An Improvement In Mechanical Characteristics Through The Application Of Austempered Ductile Iron (ADI): A Review

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ABSTRACT

Over the past twenty years, ADI, or austempered ductile cast iron, has been the subject of numerous investigations conducted worldwide. From the standpoint of structural applications, it has demonstrated exceptional mechanical characteristics. ADI with superior fatigue strength, fracture toughness, wear resistance, and ductility combined with high strength. Due to the special combinations of qualities these steels have developed through alloying with low-cost components, their development has become increasingly essential in the automotive industry. There has been a lot of research in this area. This paper presents a brief review.

KEYWORDS: *ADI, Heat Treatment, QP Process and Tensile Properties*

INTRODUCTION

Various microstructures are produced when austempering heat treatment is applied to ductile iron, contingent on heat treatment parameters like austenitizing time and temperature and austempering time and temperature. Comparing the austempered structure of bainitic ferrite, retained austenite, and spheroidal graphite to other ductile irons, it demonstrates exceptional comprehensive mechanical qualities such strength and toughness [1-2]. Applications for ADI include as varied as locomotive wheels, crankshafts, and gears. Other benefits of using ADI include reduced production costs because to its superior machinability and castability, which lead to larger tool life and fewer heat treatment processing cycles. However, fissures that weaken the product's mechanical qualities are frequently caused by the graphite nodules in the ADI. Many studies have been conducted utilizing electron microscopy, optical microscopy, and X-ray diffraction to examine the effects of heat treatment parameters on the microstructure.

In [3] examined the steel having the following chemical composition (weight%): 0.7–0.95 Manganese, 1.8–2.2 Silicon, and 0.55–0.6 Carbon; this steel is part of the AISI 9255 spring steel (EN45 spring steel). The elastic limit and fatigue strength of these heat-treated steels are very high. For this reason, these steels are excellent for making punches, chisels, leaf springs, and coiled springs. Austenitizing is the most often used heat treatment, which is followed by oil quenching and tempering. Mandal [4] Examined how the transformation temperature affects the microstructure of these Carbide Free Bainite (CFB) steels produced by the austempering technique. Ferrite laths have a more irregular orientation and are finer at reduced temperatures. It is demonstrated that while the ferrite laths' breadth increases with increasing austempering temperature, their length nearly stays constant. As austempering temperature rises, bainitic steel's characteristics such as hardness and tensile strength diminish. Alternatively, the ultimate tensile strength and yield strength rise with decreasing austempering temperature, while the ductility decreases. Bhadeshia, [5] Conduct research on bainitic steel; it has been observed that the impact toughness of these materials is significantly decreased when carbides are permitted to precipitate in the microstructure. In [6] demonstrates how the mechanical characteristics of spheroidal cast iron are affected by varying austempering temperatures and times. The samples were austempered for 10, 20, and 30 minutes at different temperatures between 250 and 300 degrees Celsius. The findings indicate that as temperature and austempering duration increase, elongation increases and tensile strength and hardness decrease. In [7] An analysis of the microstructure and hardness of steel (9260) heat-treated using the QP technique is conducted. Here, the samples were austenitized in molten salt for 15 minutes at 900 degrees Celsius. They were then quenched in a tin-bismuth molten bath at a temperature range of 150 to 210 degrees Celsius. After 120 seconds of equilibration, the samples were partitioned at a temperature range of 250 to 500 degrees Celsius in molten salt for a duration of 10 to 3600 seconds, and finally, they were quenched to room temperature. The acquired result demonstrates that significant quantities of retained austenite can be achieved with the QP process. Bagliani.et.al [8] examined the medium carbon steel's microstructure and mechanical characteristics, such as toughness and tensile strength, following the Q P procedure. In this experiment, samples were austenitized for 600 seconds at 940 ^{o}C. They were then quenched in a molten salt bath at 260 to 325 ^{o}C, equilibrated for 100 to 600 seconds, and then quenched to room temperature. The results indicate that 250^{o}C was the quenching temperature that produced the optimum mix of toughness and yield strength. In [9] Two distinct nanostructured bainitic steels are investigated in order to characterize their mechanical characteristics and microstructure. The samples in this case were austenitized for three minutes at 900 ^{o}C. After that, they underwent isothermal heat treatment at 200, 250, and 300 ^{o}C, where they were kept until the bainitic transformation was completed. The findings show that two high carbon steels are produced from distinct nanostructured composites, such as microstructures made of bainitic ferrite and high carbon retained austenite, which were produced via isothermal transformation at low temperatures (between 200 and 300 ^{o}C).

Rivas L M et.al [10] examined the tensile behavior of two high carbon, high silicon steel nanoscale bainite composite-like structures (Fe-0.7C-1.4Si-1.3Mn-1.0Cr-0.2Mo-0.1Ni). The samples were austenitized for 60 minutes at 900 ^{o}C in this experiment, and then they underwent an isothermal transformation at 200 ^{o}C for 24 hours (HT24) and 168 hours (HT168). The findings indicate that if the material's ductility is low and its resistance to damage and failure mechanism is not scarified, high ductility can be achieved through efficient work hardening. The above traits are not met in HT 168, and as a result of its high ductility, a high total elongation is shown. Anusha K et.al [11] Research has been done on how the structure of a steel changes with varying austempering times. It was found that at short austempering times, retained austenite and ferrite made up the microstructure; as the time increases, austenite becomes more stable; and at longer times, the retained austenite breaks down into carbide and ferrite. Ultimately, it was found that longer austempering times did not

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result in further improvements in hardness and strength.

Tomita Y et.al [12] examined how the microstructure affected the mechanical characteristics of 300M of isothermally converted bainite (0.4C-1.7Si-0.8Mn-0.8Cr-1.76Ni-0.41Mo-0.08v {wt% steel}). Here, the samples underwent an hour of austenitization at 900 ºC, followed by an isothermal transformation in a tin lead bath at varying temperatures and times (320 to 400 ºC, 1000 to 1800 sec, respectively), and oil quenching. When compared to traditional quenched and tempered steel, the results show an improvement in the fracture toughness and impact energy of the isothermally converted steel. Navara E et.al [13] He used ausferrite to carry out his studies. The material was high strength steel (EN45 spring steel), with compositions of 0.5-0.6 C, 1.5-2.0 Si, and 0.7-1.0 Mn. Here, the samples were austenitized at 880 degrees Celsius for 60 minutes. After that, some of the samples underwent 400–500 degree Celsius oil quenching and tempering. After that, the remaining samples were austempered at 300–350 degrees Celsius in a salt bath for as long as necessary to fully develop the ausferite structure. The results indicate that the mechanical properties of ausferrite are significantly influenced by the austempering temperature. Strength and impact toughness are two qualities of low alloy quenched and tempered steel that are superior to tempered martensite. In [14] High silicon cast steel's characteristics were investigated. Here, the samples underwent three stages of heat treatment: an initial 30-minute austenitization at 900 ºC, a 30-minute salt bath austempered at a temperature between 240 and 400 ºC, and an air cooling step. The results show that the ausferite structure has good qualities. It has also been noticed that higher values of strength, toughness, and hardness may be achieved at the austempering temperature, which is between 320 and 360 ºC. Putatunda S K et.al [15] investigated the fracture toughness property of a high carbon and high silicon steel (Fe-1C-2.5Si). In this experiment, the specimens were air cooled after being austenitized for 120 minutes at 927 ºC. They were then treated to austempering at various temperatures (260, 288, 302, 385, and 399 ºC) for another 120 minutes. The findings show that the retained austenite concentration rises with the austempering temperature, reaches its maximum value at 385 ºC, and then starts to decline once more. . Sajjadi & Zebarjad [16] examined the isothermal transformation of the HCS austenite to bainite structure. In this instance, the samples were water quenched after being austenitized for 60 minutes at 1000 ºC, then austempered for varying amounts of time at temperatures between 250 and 500 ºC. The findings show that in HCS, the austenite phase transforms into bainite at temperatures between 250 and 475 ºC.

In [17] The effects of austempering temperature on the mechanical characteristics and microstructure of medium carbon low alloy steel (0.4C-2Si-1Cr-0.6Mn-0.2Mo-0.5Cu) have been studied. Here, the specimens were air-cooled after being austenitized for 120 minutes at 927 ºC. They were subsequently austempered for another 120 minutes at various temperatures, including 260,315,357,385 and 399 ºC. The results show that greater values of yield strength and fracture toughness were attained after 120 minutes at an austempering temperature of 316 ºC. They discovered that a mixed microstructure—a blend of austenite and bainitic ferrite—can be achieved at the austempering temperature, which is between 316 and 400 ºC. In [18] Research was conducted to determine how retained austenite affected the multiphase martensitic-banitic steel's impact toughness. After being austenitized at 900 ºC, the samples underwent isothermal treatment for 0.5 to 48 hours, resulting in a microstructure composed of martensite, bainite, and preserved autenite. Specimens are cooled to room temperature following the isothermal technique. The remaining examples of this procedure were then once

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more tempered for an hour at 400 ºC before being cooled to room temperature. The findings indicate that specimens that underwent isothermal heat treatment plus tempering exhibited superior mechanical properties in comparison to those that underwent heat treatment alone. In[19] Research has been conducted to determine how the austempering temperature affects the mechanical characteristics and microstructure of high carbon, high silicon, and high manganese (1:3:2) cast steel. The heat treatment conditions in this instance were referred to as heat treatment conditions 1–4. After two hours of austenitization at 1010 ºC, all of the samples underwent austempering. In the first heat treatment condition, the samples were austempered for six hours at 288 ºC. For six hours, conditions two and three were austempered at 316 and 343 degrees Celsius, while condition four was austempered at 371 degrees Celsius. The findings show that following various austempered heat treatments, the material's mechanical qualities, such as its yield and tensile strength increase as the austempering temperature increases, and as austempering temperature increases. ductility of the specimen decreases.

S S Nayak et.al [20] This study looks at the Q & P method to assess the microstructure and hardness change in high and medium carbon steels with varying silicon, chromium, and manganese content. The findings show that the martensite lath class was observed in high and medium carbon silicon steel, irrespective of the quenching temperature. It was also discovered that the hardness of high carbon steel decreased as the partitioning temperature increased. In [21] study done on low carbon steel's microstructure development during the QP process. The findings suggest that austenite stabilization will occur in this material automatically and more quickly than in bainitic isothermal storage. Palaksha et.al [22] examined the wear behavior of AISI 9255 high silicon steel that has been austempered at different temperatures and times. In this experiment, the samples were first austenitized for 30 minutes at 900 ºC, and then they were austempered for one to four hours at 300, 350, and 400 ºC in a salt bath. After that, the samples were cooled to room temperature outside. Optical microscopy, SEM, and XRD have all been used to analyze the microstructure. The findings show that a certain wear rate rises with rising temperatures and falls with increasing time.

Sandvik et.al [23] proves that austempering heat treatment of Si-alloyed steel can produce steel with a bainitic microstructure free of carbides. It also demonstrates that the mechanical properties of this steel were dependent on the austenite shape, austenite volume fraction, and grain size. the temperature. In [24] the examination of two distinct high silicon steels that were austempered at two distinct holding times with regard to their erosion resistance. A completely CBF microstructure exhibits good resistance to erosive wear, according to the data. Ping et.al [25] compared the sliding wear properties of high silicon steels and austempered cast iron. The findings showed that graphite had no effect on friction and that, in contrast to austempered steel, high silicon steel had surface weakening brought on by nodules. Claytan et.al [26] An investigation on the microstructure of bainitic steel revealed that a higher CFB rate would be beneficial for rolling and sliding wear. . In [27] An investigation has been conducted into the impact of austempering temperature on the sliding wear performance of CFB steels. According to the results, the wear rate was lowest when an austempering heat treatment was used. Bhadesia et.al [28] demonstrates that the absence of carbides will improve the mechanical properties of CFB steel, while the presence of austenite will be beneficial since it increases toughness and plasticity. . In [29] Research comparing the rolling and sliding wear resistance of several high silicon austempered steels revealed that the steel with an almost entirely CFB microstructure had a very low wear rate and that, when tested, the retained austenite in the contact surface would turn into martensite. Vuorinen et.al [30] compared CFB's wear characteristics to those of other quenched and tempered steels. This experiment looked at the wear characteristics of austempered steel that has been Si-alloyed in relation to hardened, quenched, and tempered steel. According to the data, the CFB steel had a particular wear rate that was two to three times higher than the hardened steel's.

Yang et.al [31] examined the mechanical characteristics and microstructure of high carbon, silicon-rich, aluminum steel through low-temperature austempering. Here, the specimens were austenitized before being heated isothermally for 0.5 to 4 hours at 220 to 260 ºC. The outcomes show that a better combination of mechanical characteristics and a nanostructured bainitic microstructure were achieved. In [32] examined how the austempering temperature affected the ADI's wear and mechanical characteristics. The samples were first austenitized for thirty minutes at 840 ºC. They were then austempered for thirty minutes at four different temperatures—300, 320, 340, and 360 ºC—in a molten salt bath. The findings show that when the austempering temperature increases, hardness and strength drop but ductility and impact strength rise. O Eric et.al [33] examined how austempering affected the toughness and microstructure of nodular cast iron. The samples were quenched in ice water after being austenitized at 860 ºC and then austempering for varying periods of time at 320 and 400 ºC. The microstructure formed by austempering at 320 ºC is found to be a combination of stable carbon-enriched austenite and acicular banitic ferrite, according to the results. P Shanmugam et.al [34] A rotating bending fatigue test with 1.5 weight percent nickel and 0.3 weight percent molybdenum is explored and performed on austempered ductile iron. To obtain different microstructures, samples were austenitized at 900 or 1050 ºC and then austempering at 280–400 ºC for varied times. The findings show that when retained austenite content increases, tensile strength drops and fatigue strength increases.

In [35] It has been investigated how the mechanical characteristics of ductile cast iron are affected by the austempering time. Before being austempering for varying lengths of time—1, 2, 3, and 5 hours—the samples were austenitized at 950 ºC and soaked for 60 minutes in rubber seed oil at 250 ºC. The outcomes show a strongly positive correlation between the hardness and the tensile strength and impact energy. M Kaczorowski et.al [36] examined the ADI's structure-property relationship. This 500 7 grade ductile iron is subjected to different heat treatment requirements throughout the austempering process. The samples were first immersed in the solution for 60 minutes at 910 degrees Celsius. They were then isothermally quenched for varying periods of time in a silicon oil bath at temperatures of 275, 325, 300, and 350 degrees Celsius. The lowest temperature isothermal quenching yields high strength ADI when compared to identical ADI that is austempered at 350 ºC. It also yields maximum tensile strength while short-term quenching at 275 ºC results in low yield strength ADI. In [37] The effects of heat treatment parameters on the microstructure and impact energy as an indicator of ADI toughness have been studied. The composition of the samples was 2.5% Si, 1.09% Ni, 0.87% Cu, 0.5% Mo, 0.16% Mn, and 3.2% C. Following an hour of austenitization at 900 ºC, the samples were all subjected to varying times of austempering at 250, 300, 350, and 400 ºC. The samples that were austenitized at 900 ºC and austempered at 350 ºC for 2.5 hours had the highest impact energy (105 J), according to the data.

In[38] A comparison of the mechanical characteristics and microstructure of nodular cast iron treated with traditional austempering (TA) and two-step austempering (SA) heat treatments has been conducted. In this test, both approaches were run for 60 minutes at an austenitic temperature of 900 ºC. The second phase of the two-step austempering procedure began at 260 ºC and climbed steadily over the course of 60 minutes to 280, 310, and 340 ºC. The mechanical characteristics of nodular cast iron are significantly improved by the two-step austempering method, according to the results, as compared to the single-step method. In [39] To obtain an ADI with the right impact strength, research has been done on the selection of heat treatment parameters. Samples were austenitized in this experiment for one hour at 830 to 950 ºC. then austempered for 16, 32, and 64 minutes at a temperature between 300 and 400 ºC. The impact energy of ADI is influenced by austenitizing temperature and austempring circumstances, according to the results. . In [40] The mechanical behavior and characterisation of low manganese ADI have been studied. In this salt bath furnace, the specimens were first heated for 60 minutes at 350 ºC and then austenitized for another 60 minutes at 900 ºC. In the austempering salt bath furnace, the three sets of specimens were rapidly austempered for 90, 120, and 150 minutes, respectively, at uniform austempering temperatures of 300, 350, and 400 ºC. According to the results, the austempering temperature of 350 ºC for 150 minutes produced the maximum levels of hardness, tensile strength, and yield strength. Additionally, it was noted that hardness and strength increase with austempering duration at temperatures of 300 and 350 degrees Celsius.

TheinTun et.al [41] The effects of austenitizing temperature and austempring time on the mechanical characteristics and microstructure of ADI are investigated. The samples were austempering at 350 ºC for 0.5 to 2 hours after being austenitized for 1.5 hours at 850, 900, and 950 ºC. The excellent combination of high tensile strength with good toughness and ductility is demonstrated by the results. Je Young et.al [42] The influence of the microstructure and mechanical characteristics of austempering high silicon (2.3%Si) and high carbon (0.9%C) cast steel is being investigated. In this case, the samples were first austenitized for 60 minutes at 900 ºC. They were then austempered for 30 to 240 minutes at 260, 320, and 380 ºC. The findings show that, in comparison to ADI, high silicon, high carbon cast steel without graphite has greater tensile strength (1300 Mpa to 2200 Mpa) and elongation (25%) In [43] The effects of a one-step and two-step heat treatment method on the mechanical characteristics and microstructure of ADI have been compared. In this instance, the specimens underwent two steps of cooling: first, they were austenitized at 900 ºC for 1.5 hours, and then they were cooled in a salt bath for 30 minutes at a temperature of 300 ºC. After five minutes at this temperature in the salt bath, the specimens were heated in a second salt bath for 30 minutes at a temperature of 300 ºC. The findings show that impact resistance falls by 3.5% and hardness increases by 4.7% for two-step processes. Additionally, it is noted that ausferite microhardness was 6.2% higher in one-step austempering than in two-step processes.

In [44] Research has been done to determine how austempering time affects a low manganese ADI's mechanical characteristics. For varied times ranging from 30 to 240 minutes, the samples were austempered in the upper 371 ºC and lower 260 ºC bainitic temperature ranges. The findings indicate that in the lower bainitic temperature range, the material's tensile and yield strength improve with an increase in austempering duration; in the upper bainitic temperature range, however, time has no discernible effect on mechanical parameters. Abhishek Sharma et.al [45] examined the impact of austempering factors and copper on the mechanical characteristics and microstructure of ADI. According to the results, the ADI that contains copper exhibits greater strength, harderness, and reduced elongation than the ADI that does not. Mantesh C Choukimath et.al

[46] Examine how the austempering procedure affects the ADI's tool life machinability. It was austempering for the specimens at 270, 320, and 360 ºC. The findings show that the machinability index rises as the austempering temperature rises, and they also show that tool wear rises in tandem with the temperature increase.

In [47] The impact of austempering temperature and duration on the wear properties of ADI is investigated. The specimens in this experiment were austenitized at 900 oC and then austempering at different temperatures (235, 260, 285, and 310 ºC) for 60 and 120 minutes. The findings show that abrasion resistance rises in tandem with an increase in austempering temperature. SasanYazdani et.al [48] Examine how the austempering temperature affects an ADI's high cycle fatigue action. Here, the samples were placed in a salt bath furnace and austenitized at 875 ºC, followed by austempering at 320, 365, and 400 ºC. Rotating bending tests were performed, and the findings show that specimen fatigue life increases by 10, 20, and 24% for every degree Celsius that the austempered temperature rises to (320, 365, and 400 ºC, respectively). In [49] The impact of austempering time on the mechanical characteristics of ADI is investigated. In this, the specimens underwent 100 minutes of austenitization at 900 ºC, followed by 300 ºC austempering. The findings indicate that there is an increase in ductility and wear resistance but no additional improvement in strength and hardness when the austempering period is increased from 45 to 180 minutes.

The aforementioned research cites numerous publications from reputable journals to demonstrate how ADI's qualities have improved when compared to alternative materials.

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