

Tensile Properties and Microstructure Relationship of Austempered Ductile Cast Iron Quenched in Jatropha seed oil

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I. Introduction

Austempering heat treatment is a proven way of obtaining the desired microstructure for improved mechanical properties such as increased strength, toughness, wear resistance, hardness and fatigue strength in ductile iron components. It is an isothermal heat treatment process which depending on the applied austempering conditions, attractive combination of mechanical properties of the austempered ductile iron (ADI) may be produced. This renders the austempered ductile iron useful in a relatively large number of applications as an economical substitute for high strength steels, Blackmore 1984. The important microstructural features of austempered ductile iron (ADI) are the morphology of the ferrite, the volume fraction of retained austenite, the carbon content in retained austenite, and the presence or absence of carbide in austenite or ferrite. A mixture of bainitic ferrite and retained austenite, along with graphite nodules, is the most desirable combination of phases in the cast iron. Undesirable phases, such as martensite and iron carbides, may also be present in smaller quantities, but it is understood that the high volume fraction of retained austenite is very important towards the achievement of optimum combination of mechanical properties Harding 1991. Thus, the mechanical properties of austempered ductile iron may be related to three microstructural variables: bainite morphology, austenite volume fraction and the formation of martensite Blackmore 1984. Austempered ductile iron, ADI components, competes favorably with steel forgings, especially for heavy-duty parts where reliability is paramount. It is used to upgrade from standard ductile irons, and as a substitute for manganese steel and nickel-hard materials. When strength is required ADI is particularly cost-effective: tensile and yield values are twice those of standard ductile iron; fatigue strength is 50 % higher. With its high strength-to-weight ratio austempered ductile iron can even replace aluminium when reduced section sizes are acceptable.

ADI castings are increasingly displacing steel forgings and castings, welded fabrications, carburized steel, and aluminium due to superior performance. Because of its equivalent strength, nearly 80 % of all cast and forged steels can be replaced with some grade of ADI. The relative weight per unit of strength of ADI allows economy in design without loss of performance. For a given shape, an ADI component will be 10 % lighter than steel. ADI is three times stronger than the best cast or forged aluminium and weighs only 2.5 times as much. Because it is twice as stiff, a properly designed ADI part can replace aluminium at a weight saving. ADI's dynamic properties exceed those of forged, cast and micro-alloyed steels. Unlike aluminium, ADI's endurance limit remains nearly constant after tens of millions of cycles. The presence of graphite in the ADI matrix improves noise damping, for quieter, smoother running components. ADI's abrasion resistance exceeds that of conventionally processed steels and irons at a lower 'bulk' hardness level. Unlike carburized steel, which loses wear resistance as the carburized layer is removed, ADI improves in service. Wear resistance is superior to steel at any given hardness level, making it ideal for earth moving and other high abrasion applications, Metals Handbook, 1981.

Austempering is mostly carried out in a nitrate/nitrite salt bath, due to the advantages they offer compared to other hot baths like lead, mineral oils and polymer solutions. It consists of heating a ferrous material above the critical temperature; soaked at that temperature for a time sufficient to result in a uniform temperature and microstructure; cooled rapidly enough to avoid the formation of pearlite to a temperature above where Martensite forms (Ms) and then held (Austempered) for a time sufficient to produce the desired matrix structure. Metals Handbook (1981), In recent years, attention is been given to vegetable oils by many researchers. Larry, 2004 compared the cooling time-temperature and the cooling rate curves of soy bean oils reported that vegetable oils exhibited faster cooling rates than the mineral oil used. Jatropha seed oil is employed as quenchant in this research.

II. Experimental Procedure

2.1 Jatropha oil production

Dry seeds of jatropha were collected from Rafin Sewa Gora village of Zango LGA, Kaduna state where most people use the plant as fence. The seeds were manually shelled and dried inside the house to prevent them from being exposed to direct sun rays. They were then taken to National Research Institute for Chemical Technology (NARICT) Zaria, Nigeria for oil extraction. The Cold Pressed method was employed to extract oil from the seeds. The mechanically extracted jatropha oil was used in its crude form for austempering ductile iron and medium carbon steel without further processing.

Table 1: Chemical Properties of the Jatropha Oil Produced

Oil	Flash Point	Acid Value	Free fatty Acid	saponification value mgKOH	Iodine value g/100g	Peroxide value meg/kg	Viscosity at 38 ⁰ C mm ² /sec
(J)	8.43	4.22	210	62.12	40	88.15	249

2.2 Production of ductile iron samples

The charge material used for its production were pig iron obtained from and ferro-alloys of silicon manganese and magnesium. Charges consisting of 50 kg pig iron with composition C=4.17%, Si=1.66%, Mn=0.19%, S=0.01%). The chemical composition of the 25mm ferrosilicon nodularizing alloy used was (Si=45.5%,Mg= 5.85% Ca1.08%,). Sandwich treatment technique was used. In this technique, the ferrosilicon alloy was placed on a pocked in the bottom of an open heated ladle and covered with scrap. The melt was poured on the other side of the ladle to react with the magnesium alloy effectively. The melt was then cast into 'Y' blocks. The pouring temperature was 1380 °C.

Table 2: Chemical Composition of the Ductile Iron Produced

%C	%Si	%Mn	%Cr	%P	%Ni
3.42	3.1	0.21	0.02	0.11	0.0004

2.3 Heat treatment procedure

A total of one hundred and twenty ductile iron test samples were used for the study. Three samples were used for each experimental group and an average found. Six samples were used as control to determine the tensile, impact and microstructure of the samples in the as-cast conditions. Twelve samples were annealed and normalized and their tensile and impact strength measured. One hundred and two samples were normalized and used to study the tensile properties after being austenitised at 950 °C for 1 hr in a Nobertherm furnace, German type. The samples were austempered in hot jatropha seed oils at 250 °C for 1 to 5 hrs in Hraeus oven, after which they were air cooled to room temperature.

2.4 Tensile properties determination

Tensile test was carried out according to ASTM (A 370-2002). The machined test samples were subjected to tensile test using Norwood Universal Testing machine with maximum capacity of 10 tons. Each sample was subjected to tension till fracture after which the tensile strength, 0.2 % proof stress, and percentage elongation at failure were calculated. Three samples were used for each test condition and the average value recorded.

2.5 Metallographic Analysis

Metallographic examination was carried out on the austempered ductile iron specimens. Standard techniques of specimen preparation for the microstructure observation were adopted. Metallographic samples mounted in were ground using silicon carbide abrasive papers (240 to 1000grits) sizes. The samples were next polished on a rotating disc with 6 and 1 micron diapat diamond suspension monocrytalline paste (Plate 52) and surface cleaned, after which etching was carried out using 2% Nital (2% Nitric acid in ethyl alcohol) for 15-30 seconds to develop the structure. The microstructures obtained from specimens were photographed using optical metallurgical microscope with an in-built camera shown in Plate 53

III. Result and Discussion

The effect of austenitizing temperatures, austempering temperatures and time on the tensile properties of ductile iron austempered in jatropha oil was studied. Plates 1 to 6 show the microstructures of ductile iron austenitized at 950 °C, then austempered in jatropha seed oil each at 250 °C for varying periods of 1hr, 2 hrs, 3 hrs 4 hrs and 5 hrs. The austempered structure of ductile iron consists of nodules of graphite in ausferrite matrix. The results of the tensile properties of the austempered ductile iron is graphically shown in Figures 9 to 28. Figures 9 and 10 show the result of tensile strength values of ductile iron. Optimum values of 1039 and 1031N/mm² at 4 hours austempering time were achieved for ductile iron austempered in jatropha seed oil at 250 °C. Tensile strength values of 914 and 895 N/mm² were the optimum values obtained when austempered at 300 °C after being austenitized at 950 °C. The results show that the tensile strengths of the austempered ductile iron samples increased as the austenitizing temperature increased from at 850 to 950 °C and austempering temperatures increased from 250 to 300 °C. The combination of high austenitizing temperature at 950 °C with low austempering temperature at 250 °C yielded higher tensile strength values. The highest tensile strength values of 1039N/mm² for austempered ductile was obtained when the samples were austenitized at 950 °C and austempered at 250 °C for 4 hours. This is attributed to the low amount of retained austenite developed in the bainite. Figures 11 and 12 show that the yield strength of the austempered ductile iron increase as the austenitizing temperature increased from 850 to 950 °C and austempering temperature increased from 250 to 300 °C as the austempering time increased. The optimum yield strength values were obtained at austempering time of 4 hours in all the cases and thereafter reduced. This is in line with the two stages reaction involved in the isothermal transformation. The stage I reaction involves, austenite (γ) decomposing into ferrite (α) and high carbon austenite (γ_{hc}); ($\gamma \rightarrow \alpha + \gamma_{hc}$) up to 4 hours. Substantial amount of retained austenite was observed. As the austempering time is increased to 5 hours, the amount of retained austenite decreased indicating the commencement of stage II reaction where retained high carbon austenite; decomposes into ferrite and carbide; $\gamma_{hc} \rightarrow \alpha + \text{carbide}$. Yield strength values obtained at higher austempering temperature of 300 °C were lower than those obtained at a lower austempering temperature of 250°C. This could be attributed to the different bainitic structures formed in the specimens. At higher austempering temperature, upper bainite is formed which imparts less strength than the lower bainite formed at lower temperatures. The same pattern was noticed in yield strength values of austempered medium carbon steel shown in Figures 21 and 22. Figures 13 and 14 show that the hardness of austempered ductile iron samples increased as the austenitizing temperature increased from 850 to 950 °C and austempering temperature increased from 250 to 300 °C and as the austempering time increased from 1 to 5 hours. Similar pattern was also developed for austempered medium carbon steel as that obtained for austempered ductile iron.

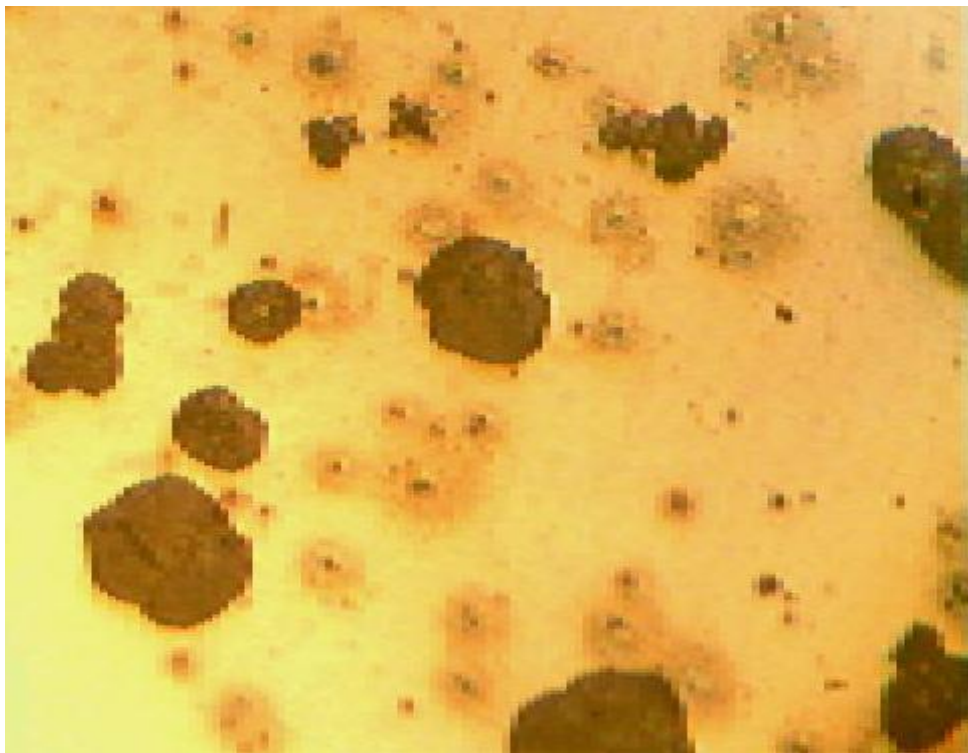


Plate 1: The as-cast structure of ductile cast iron showing graphite nodules (black) in pearlite matrix (grey); (x400)

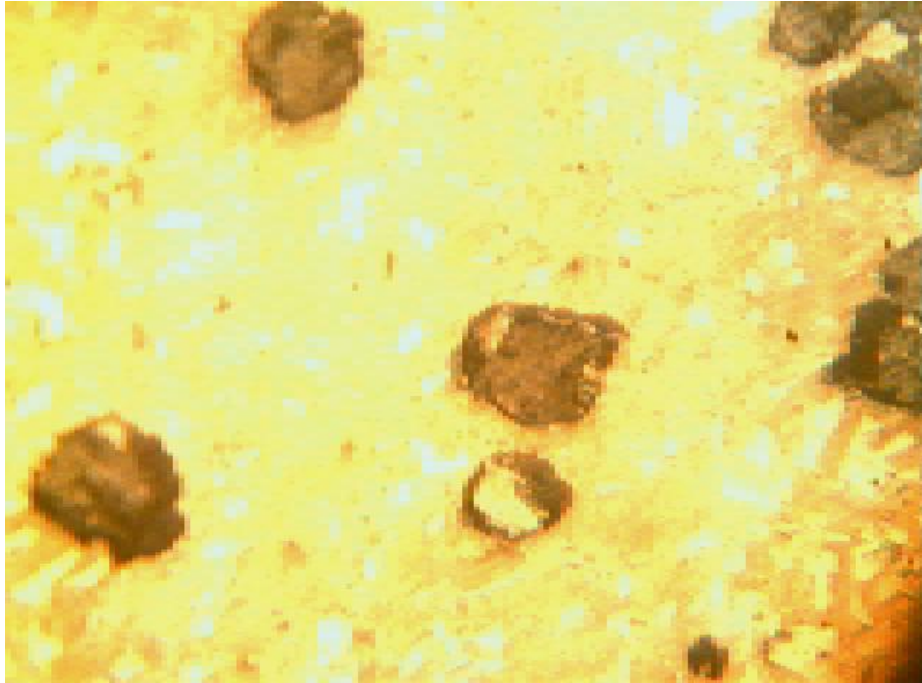


Plate 2: Microstructure of ductile iron austenitised at 950 °C, austempered in jatropha seed oil at 250 °C for 1 hr, showing graphite nodules (black) and retained austenite (white); (x400)

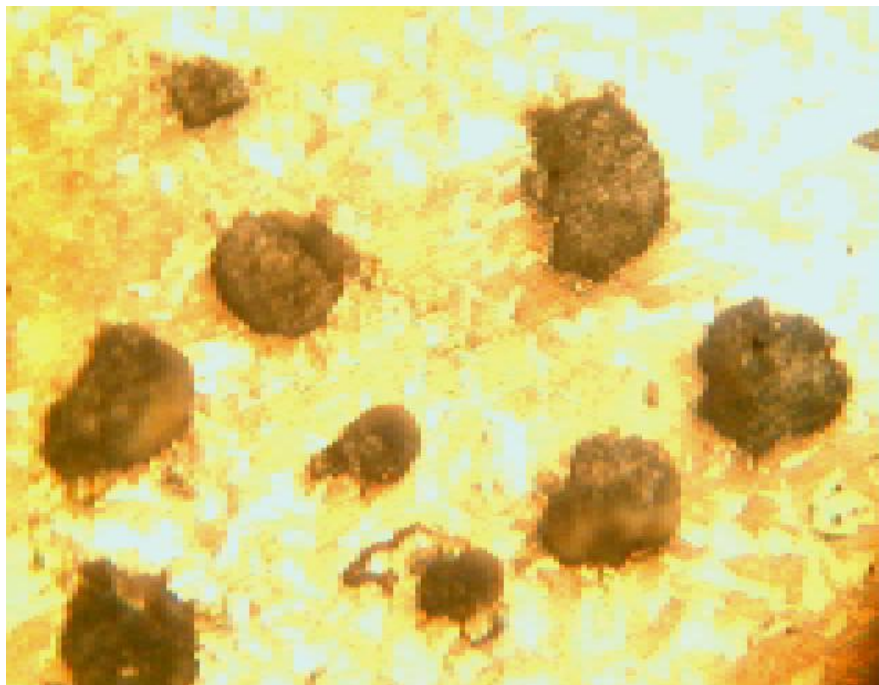


Plate 3: Microstructure of ductile iron austenitizes at 950 °C austempered in jatropha seed oil at 250 °C for 2 hrs, showing graphite nodules (black) in increased ausferrite phase (white); (x400)

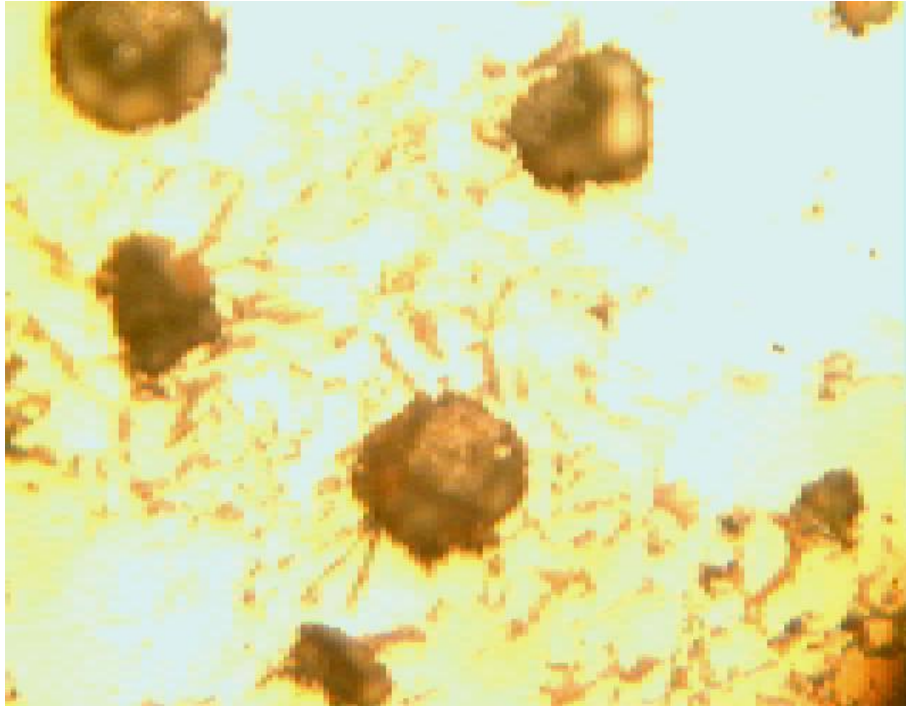


Plate 4: Microstructure of ductile iron austenitized at 950 °C austempered in jatropha seed oil at 250 °C for 3 hrs, showing graphite nodules (black) in austenite matrix; (x400)



Plate 5: Microstructure of ductile iron austenitized at 950 °C austempered in jatropha seed oil at 250 °C for 4 hrs, showing graphite nodules (black) in austenite matrix; (x400)



Plate 6: Microstructure of ductile iron austenitized at 950 °C austempered in jatropha seed oil at 250 °C for 5 hrs, showing graphite nodules (black) in ausferrite matrix; (x400)

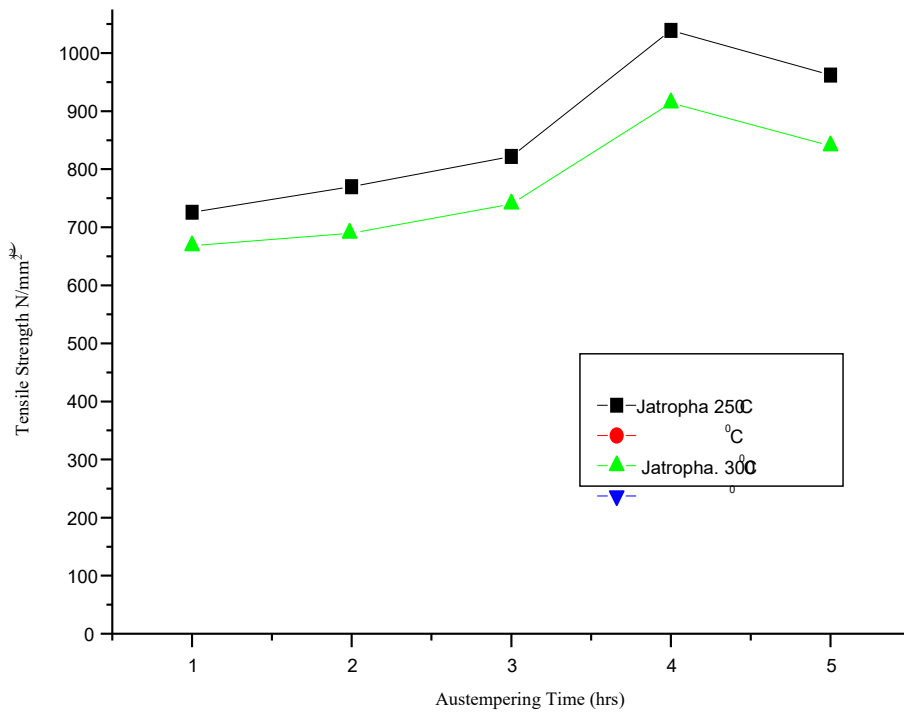


Figure 9: Tensile strength of ductile iron austenitized at 950 °C austempered in jatropha and rubber seed oils at 250 and 300 °C .

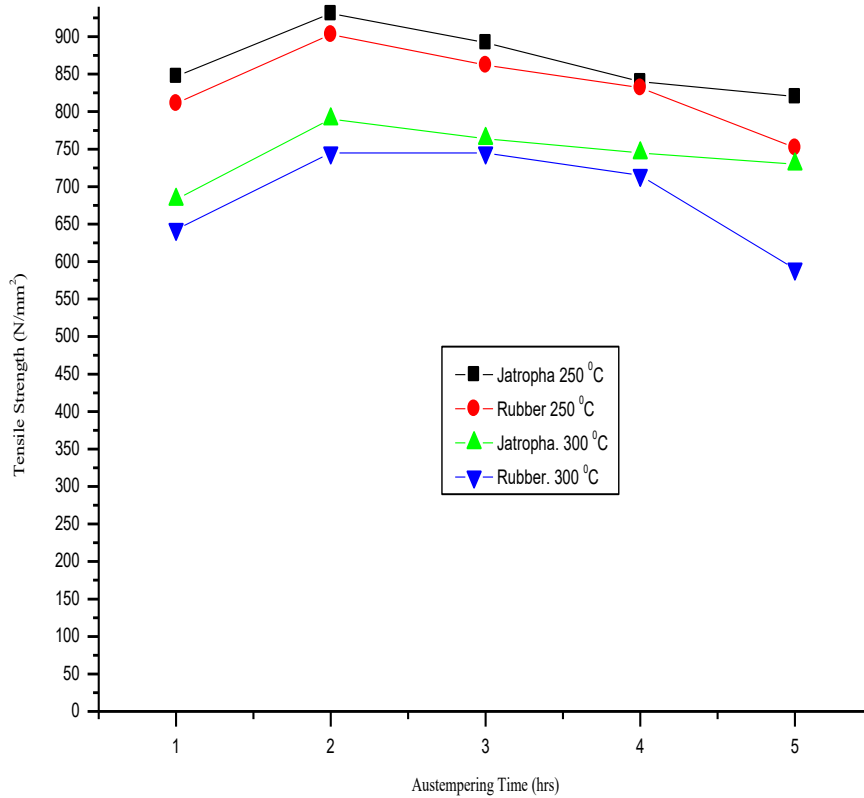


Figure 10: Tensile strength of ductile iron austenitized at 850 °C austempered in jatropha and rubber seed oils at 250 and 300 °C

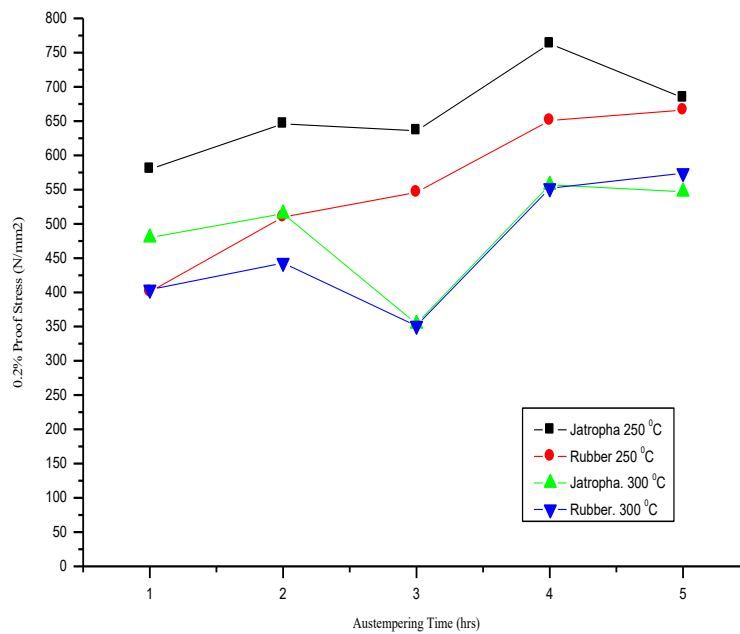


Figure 11: 0.2% proof stress of ductile iron austenitized at 950 °C austempered in jatropha and rubber seed oils at 250 and 300 °C .

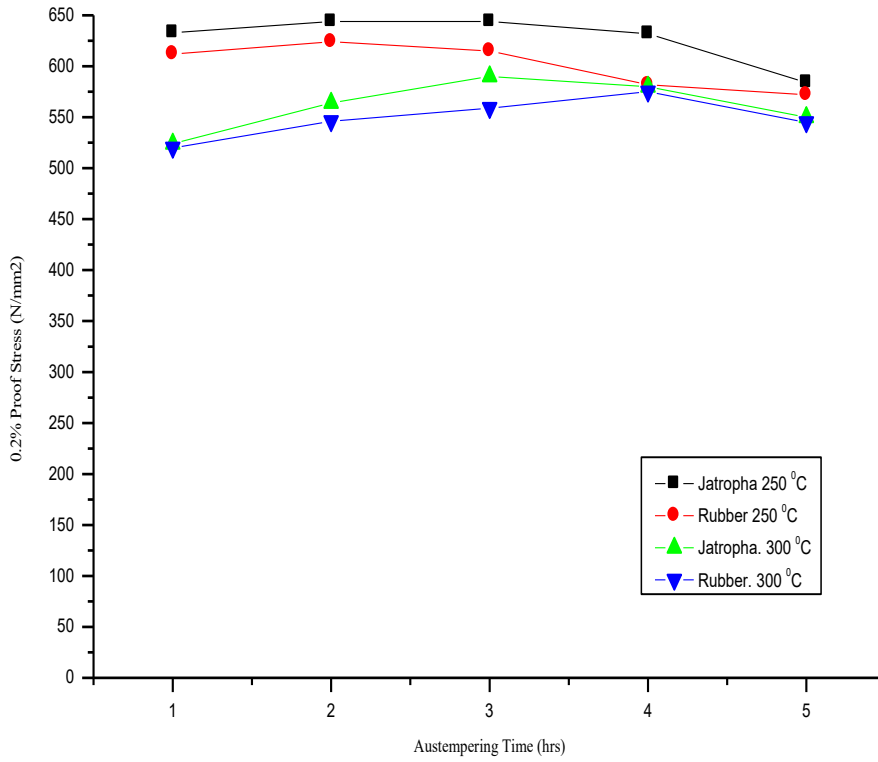


Figure 12: 0.2% proof stress of ductile iron austenitized at 850 °C austempered in jatropa and rubber seed oils at 250 and 300 °C .

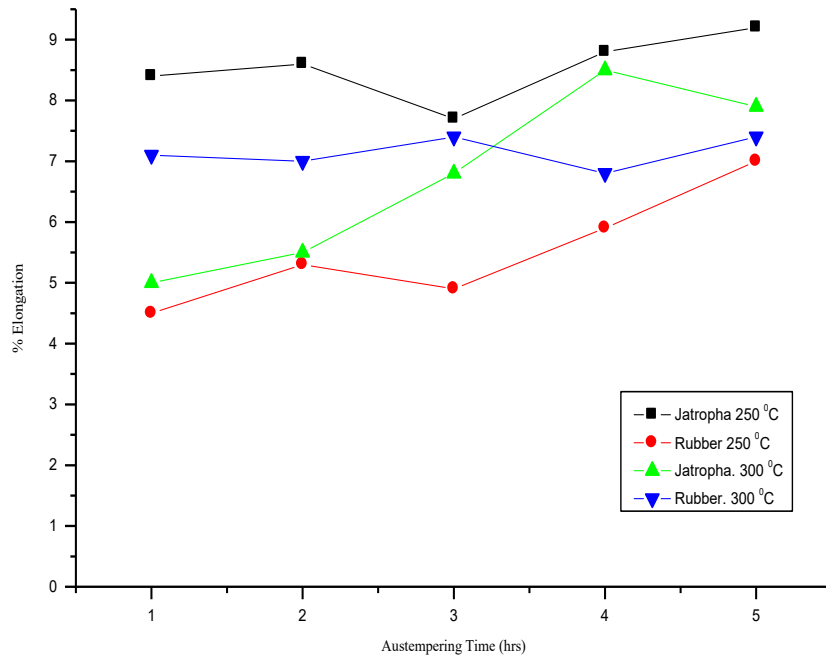


Figure 15: Percentage elongation of ductile iron austenitized at 950 °C austempered in jatropa and rubber seed oils at 250 and 300 °C .

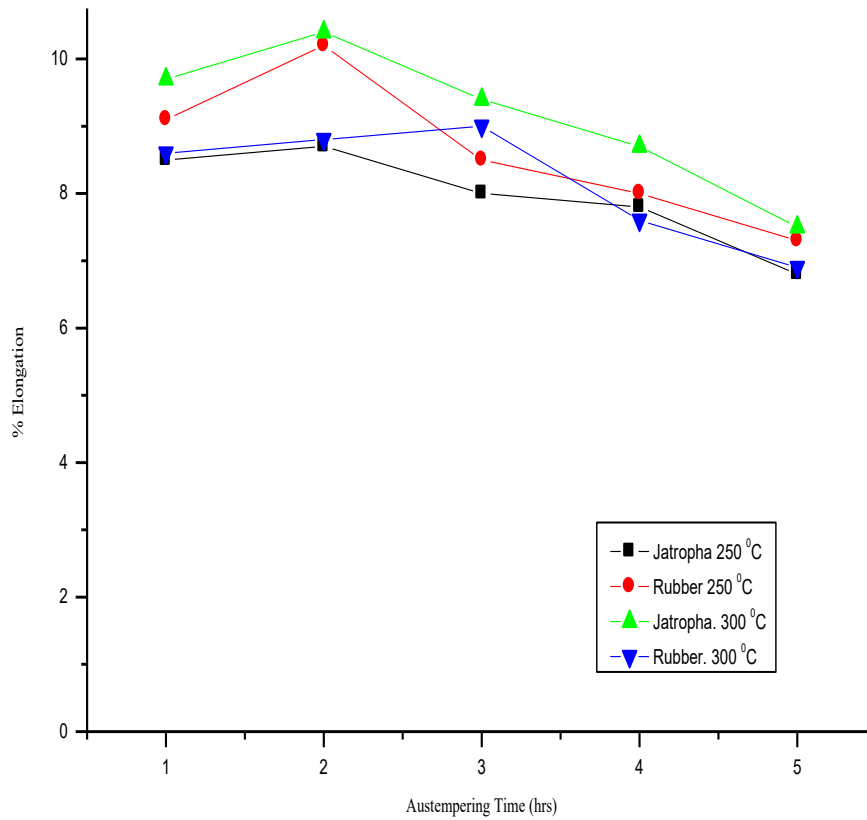


Figure 16: Percentage elongation of ductile iron austenitized at 850 °C austempered in jatropha and rubber seed oils at 250 and 300 °C .