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Effect of Cryogenic Condition on Mechanical Properties and Corrosion Behavior of Corten ASTM A242 Steel

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Abstract
The Corten steel being a weathering steel, is preferred in fabrication of railway coaches, bridges, structures etc. The Corten steel in its field of application, is exposed to harsh climatic conditions, like extreme heat, cold climates, humidity, etc. Hence in the experimental investigation an effort is made to study the effect of low or cryogenic conditions on the mechanical and corrosion properties of the corten steel. Even though generally deep cryogenic treatment (DCT) is applied on materials to improve their properties, in this study the corten steel is exposed to a shallow cryogenic condition to replicate the natural cold snow and below freezing temperatures in the field of application. In this study the corten steel specimens are exposed to a cryogenic temperature of -15ºC and tested to determine the mechanical properties and corrosion behavior. This experimental investigation showed that the corten steel when exposed to cryogenic condition, has inherent property to improve its mechanical properties and considerably improve its corrosion resistance.

Keywords: Cryogenic condition, Mechanical properties, Salt spray test, Corten ASTM A242 Grade Steel

1. Introduction

The metal based components are subjected traditionally to heat treatments to modify the microstructure and there by achieve improved properties like, tensile strength, impact strength, wear resistance, corrosion resistance, etc. Similarly studies have been carried out in order to enhance the material's properties by exposing the material to cold temperature conditions and complimented by the traditional heat treatment processes. The low temperature or cryogenic treatments are basically three types, viz., conventional cold treatment (CCT), deep cryogenic treatment (DCT) or sub-zero treatment (SZT) or ultra-low temperature process (ULTP) and shallow cryogenic treatment (SCT). The SCT yields Microstructural changes leading to enhanced hardness, reduced size and increase in number of carbide precipitates and their homogenous distribution [1, 2]. The cryogenic treatments are given to tool steel and other tool materials to impart wear resistance and high hardness and

good impact toughness to tools and thereby improving the life of the tools [3 – 12]. Generally cryogenic treatment is carried out on structural steels to improve their mechanical properties with minimal alloying and embrittlement [13 – 20]. In this study the effect of extreme cold climatic conditions on corten steel is studied by using cryogenic treatment with liquid nitrogen and exposing the corten steel to low temperatures like -15 ºC. At the onset of this study it was feared that the corten steel may exhibit signs of embrittlement. But the corten steel exhibited promising results which indicate its good performance even in extreme cold conditions. Further there is scant literature on the influence of cryogenic conditions on corten steel, which necessitated this study.

2. Materials and Methods

Corten ASTM A242 Grade Steel of 3 mm thickness was subjected to cryogenic condition of -15 ºC by exposing it to liquid nitrogen. The hardness of corten steel was determined using Vickers hardness machine conforming to ASTM E384 - 10e2 Standard Test Method. The tensile properties and flexural strength test were done in a universal testing machine (UTM) were carried as in conformance to ASTM-E8 and ASTM E290 respectively. The impact strength of the corten steel was determined using charpy impact testing machine conforming to ASTM E23 standard. The salt-spray test was used to study the material deterioration due to corrosion.

3. Results and Discussion

3.1 Hardness test

The microhardness measurements exhibited a minor increase of around 5% microhardness in the specimens subjected to cryogenic condition and is shown in Fig.1. This increase in microhardness shall be caused by the microstructural changes and the formation of hard particles when corten steel is exposed to cryogenic temperature of -15ºC. The increase in hardness shall produce a synergetic influence and yield enhanced mechanical properties and corrosion resistance.

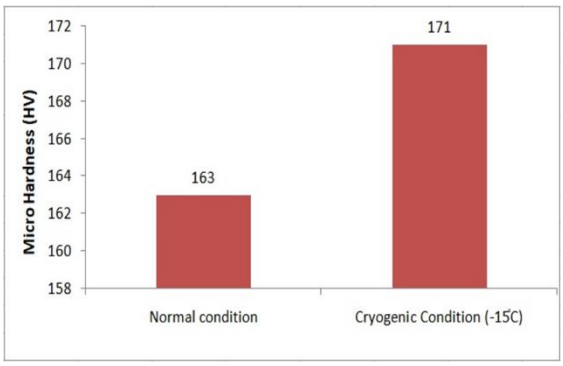
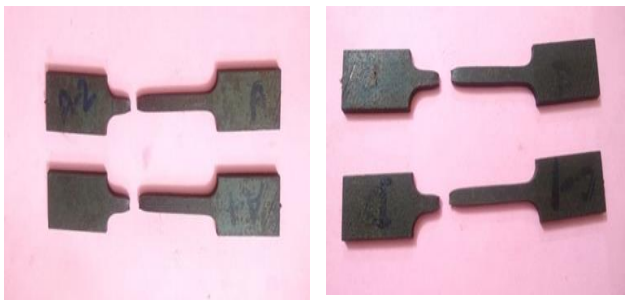


Fig. 1 - Micro hardness of Corten steel specimens

3.2 Tensile properties

The corten steel samples exposed to hot condition exhibited an increase of 14 % in tensile strength reduction in percentage elongation of 4% and is shown in Fig.2 and Fig.3. This

reduction of percentage elongation can be correlated with the increase in microhardness and tensile strength. Even though there is reduction in % elongation, this does not mean increase of brittleness.



(a) (b)

Fig. 2 - Tensile fractured Corten steel specimens (a) Normal condition. (b). Cryogenic condition

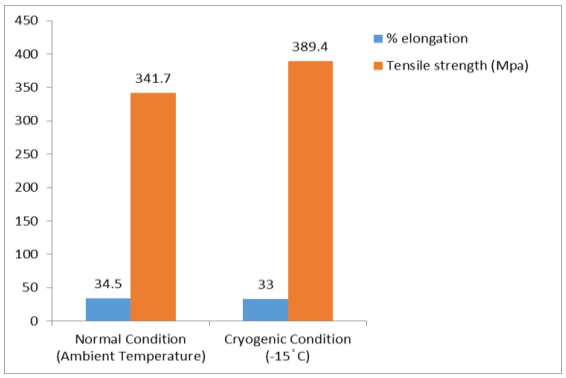
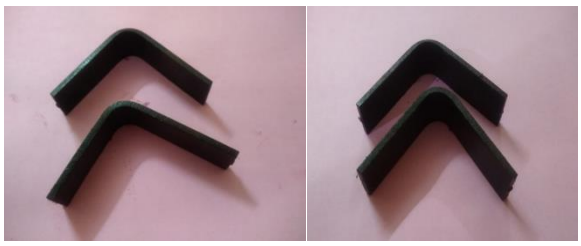


Fig. 3 - Tensile Properties of Corten steel specimens

3.3 Flexural test

The corten steel treated to cryogenic condition performed fairly well in the flexural test. The flexural test results show that the corten steel does not become brittle when exposed to cryogenic conditions and is shown in Fig. 4. In spite of slight increase in the displacement the corten steel is able to have better ultimate load bearing capacity with a 19% increase in cryogenically treated specimens and is shown in Fig.5.



(a) (b)

Fig. 4 - Flexural tested Corten steel specimens (a) Normal condition. (b). Cryogenic condition.

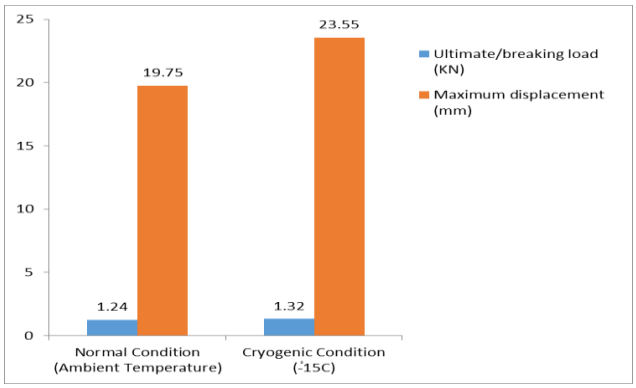
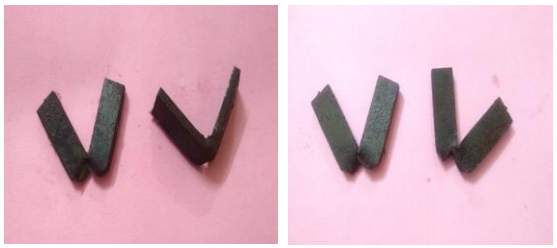


Fig. 5 -Flexural Properties of Corten steel specimens

3.4 Impact test

The corten steel exposed to cryogenic condition exhibited an increase of 10% in the impact strength, as shown in Fig. 6 and Fig.7. This result indicates that the cryogenic temperature aids in strengthening the corten steel and improving its impact strength. Further the increase in impact strength shows that the corten steel is immune to embrittlement at -15 ºC cryogenic temperature.



(a) (b)

Fig. 6 - Charpy impact test fractured Corten steel specimens (a) Normal condition. (b). Cryogenic condition.

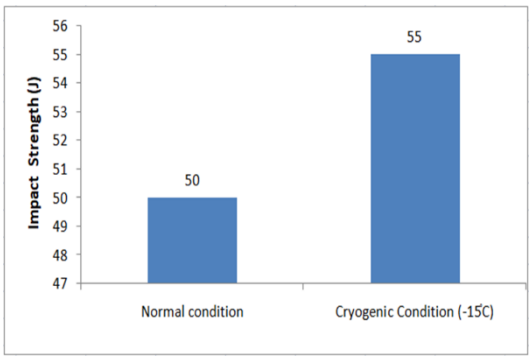


Fig. 7 - Impact strength of Corten steel specimens

3.5 Salt spray test

The corten steel corrosion test coupons subjected to salt spray test exhibited a 72.75% reduction in corrosion rate, in the cryogenically treated specimens. This shows that the -15 ºC treatment modifies the corten steel and improves the corrosion resistance greatly. Further the loss of material due to corrosion is negligible after cryogenic treatment as shown in Fig. 8 and Fig.9.

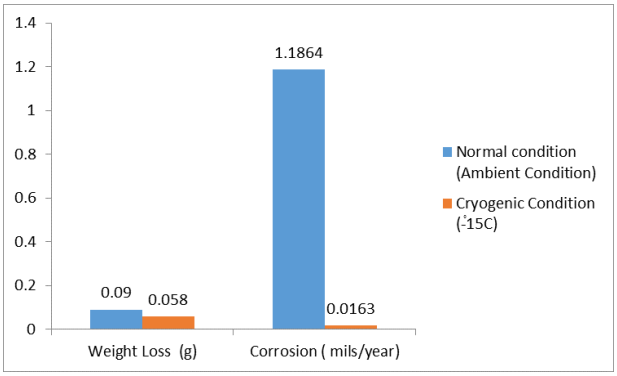
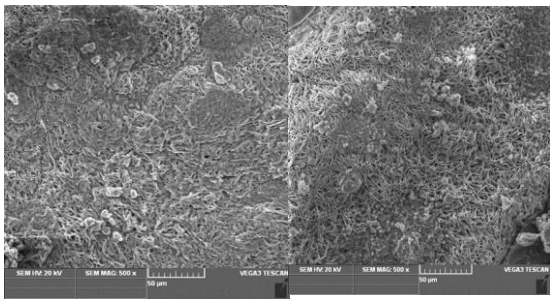


Fig. 8- Corrosion Properties of Corten steel specimens

The Fig. 9 (a) shows the uniform formation of oxides (rust) on the surface of the normal condition test coupons with bigger primary carbides. Fig. 9 (b) shows a uniform rusting throughout the surface of the corten steel subjected to cryogenic treatment. The big primary carbides appear as smaller uniformly distributed secondary carbides in the cryogenically treated corten steel. This shall attribute to the increase in mechanical properties and increase in corrosion resistance.



(a) (b)

Fig. 9- Morphology of corroded corten steel (a) Corten steel in normal condition (b) Corten steel in cryogenic temperature

Conclusions

The Corten steel subjected to cryogenic condition of -15 ^{O}C exhibited better tensile, flexural and impact properties than the specimens from normal condition. This experimental study proves that the corten steel when exposed to shallow cryogenic condition exhibits an improvement in its mechanical and corrosion properties. Hence the corten steel is conducive to be applied in places where extreme cold conditions prevail. The patina (rust layer) formation is uniform over the surface of the corten steel and it becomes adherent after

exposure to cryogenic condition. This investigation indicates that the corten steel is an ideal candidate for cryogenic temperature conditions.

References

1. Patricia Jovi cevic-Klug, Bojan Podgornik, (2020). Review on the Effect of Deep Cryogenic Treatment of Metallic Materials in Automotive Applications. Metals, 1-12.
2. Anil Kumar Singla, Jagtar Singh, (2018). Processing of materials at cryogenic temperature and its implications in manufacturing: A review. Materials and Manufacturing Processes, 1-39.
3. Patricia Jovi cevic-Klug, Gasper Pus a, (2022). Influence of heat treatment parameters on effectiveness of deep cryogenic treatment on properties of high-speed steels. Materials Science & Engineering, 1-12.
4. Molinari, A., Pellizzari, M. (2001). Effect of deep cryogenic treatment on the mechanical properties of tool steels. Materials processing technology, 350-355.
5. Mohan Lal, D., Renganarayanan, S. (2001). Cryogenic treatment of augment wear resistance of tool and die steels. Cryogenics, 149-155.
6. Leskovsek, V., Kalin, M. (2006) Influence of deep-cryogenic treatment on wear resistance of vacuum heat-treated HSS. Vacuum, 507–518.
7. Oppenkowski, Weber, S. (2010). Evaluation of factors influencing deep cryogenic treatment that affect the properties of tool steels. Journal of Materials Processing Technology, 1949–1955.
8. Akhbarizadeh, Shafyei, A. (2009) Effects of cryogenic treatment on wear behavior of D6 tool steel. Materials and Design, 3259–3264.
9. Pello Jimbert, Maider Iturrondobeitia. (2018). Influence of Cryogenic Treatment on Wear Resistance and Microstructure of AISI A8 Tool Steel. Metals, 1-11.
10. Santosh, Manjunatha. L. H. (2018). A review: Mechanical Properties of HSS Steel by deep Cryo-Treatment. Materials Science and Engineering, Pages-1-13.
11. Dileep Korade, Kavuluri Venkata Ramana. (2019). Influence of Cryogenic Treatment on the Tribological Behaviour of AISI H21 Tool Steel. Materials Research, 1-12.
12. Sanjeev Katoch, Vishal Singh. (2019). Mechanical Properties and Microstructure Evaluation of Differently Cryogenically Treated AISI-H11 Steel. International Journal of Steel Structure, 1-12.
13. Zhirafar, S., Rezaeian, A. (2007). Effect of cryogenic treatment on the mechanical properties of 4340 steel. Journal of Materials Processing Technology, 298–303.
14. Binzhou Li, Changsheng Li, (2018). Effect of Cryogenic Treatment on Microstructure and Wear Resistance of Carburized 20CrNi2MoV Steel. Metals, 1-13.
15. Srinivasagam Ramesh, Bhuvaneshwari, B. (2019). Enhancing the corrosion resistance performance of structural steel via a novel deep cryogenic treatment process. Vacuum, 468–475.
16. Yifeng Yao, Yajun Zhou. (2018). Effects of Deep Cryogenic Treatment on Wear Resistance and Structure of GB 35CrMoV Steel. Metals, 1-11.
17. Nandu Mohan, Sanjivi Arul, (2018). Effect of Cryogenic Treatment on the Mechanical Properties of Alloy Steel 16MnCr5. Materials Today, 25265–25275.

18. Vinıcius Richieri Manso Goncalves, Bojan Podgornik, (2019). Influence of Deep Cryogenic Treatment on the Mechanical Properties of Spring Steels. Journal of Materials Engineering and Performance.
19. Pradeep Samuel, A., Sanjivi Arul, (2018). Effect of Cryogenic Treatment on the Mechanical Properties of Low Carbon Steel IS 2062. Materials Today, 25065–25074.
20. Chaanthin, M. K., Arul Sanjivi, (2019). Improving Surface Hardness of EN31 Steel by Surface Hardening and Cryogenic Treatment, 1-6.