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AN IMPROVEMENT IN MECHANICAL PROPERTIES USING AUSTEMPERED DUCTILE IRON (ADI): A REVIEW

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ABSTRACT

During the last two decades, austempered ductile cast iron (ADI) was the focus of various studies world-wide. It has exhibited outstanding mechanical properties from perspective of structural applications. ADI consisting of high ductility, high strength and better wear resistance, fatigue strength and fracture toughness. Now a days, the development of these steels plays very important role in automobile sector because of their unique combinations of properties achieved through alloying with inexpensive elements. Number of research has been done in this field. Brief review shown in this paper.

KEYWORDS: ADI, Tensile Properties, Heat Treatment & Quenching and Partitioning Process

A REVIEW

INTRODUCTION

When ductile iron is subjected to an austempering heat treatment, different microstructures is obtained depending on heat treatment parameters such as austenitizing time and temperature and austempering time and temperature. The austempered structure consisting of bainitic ferrite, retained austenite and spheroidal graphite which shows excellent comprehensive mechanical properties, such as strength and toughness, when compared to other ductile irons [1-2] ADI has been used in applications as diverse as gears, crankshafts and locomotive wheels. ADI has other advantages such as low production cost because of its good castability, excellent machinability and consequently longer tool life and shorter heat treatment processing cycles. However, the graphite nodules in the ADI are often the source of cracks, which decrease the mechanical properties of the product. The influence of heat treatment parameters on the microstructure has been extensively studied using optical microscopy, electron microscopy, and X-ray diffraction.

In [3] studied the Steel with chemical composition (weight %) i.e. 0.55-0.6 Carbon, 1.8-2.2 Silicon and 0.7-0.95 Manganese, which belong to AISI 9255 spring steel (EN45 spring steel). This type of heat treated steels have high elastic limit and fatigue strength. Hence these steels are well suited for producing chisels, punches, leaf springs, coiled springs. The most commonly adopted heat treatment consists of austenitizing followed by oil quenching and tempering. Mandal [4] studied the microstructure of these Carbide Free Bainite (CFB) steels obtained by austempering process strongly depends on the transformation temperature. At lower temperatures, ferrite laths are finer and their orientation is irregular. It is shown that the length of the ferrite laths are remain almost equal with the austempering temperature but there is increase in width. The properties like tensile strength and hardness of bainitic steel decrease as austempering temperature increases. On other hand as the austempering temperature decreases, the ultimate tensile strength and yield strength increases but the ductility is decreases. Bhadeshia, [5] Carry out an investigation on bainitic steel and it is reported that when carbides are allowed to precipitate in the microstructure the impact toughness of bainitic steels is reduced dramatically. In [6] shows the different austempering temperature and time on mechanical properties of spheroidal cast iron. The specimens were austempered at various temperatures ranging from 250 ^{o}C to 300 ^{o}C held at 10,20,30 min. Results shows there is an decrease in tensile strength and hardness and increase in elongation as austempering time and temperature increases. In [7] an investigation is carried out to examine microstructure and hardness of steel(9260) heat treated by (QP) process. Here the samples were austenitized at 900 ^{o}C in molten salt for 15 min, then quenched in to molten bath of tin bismuth at temperature range between 150 ^{o}C to 210 ^{o}C, and equilibrated for 120 seconds before partitioning at temperature between 250 ^{o}C to 500 ^{o}C in molten salt for the time range between 10 to 3600 seconds and lastly quenched to room temperature. The obtained result shows with QP process it is possible to achieve the substantial levels of retained austenite. Bagliani.et.al [8] studied the microstructure and mechanical properties such as tensile strength and toughness of medium carbon steel after Q P process. In this samples were austenitised at 940 ^{o}C at 600 seconds followed by quenching in a molten salt bath at temperature range between 260 ^{o}C to 325 ^{o}C and equilibrated for time between 100 to 600 seconds finally quenched to room temperature. Results shows that the best combination of yield strength and toughness was obtained at quenching temperature 250^{o}C. . In [9] an investigation is carried out to examine the characterization of microstructure and mechanical properties of two different nano structured bainitic steel. In this the samples were austenitized at 900 ^{o}C for 3 minute and then these are isothermally heat treated at 200, 250 and 300 ^{o}C, held until completion of bainitic transformation. The results indicate that the different nano structured composite like microstructure composed of high carbon retained austenite and bainitic ferrite were obtained by isothermal transformation at low temperature {200- 300 ^{o}C } are characterized in to two high carbon steels.

Rivas L M et.al [10] studied the tensile response of two nanoscale bainite composite like structures of high carbon high silicon steel (Fe-0.7C-1.4Si-1.3Mn-1.0Cr-0.2Mo-0.1Ni) In this the samples were austenitized at 900 ^{o}C for 60 minute and followed by isothermal transformation at temperature 200 ^{o}C, held for 24 Hrs(HT24) & 168 Hrs (HT168). Results shows that high ductility can be obtained by effective work hardening, if resistance to damage and failure mechanism is not scarified, and the ductility of the material is poor. In HT 168, the above characteristics are not fulfilled and there is high total elongation is observed due to high ductility Anusha K et.al [11] studied about the change in the structure of a steel with a different austempering time and it was observed that for the short austempering time, the microstructure obtained consisting of retained austenite and ferrite and as the time increases austenite becomes more stable and again increase in the time results in the decomposition of retained austenite to carbide and ferrite, finally it is noted that increase time of austempering did not cause further improvement in hardness and strength.

Tomita Y et.al [12] studied the impact of microstructure on mechanical properties of isothermally bainite – transformed 300M (0.4C-1.7Si-0.8Mn-0.8Cr-1.76Ni-0.41Mo-0.08v {wt % steel}). Here the samples were austenitized at 900 ^{o}C for one hour then goes in to isothermal transformation in Tin lead bath at different temperature between 320 to 400 ^{o}C at different durations 1000 to 1800 sec. respectively, and followed by oil quenching. Results obtained indicate that there is an improvement in fracture toughness and impact energy of steel of isothermally transformed steel when match with conventional quenching and tempered steel. Navara E et.al [13] carried out his investigation on ausferrite. The material taken was high strength steel (EN45 spring steel) (0.5-0.6 C, 1.5-2.0 Si, and 0.7-1.0 Mn) Here the samples were austenitized at 880 ^{o}C for 60 min. after austenitizing some of the samples were oil quenched and tempered I the range of 400-500 ^{o}C, remaining samples were austempered in salt bath at temperature range 300-350 ^{o}C held there for sufficient duration to attain complete ausferite structure. Results indicate that mechanical properties of ausferrite were strongly depends on austempering temperature. The properties like strength and impact toughness exceeds that of tempered martensite in a low alloy quenched and tempered steel.

In [14] the properties of high silicon cast steel were studied. Here the samples were austenitized at 900 ^oC for 30 min then it is austempered in a salt bath at a temperature range between 240 to 400 ^oC for 30 min and finally it is air cooled. Results indicate that ausferite structure has excellent properties and it has also observed that the austempering temperature between 320 to 360 ^oC, it is possible to achieve higher values of strength, toughness and hardness. Putatunda S K et.al [15]Studied the fracture toughness property of a high carbon and high silicon steel (Fe-1C-2.5Si,) in this experiment the specimens were austenitized at 927 ^oC for 120 min. followed by austempering treatment at different temperature 260,288,302,385 and 399 ^oC retained for 120 min. finally it is air cooled. The results indicates that as the austempering temperature increases the retained austenite content also increases and gains a highest value at 385 ^oC and begins starts to decrease again. Sajjadi & Zebarjad [16] Studied isothermal conversion of austenite to bainite structure in HCS. Here the samples were austenitized at 1000 ^oC for 60 min. then it is austempered at temperature range between 250-500 ^oC hold for different durations, finally water quenched. Results indicate that at the temperature 250-475 ^oC austenite phase convert in to bainite in HCS.

In [17] Study has been made to know the impact of austempering temperature on the microstructure and mechanical properties of medium carbon low alloy steel(0.4C-2Si-1Cr-0.6Mn- 0.2Mo-0.5Cu) Here the specimens were austenitized at 927 ^oC for 120 min. and then it is austempered at different temperature 260,315,357,385 and 399 ^oC for 120 min. followed by air cooling. Results were indicate that at austempering temperature of 316 ^oC for 120 min. a higher values yield strength and fracture toughness was achieved. and also found that at austempering temperature 316-400 ^oC it is possible to achieve a mixed microstructure which is a mixture of austenite and bainitic ferrite. In [18]Study taken to know that the effect of retained austenite on the impact toughness of multiphase banitic – martensitic steel. The samples were austenitized at 900 ^oC followed by isothermal treatment for 0.5 to 48 hours to get microstructure made up of retained autenite, bainite, and martensite. After the isothermal process the specimens are bring down to room temperature. And remaining specimens of this process were again tempered at 400 ^oC for 1 hour and again bring down to room temperature. Results shows that better mechanical properties will get from the specimens those who were isothermally heat treated and tempered compared to only heat treated specimens. In[19] Study has been made to know the impact of austempering temperature on microstructure and mechanical properties of high carbon, high silicon, high manganese (1:3:2) cast steel. Here the heat treated conditions were termed as heat treatment conditions 1 2 3 4. All the samples were austenitized at 1010 ^oC for 2 hours followed by austempering. The heat treatment condition on 1, the samples was austempered at 288 ^oC for 6 hour. For condition 2 & 3, they were austempered at 316 ^oC & 343 ^oC for 6 hours and condition 4 were austempered at 371 ^oC for 6 hours. Results were indicate that after different austempered heat treatment mechanical properties like yield and tensile strength of the material increases with increase in austempering temperature and as austempering temperature increases. ductility of the specimen decreases.

S SNayak et.al [20] in this Quenching and Partitioning (Q & P) process is examined to evaluate the microstructure and alteration in hardness in a high and medium carbon steel made up of different amount of chromium, manganese and silicon. Results indicates that in high and medium carbon silicon steel regardless of quenching temperature, lath class of martensite was seen and also found that the hardness in high carbon steel decreases with increase in partitioning temperature. In [21] investigation carried out on microstructure development in QP process for low carbon steel. Results were indicates that stabilization of austenite will be attained in this material automatically in lesser time as compared to the bainitic isothermal holding. Palaksha et.al [22] studied the dry sliding wear behavior of AISI 9255 high silicon steel austempered under varying temperature and time. In this test the samples were austenitized at 900 ^{o}C for 30 min. and then austempered in a salt bath which is at a temperature of 300, 350,400 ^{o}C for time between1-4 hours. The samples were then bring down to room temperature in a open air. The microstructure analysis has been made with help of optical microscopy, SEM, XRD. The results were indicate that specific wear rate decreases with increase in time and increases with increase in temperature.

Sandvik et.al [23] shows that it is possible to obtain steel with a bainitic microstructure which does not have carbides by austempering heat treatment of Si-alloyed steel and it is also shows that the mechanical properties of this steel were depending on grain size, austenite volume fraction and austenite morphology. In [24] the investigation carried out on the erosion resistance of two different high silicon steels austempered at two different holding times. The results were indicate that a fully CBF microstructure has good resistance to erosive wear. Ping et.al [25] made comparison on the sliding wear performance of austempered cast iron with high silicon steels. Results were indicates that there is no outcome of graphite on friction and also observed that in high silicon steel there is a surface weakening caused by nodules as compared to the austempered steel. Claytan et.al [26] Study made on the microstructure of bainitic steel and found that increase rate of CFB will be helpful for rolling/sliding wear. In [27] the investigation has been carried out on the outcome of austempering temperature on the sliding wear performance of CFB steels. The results were indicate that the lowest wear rate was obtained by austempering heat treatment was applied. Bhadesia et.al [28] shows that the mechanical properties of CFB steel will be better under the absence of carbides and the presence of austenite will be helpful as it increase plasticity and toughness. In [29] Investigation has been carried out on comparison of rolling/sliding wear resistance of various high silicon austempered steels and begin that the steel with almost fully CFB microstructure gave an extremely low wear rate and also found that the retained austenite in the contact surface will transform to martensite during testing. Vuorinen et.al [30] studied the wear properties of CFB compared with the other quenched and tempered steel. In this experiment the wear behavior of Si-alloyed austempered steel was examined in correlation with hardened, quenched and tempered steel. The results indicates that the specific wear rate in the CFB steel were 2-3 times higher than that of the hardened steel.

Yang et.al [31] Investigated microstructure and mechanical properties of high carbon silicon-aluminum rich steel by low temperature austempering. Here the specimens were austenitized then these are isothermally heated at 220 – 260 ^{o}C.for 0.5 to 4 hours. Results were indicate that nanostructured bainitic microstructure and better mixture of mechanical properties were accomplished. In [32] studied the impact of austempering temperature on mechanical and wear properties of ADI. Here samples were austenitized at 840 ^{o}C for 30 min. then it is austempered for 30 min. in molten salt bathat four varying temperatures 300,320,340, and 360 ^{o}C. Results indicate that hardness and strength decreases where as ductility and impact strength improved with increase in austempering temperature. O Eric et.al [33] studied the impact of austempering on the microstructure and toughness of nodular cast iron. The samples were austenitized at 860 ^{o}C followed by austempering for different times at 320 and 400 ^{o}C and then quenched in ice water. Results indicates that austempering at 320 ^{o}C produces microstructure consisting of a mixture of acicular banitic ferrite and the stable carbon enriched austenite. P Shanmugam et.al [34] studied rotating bending fatigue test which is conducted on austempered ductile iron consists of 1.5 wt% nickel and 0.3 wt% molybdenum. Samples were austenitized at 900 or 1050 ^{o}C followed by austempering at 280 400 ^{o}C for various time durations to get various microstructure. The results were indicate that the tensile strength decreases with increase in retained austenite contain and fatigue strength increases.

In [35] the investigation has been made on the impact of austempering time on the mechanical properties of ductile cast iron. The samples were austenitized at 950 ^{o}C and socked for 60 min. in rubber seed oil at 250 ^{o}C followed by austempering for various time slots of 1,2,3,4,5 hours. The results were indicates that there is a compelling increase in the tensile strength and impact energy as well as improvement in hardness. M Kaczorowski et.al [36] Studied structure property relationship of ADI. In this 500 7 grade ductile iron goes under austempering with various heat treatment specifications. The samples were initially dipped in solution for60 min. in 910 ^{o}C and then isothermally quenched for various time in bath of silicon oil which is at temperature of 275,325,300 and 350^{o}C. Results shows that minimum temperature isothermal quenching produces high strength ADI compared to similar ADI but austempered at 350 ^{o}C and also found that low yield strength ADI obtained for short time quenching at 275 ^{o}C shows maximum tensile strength. In [37] an investigation has been carried out on the heat treatment specifications on the microstructure and impact energy as a measure of toughness of ADI. The samples were made of the composition of 3.2 % C, 2.5% Si, 1.09% Ni, 0.87% Cu, 0.5% Mo, and 0.16% Mn. All the samples were austenitized at 900 ^{o}C for 1 hour, followed by austempering at 250,300,350, and 400 ^{o}C for different time slots. The results shows that highest impact energy (105 J) for the samples austenitized at 900 ^{o}C and austempered at 350 ^{o}C for 2.5 hours.

In[38]comparison of Traditional austempering (TA) and two step austempering (SA) heat treatments for microstructure and mechanical properties of nodular cast iron has been made. In this test both methods were done at 900 ^{o}C of a austenitic temperature for 60 min. For two step austempering method the second step started at 260 ^{o}C for 10 min. increased gradually at 280,310, and 340 ^{o}C for 60 min. Results shows that in two step austempering method there is a compelling increase in the mechanical properties of nodular cast iron as compared to single step austempering. In [39] an investigation has made on the choice of heat treatment specifications to get ADI with appropriate impact strength. In this samples were austenitized at 830 – 950 ^{o}C for 1 hour. then austempered at the range of 300 - 400 ^{o}C for 16, 32 and 64 min. Results shows that the impact energy of ADI will affected by austenitizing temperature and austempring conditions. In [40] the investigation has been made on the characterization and mechanical behavior of low manganese ADI. Here specimens were initially heated at 350 ^{o}C for 60 min. and austenitized at 900 ^{o}C for 60 min. in salt bath furnace. The three groups of specimens were quickly austempered in the austempering salt bath furnaceat uniform austempering temperature of 300, 350 and 400 ^{o}C for 90, 120 and 150 min respectively. The results shows that highest hardness, tensile and yield strength were obtained at austempering temperature of 350 ^{o}C at 150 min. it was also observed that at temperature 300 ^{o}C and 350 ^{o}C, hardness and strength increases with austempering time.

TheinTun et.al [41] an investigation is made to know the impact of austenitizing temperature and austempring time on the microstructure and mechanical properties of ADI. The samples were austenitized at 850, 900 and 950 ^{o}C for 1.5 hour followed by austempering at 350 ^{o}C in the time interval of 0.5 to 2 hours. Results shows admirable consolidation of high tensile strength with good ductility and toughness. Je Young et.al [42] an investigation is made to know the impact of microstructure and mechanical properties of austempering high carbon (0.9%C), high silicon(2.3%Si) cast steel. Here the samples were austenitized at 900 ^{o}C for 60 min. then these are austempered at 260, 320, and 380 ^{o}C for the time range between 30 to 240 min. Results indicates high silicon high carbon cast steel without graphite and with higher tensile strength (1300 Mpa to 2200 Mpa) and elongation (25%) as compared to ADI In [43] comparison has been made between one step and two step heat treatment process on microstructure and mechanical properties of ADI. Here for one step the specimens were austenitized at 900 ^{o}C for 1.5 hour and cooled in a salt bath at a temperature of 300 ^{o}C for 30 min. and for two step the specimens were cooled from 910 ^{o}C to 245 ^{o}C, kept at this temperature for 5 min. in salt bath, then again heated in another salt bath at a temperature 300 ^{o}C for 30 min. The results indicate that for two step process hardness increased by 4.7 % and impact resistance decreases by 3.5% and it is also observed that micro hardness of ausferite was 6.2% higher in one step austempering as compared to two step.

In [44] study has been to know the impact of austempering time on the mechanical properties of a low manganese ADI. In this samples were austempered in the upper 371 ^{o}C and lower 260 ^{o}C bainitic temperature ranges for various time durations between 30 to 240 min. Results shows that tensile and yield strength of material increases with increase in austempering time in lower bainitic temperature range, where as in upper bainitic range time has no important impact on mechanical properties. Abhishek Sharma et.al [45] studied the effect copper along with austempering variables on the microstructure and mechanical properties of ADI. Results indicates that ADI with copper shows higher strength, hardness and lower elongation as compared to the ADI without copper. Mantesh C Choukimath et.al [46] Study the effect of austempering process on the machinability of tool life of ADI. The specimens were austempering at 270, 320, 360 ^{o}C. Results indicates that machinability index increases with increase in austempering temperature and also found that as austempering temperature increases tool wear also increases.

In [47] an investigation is made to know the importance of austempering temperature and time on the wear characteristics of ADI. In this the specimens were austenitized at 900 ^{o}C followed by austempering for 60 and 120 min. at various temperature 235,260, 285, and 310 ^{o}C. Results indicates that as the austempering temperature increases abrasion resistance also increases. SasanYazdani et.al [48] study the impact of austempering temperature on high cycle fatigue action of an ADI. Here the samples were austenitized at 875 ^{o}C followed by austempering at 320,365 and 400 ^{o}C in a salt bath furnace. Rotating bending tests were conducted and results indicates that fatigue life for specimen increases by 10,20 and 24% as the austempered temperature increases by 320,365 and 400 ^{o}C respectively. In [49] an investigation is made to study the effect of austempering time on mechanical properties of ADI. In this the specimens were austenitized at 900 ^{o}Cfor 100 min. followed by austempering at 300 ^{o}C. Results shows that when austempering time increases from 45 to 180 min. there is no further improvement in strength and hardness but there is an increase in ductility and wear resistance..

The above paper takes the reference of many number of publications from reputed journals to inculcate the improvement in properties of ADI as compared to other materials.

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