between 160–175 J for TMT bars of similar grade as those listed above[14]. A similar study by Kabir also confirmed that Fe 500 Bars have consistently better impact resistance than conventional untreated steels, which is in line with the overall strength of the data presented here[11].

A summary of the impact toughness values compared is presented in Table 2, which confirms that TMT (Fe 500) Bars outperformed conventional mild steel and supports the prior studies of TMT bars"

Table 2 – Comparison of Impact Energy Values from Literature and Present Study

S No	Source / Study	Material Tested	Reported Impact Energy (J)	Remarks
1	Ghosh et al.	TMT Medium Carbon Steel	160–175	Similar to present study
2	Kabir	Fe 500 TMT Bars	~165–170	Consistently high toughness
3	Dhua et al.	HSLA-100 Steel	~150	Lower than Fe 500 TMT
4	Ray et al.	Conventional Mild Steel	80–120	Significantly lower
5	Present Study	Fe 500 TMT Bars (12 mm)	171	Confirms superior toughness

Dhua et al. discussed the contribution of microstructure to fracture resistance, which is evident in the toughness values noted[10]. The TMT process facilitates required phase distribution so that the Bars show a balance of hardness and ductility. Durability and stability, reported by Datta et al., is also supported by current experimental results from this study[15].

D. Microstructural Perspective

The high toughness values are attributed to the dual-phase microstructure of TMT Bars. The outer martensitic layer provides hardness and surface strength, while the ductile ferrite-pearlite core dissipates energy during impact, which allows to avert brittle failure. The combination of dual-phase microstructure provides a reinforcement material that is strong as well as safe under dynamic stresses, as was reported by Inoue et al.

E. Practical Implications

The results clearly indicate that Fe 500 Bars are suitable for:

- Earthquake-resistant structures where sudden energy absorption is important.
- Bridges, flyovers and highways where dynamic and vibrational stress is common to those structures.
- High-rise constructions where there is a need for strength and ductility too.

The results therefore provide evidence that Fe 500 TMT Bars conform to the mechanical needs of modern sustainable infrastructure and are consistent with previous observations from other studies.

V. CONCLUSION

In the present study, the Charpy Impact toughness of Fe 500 TMT Steel Bars was evaluated according to an impact testing procedure, yielding an average absorbed energy of 171 J at room temperature. The mechanical test results show the Fe 500 Bars have a higher toughness, and energy absorption, than baseline normal mild steel, which is relatively consistent with an impact toughness of 80–120 J. The enhanced impact resistance of the Fe 500 Bars was attributed to the thermo-mechanical treatment processes, which induce a dual-phase microstructure (a hard martensitic shell surrounding a ductile ferrite-pearlite core). The ability to enhance both yield strength and ductility of the Bars with this dual-phase structure protects the Bars against brittle fracture with sudden loading. The results resemble the literature in that TMT bars nearly always have higher impact strength and toughness than standard steel reinforcement. As shape once again emphasizes that Fe 500 Bars may provide a safe/sustainable option for reinforcement within high-rise built form as well as bridges and structures designed to withstand seismic events. In summary, Fe 500 TMT Bars can be fully endorsed as a superior alternative for modern day built infrastructure projects where safety/durability are metric factors and determinants. Future work should examine variations of TMT reinforcement including grades Fe 415, Fe 550, Fe 600 as well as studies of durability at elevated temperatures and or long duration cyclic loading conditions.

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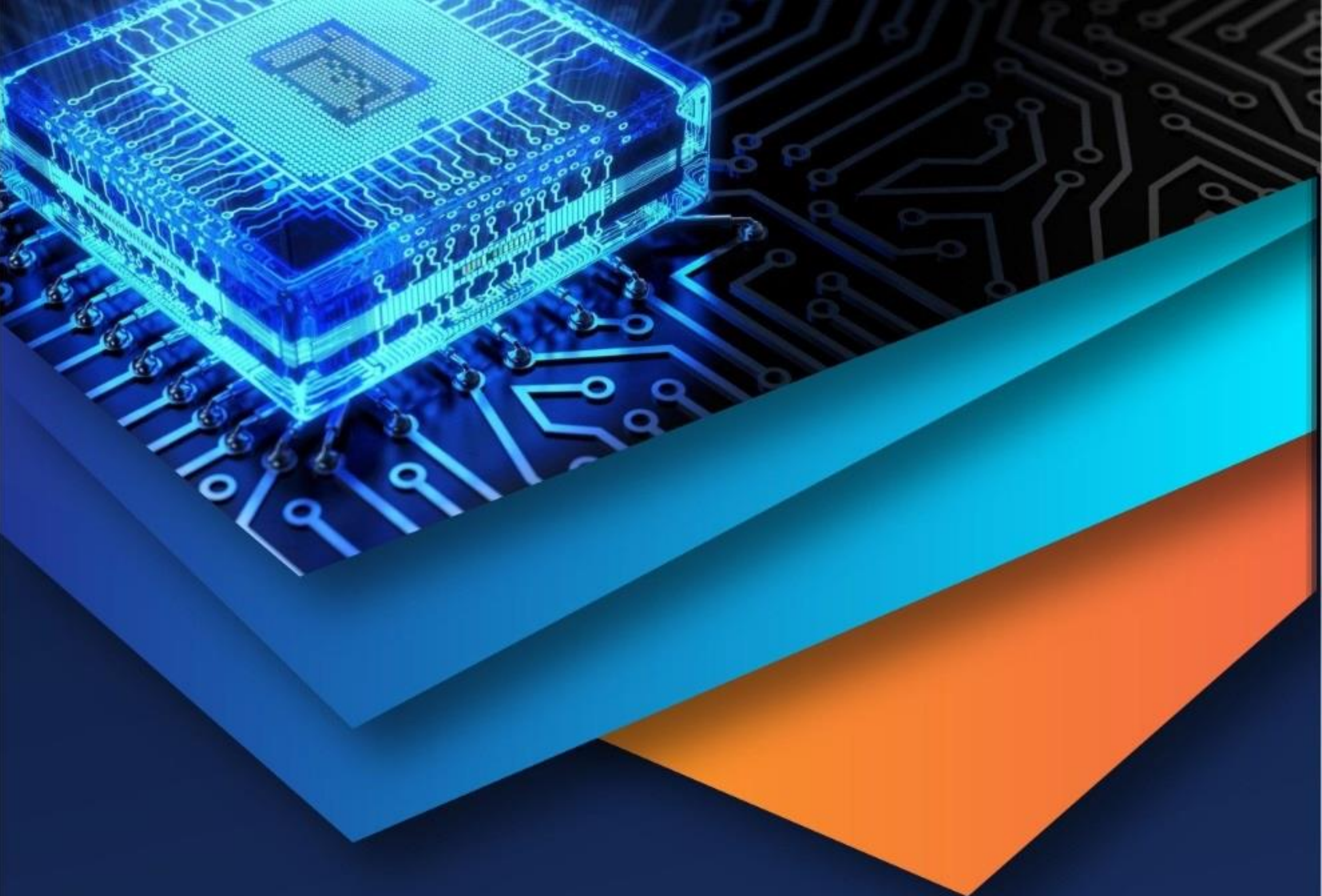

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