UNIZIK JOURNAL OF AGRICULTURAL AND BIOSYSTEMS ENGINEERING

UJABE

Journal homepage: https://journals.unizik.edu.ng/ujabe/

June (2026), 1(3): 27-42

ISSN: 3141-2912

CRYOGENIC TREATMENT STRATEGIES AND ITS INFLUENCE ON THE MECHANICAL PROPERTIES OF STRUCTURAL STEEL GRADES: A REVIEW

***Adeniyi, E. K.[1], Ajide, O. O.[2] and Towoju, O. A.[1]**

[1]*Department of Mechanical Engineering, Lead City University, Ibadan, Oyo State.*

[2]*Department of Mechanical Engineering, University of Ibadan, Ibadan*

**Corresponding Author's E-mail:emakenny76@gmail.com,*

Received: 31st January 2026; **Accepted:** 4th May 2026; **Available Online:** 30th June 2026

ABSTRACT

Cryogenic treatment (CT) is the post – treatment process applied after conventional heat treatment process in steel. It is a process of using materials (structural steel grades) at a very low temperature. It involves subjecting materials to an extreme low temperature. When structural steels are subjected to cryogenic treatment, it will improve the mechanical and physical properties of the steel. The noticeable enhancements observed in materials subjected to cryogenic treatment are increased thermal conductivity, increased in dimensional stability, toughness, increased in wear resistance, fatigue resistance, increased in hardness, reduce residual stress. The cryogenic treatment temperature at which hardened material is further cooled may range from -80℃ to -196℃. Cryogenic treatment helps in converting retained austenite to martensite and also refining of grain structure of structural steels. The aim of this paper is to carry out a review of cryogenic strategies and its influence on mechanical properties of structural steel grades. The review paper discussed cryogenic treatment procedure, comparison of various mechanical properties as well as influence of cryogenic treatment on structural steel grades.

Keywords: Cryogenic Treatment; Structural Steels, Mechanical Properties, Parameters, Retain Austenite, Martensite

1.0 INTRODUCTION

Structural steel is a fundamental material extensively used in engineering applications due its excellent mechanical properties, such as high strength, ductility, and toughness. However, the demand for improved performance and durability of structural steel components in harsh operating environments has led to the exploration of advanced processing techniques. Heat treatment process is commonly used to improve properties of structural steel grades. For structural steel grade, properties such as hardness, wear resistance, toughness, thermal conductivity, dimensional stability, residual stresses, fatigue resistance are improved by conventional heat treatment process – involving hardening (austenitizing and quenching) and tempering. (Mansi and Niyati, 2017) Conventional heat treatment lacks the ability of converting sizeable quantity of retained austenite into martensite during quenching in hardening process. This retained austenite is trapped in the matrix of martensite manifests in form of defects that weaken the part and noticeable changes in mechanical properties of steel (Mansi and Niyati, 2017; Patil and Tated, 2012; Volgar et al. 2020). Cryogenic Treatment (CT), otherwise known as Cryogenic processing, is majorly referred to be complementary process of conventional heat treatment process. It is usually performed after hardening and done before tempering (Mansi and Niyati, 2017; Patil and Tated, 2012) (. Cryogenic treatment is applied to enhance some mechanical properties of materials through changing the microstructure in order to improve service performance or extend the service life of structural steel grades (tools or parts) (Haidong et al. 2021). Cryo-treatment technology is eco-friendly, non – toxic, non – explosive and not expensive. This technology has been largely studied on numerous ranges of materials by many researchers in present times, like different structural steel grades (Soleimany et al. 2019; Varghese et al. 2019), non – ferrous alloys (Gao et al. 2019), metallic glass (Patil and Tated, 2012), polymers (Mansi and Niyati 2017). Apparently, there are mainly two classifications involved in cryogenic treatment, which are Shallow Cryogenic Treatment (SCT) and Deep Cryogenic Treatment (DCT) (Chen, et al. 2020). The two classes are differentiated as follows:

- The highest treating temperature for shallow cryogenic treatment is around -80^{0}C whereas highest treating temperature for deep cryogenic treatment is around -196^{0}C.
- Holding time for SCT varies between 5 hours to 8 hours, whereas holding time for DCT varies between 16hours to 48hours.
- There is no specific cooling rate and warming rate in SCT whereas DCT maintained uniform cooling rate and warming rate ((Mansi and Niyati, 2017; Patil and Tated, 2012).

2.0 Cryogenic Treatment Procedure

The cryogenic treatment consists of gradual cooling of the material being subjected to the treatment at a constant rate, holding it at the desired temperature and finally return it back to room temperature at a steady heating rate (Herrera, 2020). The deep cryogenic treatment process is most commonly used in industry. The material samples are kept inside an insulated treatment chamber with a liquid nitrogen storage tank used as a cooling medium. Fig.1. below is block diagram of cryogenic treatment set up. In the set up the cooling can be achieved by submerging the samples in a liquid nitrogen bath. This can lead to thermal shock and, subsequently, cracking of the samples (Herrera, 2020), to prevent thermal shock it is necessary to control the cooling rate by regulating the nitrogen flow to gradually reduce the temperature inside the chamber where the samples are being treated. The temperature control system is composed by a nitrogen reservoir connected to the treatment chamber through a solenoid-controlled valve, link to by programmable temperature and cycle controller and was connected to the thermocouple inside the treatment chamber (Herrera, 2020).

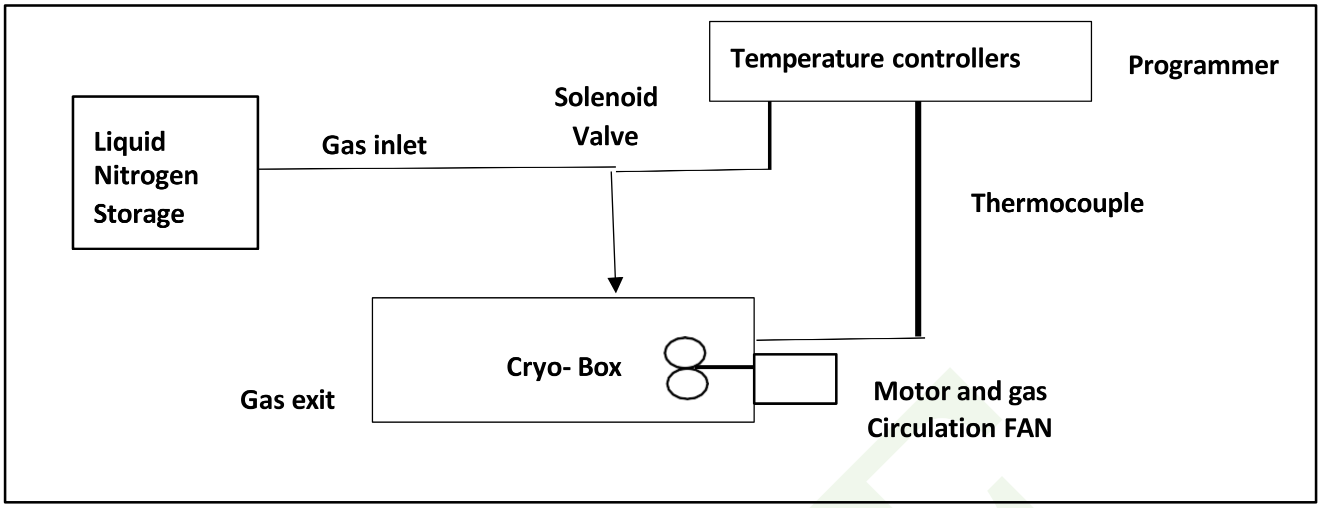

Fig. 1: Block diagram of cryogenic treatment set up. **Source:** (Lakhani and Rant, 2017)

Obviously, there are four major parameters of the cryogenic treatment that affects the output of the treatment, these are cooling rate, cryogenic temperature, holding time and warming rate. Cooling and warming rate are majorly controlled at a low value to avoid thermal shock which may lead to increase in inter atomic spacing resulting in cracks development in steels (Mansi and Niyati, 2017; Patil and Tated, 2012; Haidong, et al. 2021). Fig.2. is a time - temperature diagram for cryogenic treatment process. Cryogenic treatment process involves cooling of materials to cryogenic temperatures at a constant cooling rate (ramp down rate), holding the material at that temperature for specific time (soaking period), then bringing the materials back to the room temperature at constant heating rate (ramp up heat). (Maximov and Duncheva, 2024).

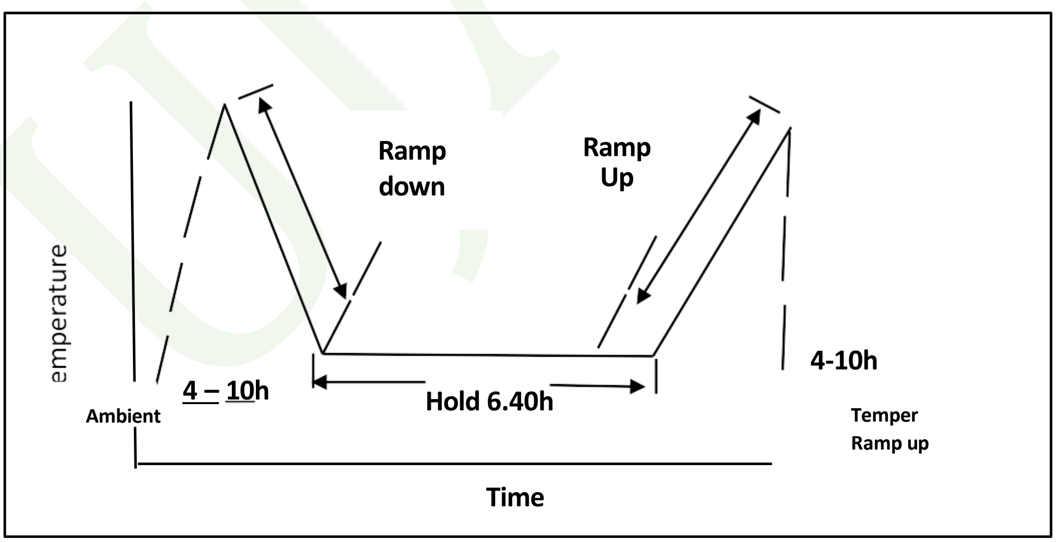

Fig. 2: Time – Temperature diagram for general cryogenic treatment process. **Source:** (Lakhani and Raut, 2017).

Research from over two decades showed that improvement of mechanical properties, mostly wear resistance can be achieved substantially by lowering the temperature of sub-zero treatment by using liquid nitrogen (LN_2) as cryogen or as cooling agent (Patil and Tated, 2012). Any alteration in property is attributed to the microstructural changes. Thus, in tool steels, the following are the likely process changes that need to be considered for the property change (Patil and Tated, 2012). However, the effectiveness of the cryogenic treatment at liquid nitrogen depends on;

- Removal of retained austenite
- Transforming retained austenite to more stable tempered martensite matrix
- Formation of Eta – carbides
- Precipitation, nucleation and development of ultra-fine carbides with high population density.
- Homogeneous and well distributed microstructure.

There are many developed empirical studies on cryogenic treatment cycles and the treatment indicated different results for different materials. The variation in results is due to variation in parameters of cryogenic treatment. The paper aims at reviewing cryogenic treatment strategies and its influence on mechanical properties of structural steel grades.

Table.1: Comparison of Various Mechanical Properties

Author	Objective	Mechanical Property	Stal. Grade	Cryogenic Temperature ^{0}C , time h or min	Results
Bansely, et al. (2005)	Conducting wear test with no lubrication as per ASTM Standard	Wear Resistance	En 353 carburized steel	193K (5h) 433K (90min)	+85% wear resistance for SCT +372% wear resistance for DCT
Zhirafar, et al. (2007)	Effects of cryogenic treatment was investigated on the mechanical properties and microstructure of AISI 4340 steel	Hardness and Fatigue resistance	En 353 and E23 ASTM Standard	845 (15min)	Cryogenically treated samples have a lower value in comparison with conventionally treated.
Darwin, et al. (2008)	Using Taguchi method to optimize the process parameters of DCT for piston ring	Wear resistance	SR 34 18% Cr martensitic stainless steel	-80, -184	-43.8% wear rate
Silva, et al. (2006)	Examine microstructural changes in treated high speed steel	Wear Resistance	AISI M2	600, 625, 630	-44% tool life, +343% tool life, -22.8% produced parts.

Ferguson, et al. (2005)	Derive the phase transformation kinetic parameters through optimization method.	Hardening	Pyro wear 53 steel	900	Improved compressive residual stress
Yong, et al. (2006)	Study the effects of cryogenic treatment of tungsten carbide	Wear Resistance	ASSAB 760	-184	Better performance of cryogenically treated tools than untreated tool when carried out continuous cuts for short period of time.
Yun, et al. (1998)	Investigation the effect of cryogenic treatment on Mechanical property on high-speed steel and W18CrV(T1)	Hardness impact toughness	W18Cr4V (T1) High Speed Steel	-185	+2.8% hardness +57.7% toughness
Liu, et al. (2019)	Examine microstructure evolution and mechanical/physical properties of 25# valves alloy steel subjected to deep cryogenic treatments	Hardness Tensile strength Yield strength	25# valves alloy steel	-196^{0}C (24h)	+28.9% hardness +215% tensile strength +511% yield strength
Weng, et al. (2020)	Investigating reinforcement role of deep cryogenic treatment on the strength and toughness of alloy structural steel.	Hardness Impact Toughness Tensile strength	30 CrMnSi alloy Structural Steel	-186^{0}C (36h)	+8% hardness +5% impact toughness +6% tensile strength

Hariharan, et al. (2019)	Study life time improvement of D7 tool steel by cryogenic treatment	Hardness	D7 tool steel	-196℃ (24h)	+4.6% hardness
Pillai, et al. (2018)	Investigate effect of cryogenic treatment on VIKING cold working tool steel and development of wear mechanism maps.	Hardness Wear Resistance	VIKING Tool Steel (AISI A8)	-185^{0}C (16h)	+14.8% hardness +16.5% wear resistance
Li, et al. (2017)	Study influences of different cryogenic treatments on high temperature wear behaviour of M2 steel.	Hardness Wear resistance	AISI M2 Tool steel		+64% hardness +54% wear wear resistances
Yumak, et al. (2017)	Examine effect of cryogenic and aging treatments on low-energy impact behaviour of T16A1-4V alloy	Hardness Tensile strength	Ti-6AI-4V		+2.2% hardness -0.3% tensile strength
Perez and Belzunce (2015)	Investigate effect of deep cryogenic treatments on mechanical properties of AISI HI3 Steel	Hardness Fracture toughness	HI3 tool steel		-1.1% hardness +24% fracture toughness

Zeju Weng, (2026)	Study effects of deep cryogenic treatment on M2 high speed steel	Hardness Thermal Stability	M2 High Speed Steel	-80^{0}C (20 min) - 120°C (30 min) - 160°C (2h)	Increased hardness Improve thermal Stability
Kara, et al. (2023)	Investigate effect of deep cryogenic treatment on microstructure, mechanical properties and residual stress of AISI 52100 bearing steel.	Tensile strength Hardness Fatigue strength	AISI 52100 bearing steel	-190°C (12, 24, 36, 48, 60 h)	5.2%, 3.6%, 3.35%, 2.9% and 1.7% tensile strength Increase hardness with DCT-36 122%, 105%, 100%, 40% and 12% fatigue strength
Piesko, et al. (2024)	Study on the use of cyclic cryogenic treatment to improve the properties of high-speed steel	Tensile strength Impact strength Hardness wear resistance	High-speed steel	-70^{0}C (6h)	5% tensile strength 17% impact strength 4% hardness 10% wear resistance
Kara, et al. (2025)	Investigate effect of shallow and deep cryogenic treatment on wear and impact performance of DIN 1.2344 steel	Hardness Wear Resistance Tensile strength Impact toughness	DIN 1.2344 steel	-80 (12h) -80 (24h) -180 (36h)	1.79% and 5.17% improvement in hardness 1.34, 9.31% and 13% improvement on wear resistance. 24.73% and 2.45% in yield strength and tensile strength respectively. 2.37% fracture energy
Herrera, (2020)	Study effect of cryogenic treatment on the abrasive wear resistance of engineering alloys	Hardness Wear Resistance	AISI 440C AISI 304L		Increase in hardness Increase in wear resistance
Ozbek and Ozbek, (2025)	Examine impact of deep cryogenic treatment on X210CrW12 steel's wear behaviour and microstructural characteristics	Hardness Wear resistance	X210CrW12 steel	-180^0 (36h)	12.06% hardness 59.27% wear resistance
Karakurt, et al. (2024)	Investigate effect of deep cryogenic treatment on microstructural and mechanical properties of high performance CPOH and WPTV tool steels.	Hardness Wear resistance	CPOH and WPTV tool steel		1.8% hardness for CPOH 1.4% hardness for WPTV 78.67% and 51.03% hardness for CPOH and WPTV respectively 76.22% and 88.95% wear resistance for CPOH and WP74 respectively.

3.0 Influence of Cryogenic Treatments on Structural Steel Grades

3.1 Tool Steels

(Zhang and Yan, 2021) studied the effect of cyclic cryogenic treatment on wear resistance, impact toughness, and microstructure of 42 CrMo steel and its optimization. Orthogonal design method was used to investigate the effect of different parameters of cryogenic treatment on wear resistance and impact toughness of the steel. The results show that after cryogenic treatment, they exhibit higher wear resistance and impact toughness, whereas no significant change in hardness. The amounts of carbon and alloying elements in tool steels are high, it resulting in lowering martensite start and finish temperatures. Specifically, martensite finish temperature becomes much lower than the environmental temperature for stool steels (Das, et al. 2010a; Das, et al. 2010b).

However, Chowwanonthapunya, et.al. (2022) carried out a brief review and a case report on cryogenic treatment of tool steels, majorly in terms of the process of cryogenic treatment and the modification of microstructures and mechanical properties. They also presented the case study of two cryogenic treatments, conventional cold treatment and deep cryogenic treatment, with respect to the conventional heat treatment. The finding revealed that DCT improve the hardness and wear resistance of tool steels when compared to CHT and conventional cold treatment. The improvement was due to removal of retained austenite as well as homogenous distribution of fine carbides. Podgornika, et al. (2016) investigated the effect of DCT on fracture toughness, wear resistance and load carrying capacity of cold work tool steel. The research work was to determine the effectiveness of DCT depending on the tool steel type and chemical composition. It was concluded that the type and chemical composition of the tool steel considerably affect the way how deep cryogenic treatment changes mechanical, tribological and load – carrying capacity of the tool steel. (Amini, et al. 2012), studied the optimum soaking time during cryogenic treatment. They performed deep cryogenic treatment on 12080 tool steel bar. Post- austenite the tool at 950^{0}C, cryogenic treatment of the tool was performed at a cooling rate of 1^{0}C/min until cryogenic temperature with heating rate of 1^{0}C/min. Samples were tempered after cryogenic treatment at 180^{0}C with holding period of 1 hour. Samples were classified on the basis of holding time of 24, 36, 48, 72, 96 and 120h, and identified as DCT24, DCT36, DCT48, DCT72, DCT 96 and DCT120, respectively. The study confirmed that microstructure, hardness, carbide percentage are affected by varying the soaking duration. Hence, 36 hours of soaking duration is considered as optimum and resulted in maximum improvements in properties of tool steel.

3.2 Carbon Steel

Carbon Steel is one of the major types of structural steels. Carbon Steel is an iron – carbon alloy, which contains up to 2.1wt. %carbon. For carbon steels, there is no minimum specified content of other alloying elements, however, they often contain manganese. Lakhani and Raut, (2017) explained that plain carbon produced good balance between strength and ductility, which is obvious in many types of steel parts. They are also easily machinable. They explained further that quenching and tempering as well as carburizing are major heat treatment process used for improving properties of medium carbon steel. Zhirafar, et al. (2007) studied the effects of cryogenic treatment on the mechanical properties and microstructures of A1S1 4340 steel. Mechanical tests such as rotating fatigue, impact and hardness were carried out. It was shown that hardness and fatigue strength of the cryogenically treated specimens were a little higher whereas the toughness of the cryogenically treated specimens was lower. Harpreet Singh, et al. (2010) investigated the effect of DCT on corrosion resistance and mechanical properties of mild steel (low – carbon steel) which underwent conventional treatment and DCT. The study concluded significant improvement in tensile strength and corrosion resistance of deep cryogenic specimens. Lakhhani and Raut, (2017), evaluated influence of cryogenic treatment on mechanical properties of EN8 steel, a medium carbon steel. The specimens were subjected to cryogenic treatment after hardening. Cryogenic treatment was done at 193 ^{0}C with cooling rate and heating rate of 0.5^{0}C for 1hour was done after cryogenic treatment.

3.3 Stainless Steel

Cryogenic treatment on stainless steels is just one method that can be used to reduce commonly occurring microstructural defects in stainless steels. With cryogenic treatment the general strength properties of stainless steels can be improved and with the additional heat treatment, plasticity can also be effectively preserved. Zhenhua Li, et al. (2022) investigated the effects of different heat and cryogenic treatments on the mechanical and tribological properties of 316L stainless steel formed by selective laser melting. The mechanical properties of samples processed by heat treatment, cryogenic treatment, and a combination of heat and cryogenic treatment were compared. It was found that the samples treated by (600^{0}C x 3h) + (-196^{0}C x 24h) exhibited better mechanical properties and the best strength and plasticity, with a tensile strength of 585 MPa and elongation of 68.5%. The experimental results of friction and wear showed that the sample treated by (600^{0}C x 3h) + (-196^{0}C x 24h) exhibited a low friction coefficient of about 0.7 and a wear amount of 28 x 10 $^{-3}$mm^3, indicating that the materials have strong wear resistance. Paolo Baldissera, et al. (2010) examined the influence of deep cryogenic treatment on the hardness, tensile properties, fatigue and corrosion resistance of A1S1 302 stainless steel. The tensile and hardness tests results are compared to others martensitic stainless steel found in literature. The author has also analyzed the influence of two DCT parameters that is soaking time and minimum temperature through a design of experiment (DOE) and by first approximation model. The author also discussed the effect of A1S1 302 SS on fatigue and corrosion resistance. The test was done for both solubilized and hardened steel. The fatigue resistance was improved in solubilized SS 302 while there were no significant changes in the hardened material. However, there was not change in corrosion resistance of both the materials. (Upadhyay, et al. 2019) tested the effect of deep cryogenic treatment on the mechanical and metallurgical properties of SS 316. Deep cryogenic treatment was followed by tempering at two temperatures: 350^{0}C and 250^{0}C possessed greater hardness and tensile strength, however, the toughness of both the samples is affected negatively.

3.4 Alloy Steel

Earlier researchers worked on effect of cryogenic treatment on tool steel, carbon steel and stainless steels. After noticeable advantages of cryogenic treatment were observed in those structural steel grades, many research works were done on alloy steel. (Bensely, et al. 2005) evaluated the effects of shallow cryogenic treatment on the distribution of residual stresses in case carburized En 353 steel using XRD technique. The conclusion is that cryogenic treatment should be performed before tempering to achieve the best mechanical properties. Cracks were seen on the surface of un-tempered samples, and is detrimental to the life of the component. However, sample subjected to CHT and SCT+ tempering showed better fatigue properties as compared to samples subjected to DCT + tempering. Senthil Kumar and Rajandran, (2011) examined the influence of SCT and DCT on wear behavior of En 19 steel. The samples were treated conventionally quench hardening in oil at 875^{0}C for 1h. Other set of samples were shallow cryogenic treated in freezers at – 80^{0}C for 5 hours after conventional quench hardening. Other samples were deep cryogenic treated after conventional quench hardening. The DCT was done – 196^{0}C with soaking time of 42hrs, cooling rate of 1.26k/min and heating rate of 0.24K/min. All differently treated samples were tempered at 200^{0}C for 1h. After hardness test, wear test and microstructure analysis were carried out. Wear test was carried out at lower load values of 10N, 20N and 30N and higher load values of 60N, 70N and 80N. The results showed improvement of wear resistance by 118.38% for SCT samples and

214.94% for DCT samples when compared to conventionally treated samples. More so, the increase in wear resistance of DCT samples is 44.39% with respect to SCT samples.

It is concluded by microstructural analysis that cryogenic treatment promotes transformation of retained austenite to martensite, thereby enhancing wear resistance.

3.4 Structural Steels

Structural steels are widely used in Engineering applications due to their excellent strength, ductility and manufacturability. Structural steels serve as essential materials for load-bearing members in civil and industrial construction, including beams, columns, and trusses (Jiang, et al. 2024). Recent studies emphasize cryogenic treatment as an effective post-processing technique for improving structural steels. By exposing steel components to cryogenic temperature, retained austenite is transformed to martensite, Carbide precipitation is refined, and residual stresses are relived. These micro structural changes enhance mechanical hardness, wear resistant, and corrosion performance, Offering significant benefits for structural applications. (Maximov and Duncheva, 2024; Essam, et al. 2023). Recent experimental studies reinforce these fundamental mechanisms. For instance, in 51CrV4 spring steel, controlled DCT (-196℃, 24 h hold, multi-cycle} up to a 15% increase in tensile strength and a 43% reduction in wear loss, attributed to martensite refinement and needle-like bainite distributions enhancing toughness (Chen, et al. 2023). For high manganese Hadfied steels, shallow cryogenic exposure improved wear resistance by -20% through twinning-induced martensite formation and elevated dislocation density (Jurci and Dlouhy, 2024).

4.0 Conclusion

This review study showed possible influence of DCT on the material performance and properties. Moreover, this review presents a synopsis of current results and future possibilities for evolution and standardization of DCT technique for structural applications. The reliable conclusions are as follows:

- Many published articles have established improvements in hardness and wear resistance. Enhancements of dimensional stability, increased electrochemical corrosion resistance, ductility, toughness and other properties have been reported to improve after DCT.
- DCT mechanism on structural steel grades are refinement of grain size, precipitation of

very fine carbides, refinement of retained austenite, transformation of austenite into martensite. The affecting mechanisms vary depending on the material type, grade and composition

- Optimal parameters (soaking temperature, soaking time, cooling/warming rate and tempering time) for each type of steel grade must be determined for cost effective and easier applications in industry.

For future work, DCT's effectiveness must be explored in depth and more systematically with experiments and modeling for structural steel grades to be procured and added with comprehensive microstructural examination to clearly identify mechanisms associated with change in steel properties.

REFERENCES

Amini K; Akhbarizadah, A. and Javadpour, S; (2012) Investigating the effect of holding duration on the microstructure of 1, 2080 tool steel during the deep cryogenic heat treatment. Vacuum, vol. 86, issue 10, pp 1534 – 1540.

Baldissera, P. and Delprete, C. (2010). Deep cryogenic treatment of A1S1 302 stainless steel: Part II – Fatigue and Corrosion. Materials and Design, 31(10), pp. 4731 -4737.

Bensely, A., Prabhakaran, D., Mohan Lal, D. and Nagarajan, G. (2005). Enhancing the wear resistance of case carburized steel (En 353) by cryogenic treatment. Cryogenics, 45: 747-754.

Chen, W; Wu, W; Li, C. and Meng, X. (2020). "Influence of deep cryogenic treatment and secondary tempering of microstructure and methanical properties of medium – carbon low alloy steels". Journal of Materials Engineering and Performance. Vol. 29, no. 1, pp. 10 – 22

Chen, Z., Jing, L., Gao, Y., Huang, Y., Guo, J., and Yan, X. (2023) Impact of Cryogenic Treatment Process on the Performance of 51CRV4 Steel. Materials, 16 (12), 4399. https://dio.org/10.3390/ma16124399.

Chowwwanonthapunya,T., Peeratatsuwan C. and Rithinyo, M. (2022). Cryogenic treatment of tool steels: a brief review and a case report. Material Technology and Research; 4(1), 253445.

Darwin, JD., Lal, DM. and Nagarajan, G. (2008). Optimization of cryogenic treatment to maximize the wear resistance of 18% Cr martensitic stainless steel by Taguchi method. Journal of Materials Processing Technology, 192(10, 241-247.

Das, D; Dutta, A.K; and Ray, K.K (2010b). sub – zero treatments of A1S1 D2 steel: Part II. Wear behavior. Material Science and Engineering A, 52(9), 2194 – 2206.

Das. D; dutta, A.K; and Ray, K.K. (2010a). Sub – zero treatments of A1S1 D2 steel: Part 1. Microstructure and hardness. Material Science and Engineering A; 52(9), 2182 – 2193.

Essam, M.A, Shash, A.Y., El-Fawakhry, M.K., El-Kashif, E., and Megahed, H. (2023). Effect of deep cryogenic treatment on wear behaviour of cold work tool steel. Metals, 13(2), 382.

Ferguson, B.L., Li, Z. and Freborg, A.M. (2005). Modelling heat treatment of steel of steel parts. Comp. Mater. Sci., 34, 274-281.

Gao, W; Wang, X; Chen, J; Ban, C; Cui, J. and Lu, Z. (2019) "Influence of deep cryogenic treatment on microstructure and properties of 7A99 ultra – high strength Aluminum Alloy", Metals, vol. 9, no. 6, p.631.

Haidong, Z; Zianguo, Y; Qiang Hou; and 2 hi C. (2021). Effects of cyclic cryogenic treatment on wear resistance, impact toughness, and microstructure of 42CrMo steel and its optimization. Advance Materials Science and Engineering. Vol. 1, P p 1-13. https://doi.org/10.1155/2021/8870282.

Hariharan, K. B., Saravanan, S. and Parkunam, N. (2019). Life time improvement of D7 tool steel by cryogenic treatment, Materials Today: Proceedings. 10-12.

Herrera, P. (2020). Effect of deep cryogenic treatment on abrasive wear resistance of engineering alloys. PhD Thesis, University of Sheffield..https://iopscience.iop.org/article/10.1088/1757-899X/1327/1/012207

Jiang, P., Wang, G., Wu, Y. et al. (2024) Microstructure Evolution, Tribological and Corrosion Properties Amorphous alloy strengthening steel is fabricated by selective laser melting in NaCl solution. Acta Metall. Sin. (Engl. Lett.) 37, 825-839

Jurci, P., and Dlouhy, I., (2024). Cryogenic Treatment of Martensitic Steels: Microstructural Fundamentals and Implications for Mechanical Properties and Wear and Corrosion Performance.

Kara, F., Cicek, A. and Demir, H. (2023) Effect of Deep Cryogenic Treatment on Microstructure, Mechanical Properties and Residual Stress of AISI 52100 Bearing Steel. Engineered Science. 26, 960. https://dx.doi.org/10.30919/ex960.

Kara, F., Filiz, S. and Yarmic, C. (2025). Investigation of the Effect of Shallow and Deep Cryogenic Treatment on Wear and Impact Performance of DIN 1.2344 Steel. Journal of Material Research and Technology. Vol 35, Pg 4553-4565

Karakurt, V., Ozturk, F., Citrak, T. Gozuak, M. G. and Zigindere, O. (2024). Effect of Deep Cryogenic Treatment on Microstructural and Mechanical Properties of High-Performance CPOH and WPTV Tool Steels. The International Journal of Materials and Engineering Technology (TIJMET). 7 (2), 2667-4033. https://dio.org/10.70858/tijmet.1499365.

Lakhani, M.M. and Raut; N; (2017) A review of effect of cryogenic treatment on different grades of steel". International Journal of Innovative Research in Science, Engineering and Technology, bol. 6, issue 5, pp. 8070 – 8081.

Li, J., Yan, X., Liang, X., Hong, G., Li, D.Y.Y., Guo, H. and Li, D.Y.Y. (2017). Influence of different cryogenic treatments on high temperature wear behavior of M2 steel, Wear. 377, 11121121.

Liu, X., Zhao, C. and Zhao, K. (2019). Microstructural evolution and mechanical / physical properties of 25# valve alloys steel subjected to deep cryogenic treatment, Vacuum 160, 394-401.

Mansi, M.L. and Niyati, R. (2017). A review of effect of cryogenic treatment on different grades of steel. International Journal of Innovative Research Science, Engineering and Technology. Vol.6, Issue 5, PP 8070 – 8081. Materials, 17 (3), 548. https://dio.org/10.3390/ma17030548.

Maximov, J., and Duncheva, G (2024). Effects of Cryogenic and Cool-Assisted burnishing on the surface integrity and operating behaviour of metal components: A Review and Perspectives. Machines, 12(5), 312.

Ozbek, O. and Ozbek, A. N. (2025). Impact of Deep Cryogenic Treatment on X210CrW12 steel's Wear Behaviour and Microstructural Characteristics. Materials, 18 (4), 879; https://doi.org/10.3390/ma18040879.

Patil, P.I. and Tated, R.G (2012). Comparison of effects of cryogenic treatment on different types of steels: a review International Journal of Computer Applications PP 10 – 29.

Perez, M. and Belzunce, F.J. (20150. The effect of deep cryogenic treatments on the mechanical properties of an AISI H13 steel, Materials Science and Engineering A. 624, 32-40.

Piesko, P., Korpysa, J. and Michalowska, Z. M. (2024). On the Use of Cyclic Cryogenic Treatment to Improve the Properties of High-Speed Steel. Materials. 17 (23): 5998. https://dio.10.3390/ma17235998

Pillia, N., Karthikeyan, R. Kannan, S. and Vincent, S. (2018). Effect of cryogenic treatment on VIKING cold working tool steel and development of wear mechanism maps, Procedia Manufacturing. 26, 329-342.

Podgornika B., Pavlina, I., Zajeeb, B., Jacobsone, S., and Leskovsek, V. (2016) "Deep Cryogenic treatment of tool steels". Journal of Materials Processing Technology, vol. 229, pp. 398 – 406.

Senthil kumar, D.and Rajendran; I (2011); "Influence of shallow and deep cryogenic treatment on tribological behavior of En19 steel", Journal of Iron and Steel Research, International, vol. 18, issue 9, pp. 53 – 59.

Silva, da, F. J., Franco, S.D. Ezugwu, E.O. and Souza Jr, M. (2006). Performance of cryogenically treated HSS tools. Wear, 261, 674-685.

Soleimany, J; Ghayor, H; Amini, K.et.al (2019). "The effect of deep cryogenic treatment on microstructure and wear behavior of HII tool steel", Physics of Metals and Metallography vol. 120. No. 9, pp 888 – 897.

Upadhyay, J; Bansal, A. and Singh, J; (2019). Effect on Mechanical and Metallurgical properties of cryogenically treated material SS 316. In Manufacturing Engineering (pp. 97 – 107) Springer Singapore.

Varghese, V; Ramash, M.R; Chakradhar, D. (2019). "Influence of deep cryogenic treatment on performance of cemented carbide (INC – Co) inserts during dry end milling of maraging steels", Journal of Manufacturing Processes, vol. 37, pp. 242 – 250.

Volgar J, Novak, Z; Jovicevic – klug, P; Podgomik, B. and Kosec, T. (2020). Effect of Deep Cryogenic treatment on corrosion properties of various high – speed steels. Metals (MDP1). https//www.mdpi.com.Ajournal/metals PP 1-16.

Weng, Z., Gu, K., Cui, C., Zhang, M., Chen, L. and Wang, J. (2026). Study Effects of Deep Cryogenic Treatment on M2 High Speed Steel. Material Science and Engineering Journal 22-25.

Weng, Z., Gu, K., Wang, K., Liu, X. and Wang, J. (2020). The reinforcement role of deep cryogenic on the strength and toughness of alloy structural steel, Materials Science and Engineering: A. 772, 138698.

Yong, A.Y.L., Seah, K.H.W. and Rahman, M. (2006). Performance evaluation of cryogenically treated tungsten carbide tools in turning . Int. J. Mach. Tool. Manu, 46, 2051-2056.

Yumark, N., Aslantas, K. and Pekbey, Y. (2017). Effect of cryogenic and aging treatments on lowenergy impact behaviour of Ti-6Al-4V alloy, Transaction of non-ferrous, Metal Society of China (English Edition). 27, 514-526.

Yun, D., Xiaopin, L. and Hongshen, X. (1998). Deep cryogenic treatment of high speed -steel and its mechanism. Heat Treatment of Metals. 3, 55-59.

Zhang, H. and Yan, I. (2021). Effects of Cyclic Cryogenic Treatment on Tear Resistance, Impact Toughness and microstructure of 42 CrMo Steel and its optimization. Patrice Berthod.

Zhenhua Li, Yuyue Wang, Jian Wang and Yu Zhang, (2022) "Effect of cryogenic Heat treatment and heat treatment on the influence of mechanical, energy and wear properties of 316L stainless steel by selective laser melting". Technical article (SPRINGER LINK), vol. 74, pp. 3855 – 3868.

Zhirafar, A., Rezaeian, A. and Pugh, M. (2007). Effect of cryogenic treatment on mechanical properties of 4340 steel. J. Mater. Process. Technol, 186, 298-303.

To cite this article:
Adeniyi, E. K., Ajide, O. O. and Towoju, O. A. 2026. Cryogenic Treatment Strategies and Its Influence on the Mechanical Properties of Structural Steel Grades: A Review. 1(3): 27-42. https://journals.unizik.edu.ng/ujabe/