Study The Effect Of Austempering Temperature On The Machinability Of Austempered Ductile Iron By Milling Process

Mr. Mohd. Abbas*[a],Mr. Sajid Hussain*[a] ,Prof. Mohd. Parvez*[a] ,Prof. Tasmeem A. Khan*[a]

[a]Department of Mechanical Engineering, A.F.S.E.T, Faridabad (INDIA)

1. ABSTRACT:-

The austempering process was first developed in the early 1930's as a result of work that Bain, was conducting on the isothermal transformation of steel. In the early 1940's Flinn applied this heat treatment to cast iron, namely gray iron. In 1948 the invention of ductile iron was announced jointly by the British Cast Iron Research Association (BCIRA) and the International Nickel Company (INCO).

Since the mechanical properties of ductile iron depend essentially on the matrix, further enhancements might be achieved by improving the matrix microstructure. The austempering process is an isothermal heat treatment in the bainitic transformation range, usually 250-450°C. This resulted in austempered ductile cast iron, with twice the Strength of ductile iron at the same level of toughness and ductility. ADI also has advantages over other materials such as cast or forged steels. This is because ADI has good castebility, lower processing cost, higher damping capacity, and a 10% lower density.

What material offers the design engineer the best combination of low cost, design flexibility, good machinability, high strength to weight ratio and good toughness, wear resistance and fatigue strength? Austempered Ductile Iron (ADI) may be the answer to that question. ADI offers this superior combination of properties because it can be cast like any other member of the Ductile Iron family, thus offering all the production advantages of a conventional Ductile Iron casting.

For a typical component, ADI costs 20% less per unit weight than steel and half that of aluminium.

My thisis work pertains to study of conventional machining by Milling Process undertaken on a wear resistant materil, ADI

KEYWORD:- Milling Machine, coolant, Different grade of ADI materials cutting tool and different material job.

2. INTRODUCTION:-

Austempered ductile iron (ADI) has a microstructure containing spheroidal graphite embedded in a matrix which is in general a mixture of phases. Of these, bainitic ferrite and austenite are the most desirable phases, but in many cases small amounts of martensite and/or carbides may also present in the microstructure. The bainitic ferrite is generated during isothermal transformation of austenite at temperatures below the bainite start (Bs) temperature; this heat treatment is known as "austempering". An optimum combination of high carbon austenite and bainitic ferrite confers excellent mechanical properties to such cast irons. The proportions of phases change with the chemical composition and heat treatment, making it possible to produce a family of ADI's. This in turn allows a Wide range of applications with ADI competing favorably against steel forgings and aluminum alloys in terms of mechanical properties, manufacturing cost, physical properties and weight saving

For a typical component, ADI costs 20% less per unit weight than steel and half that of aluminium.

On analyzing the cost-per-unit-strength of ADI v/s various materials as shown in Fig. 1.1, the economic importance of ADI become apparent.

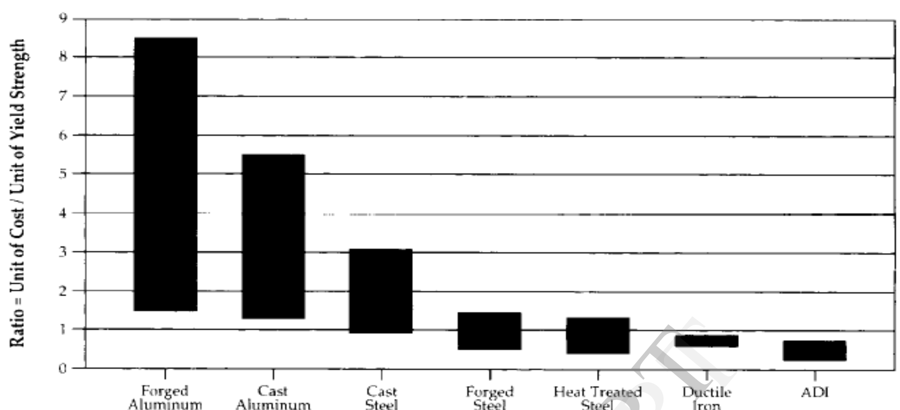


Figure 1.1: Relative cost per unit of yield strength of various materials.

Before indicating some applications of ADI it is important to remember some physical characteristics which combined with the mechanical properties of ADI,open the market for this material in many different industries, but particularly for automotive components:

1) Good castability and near net shape casting production of parts.

2) 10%lower density than steel.

3) Higher damping capacity than steel which makes the parts to absorb energy 2-5 times more than steels, thereby reducing the level of noise to about 8-10 decibels in gear boxes

The Heat Treatment

The ADI heat treatment cycle consists of three main stages.

1) Austenitizing
2) Quenching
3) Isothermal Transformation

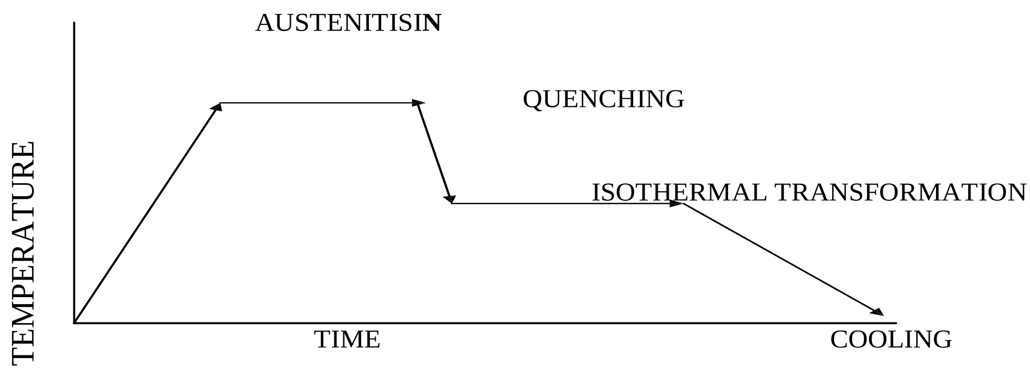


Figure 2.5: Schematic illustration of all stages of austempering heat treatment

The final properties of the ADI are determined by all of these stages. The most important stage among them is the isothermal transformation.

LITERATURE REVIEW:-

Cast Irons

Although the focus of the work in this thesis is on Austemperd ductile iron, a brief introduction to cast irons in general is useful since ADI emerged as a new member of the family during the 1960's. The list of cast irons is big and this section describes only the most important ones.

Cast iron is a Fe-C-Si alloy that often contains other alloying elements and is used in the as-cast condition or after heat treatment. Cast irons offer a virtually unique combination of low cost and engineering versatility. The tow cost together with cast ability, strength, machinability, hardness, wear resistance, corrosion resistance, thermal conductivity, and damping makes them excel even amongst casting alloys.

Typical chemical composition of ADI

ADI nominally has the composition Fe-3.6C-2.50S1-0.5Mn-0.05Mg wt%, but a variety of other additions may be made. It is common to see additions of elements such as Mo, Ni and Cu. One reason for alloying is to suppress the pearlitic reaction so that the

austenite can transform into bainite. Other elements such as chromium and vanadium may be added also to improve hardenability. However, this is not common since these are strong carbide forming elements.

Austenitizing

Austenizing temperature and time are two main factors that affect the final properties of ADI. The austenitizing temperature controls the carbon content of the austenite, which in turn affects the structure and properties of the austempered casting. The austenitizing temperatures above 925°C increase the carbon content of the austenite that increases the hardenability, while lowers the ductility through the formation of bainite after isothermal transformation stage. Reducing the austenitizing temperature produces ADI with the best properties, but in this case silicon content, which exerts a strong influence on this critical temperature, should be controlled carefully.

Quenching

Quenching is the second stage of the Austempering Heat Treatment. In this stage, the most important factor that affects the final mechanical properties of ADI is the cooling rate of the austenitized casting. The importance of the cooling rate can be seen from the TTT diagram as shown in Fig.2.10, which shows the regions of transformation according to the microstructures.

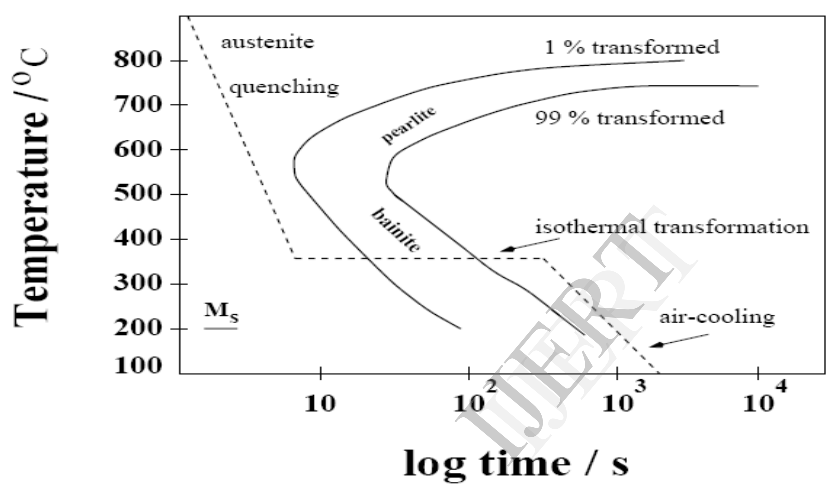


Figure 2.10 Typical TTT Diagram for a low silicon ductile cast iron [33].

The line 1 on the figure shows the path of an unsuccessful bainitic transformation, because of the low cooling rate the transformation path crosses the pearlite region, which results in reduction of mechanical properties of ADI. The bainite transformation is an isothermal transformation between temperature ranges from 400°C to 250°C, after cooling/quenching from austenising temperature.

The amount of alloying elements is also important for quenching stage. Addition of alloying elements like Cu and Mo shift the C curves to left on TTT diagram and this motion stimulates the perlitic reaction. Therefore to avoid the formation of perlitic microstructure the cooling rate must be increased.

EXPERIMENTAL PROCEDURE:-

Material

The ductile iron for the present work was developed in a commercial foundry. It was cast in the shape of 1-inch Y-block as shown in Fig.3.1(a and b). The composition and structural parameters of the as cast ductile iron are given in Tables 3.1. The microstructure of the as cast ductile iron is given in Fig.3.2.

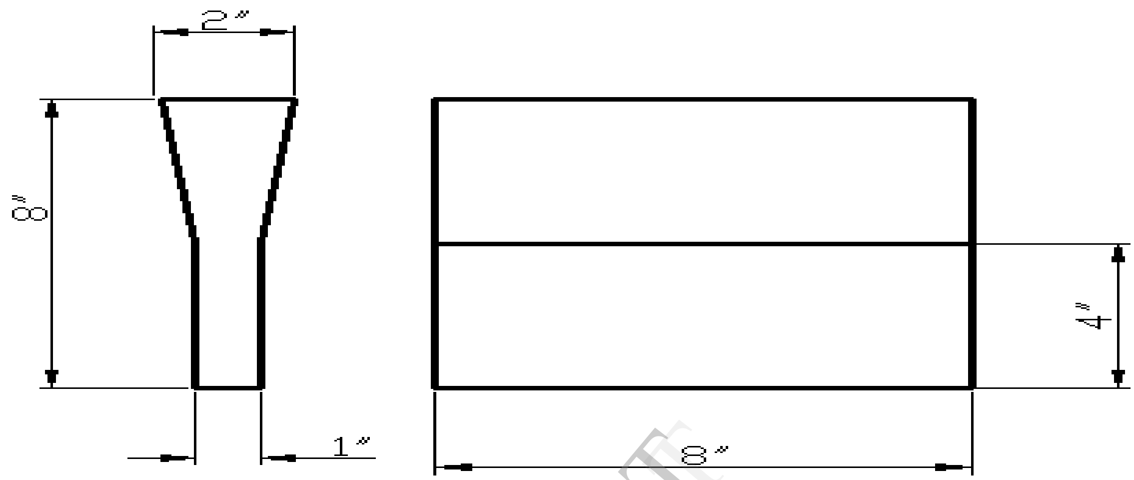


Figure 3.1(a): The dimensions of Y block. (All the dimensions are given in inches)

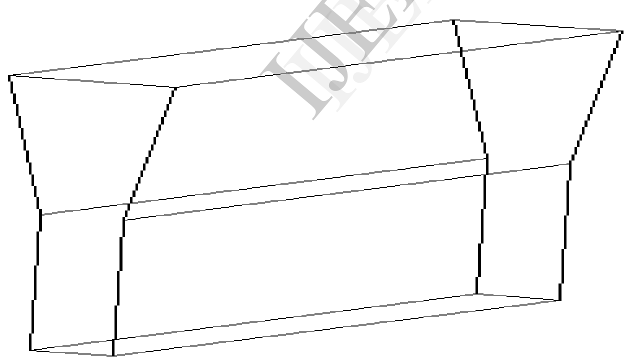


Figure 3.1(b): Isometric view of Y block.

Table 3.1: Chemical composition of the as cast ductile iron.

MATERIAL NAME	C	Ni	Si	Mn	Mg
L 1	3.2-3.6	0.00	2-2.5	<0.23	0.004
L 2	3.2-3.6	1.30	2-2.5	<0.23	0.004
L 3	3.2-3.6	1.60	2-2.5	<0.23	0.004

Specimen Preparation

The ductile iron samples were cut from the leg part of the Y - block. For optimization of austenitization and austempering parameters the ductile iron samples of dimensions 100 x 25 x 10mm were cut as shown in Fig.3.2.(a & b).

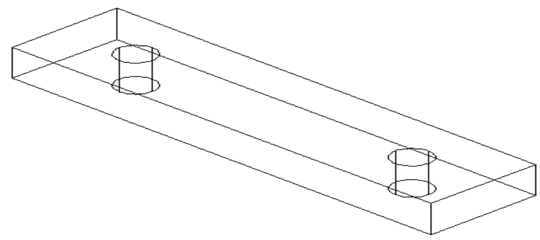


Figure 3.2(a): Ductile iron sample for austempering heat treatment process and machinability analysis

Heat Treatment

The development of Austempered Ductile Iron from the ductile iron involves austenitization followed by austempering as explained in Section 2.3 of Chapter 2 of Literature Review.

Working of horizontal milling machine

The cutter head containing the milling machine spindle is attached to the ram. The cutter head can be swiveled from a vertical spindle position to a horizontal spindle position or can be fixed at any desired angular position between vertical and horizontal. The saddle and knee are hand driven for vertical and cross feed adjustment while the worktable can be either hand or power driven at the operator's choice.

Specification of Milling Cutter

Milling cutters are usually made of high-speed steel and are available in a great variety of shapes and sizes for various purposes. You should know the names of the most common classifications of cutters, their uses, and, in a general way, the sizes best suited to the work at hand.

Figure 3.8 shows two views of a common milling cutter with its parts and angles identified. These parts and angles in some form are common to all cutter types.

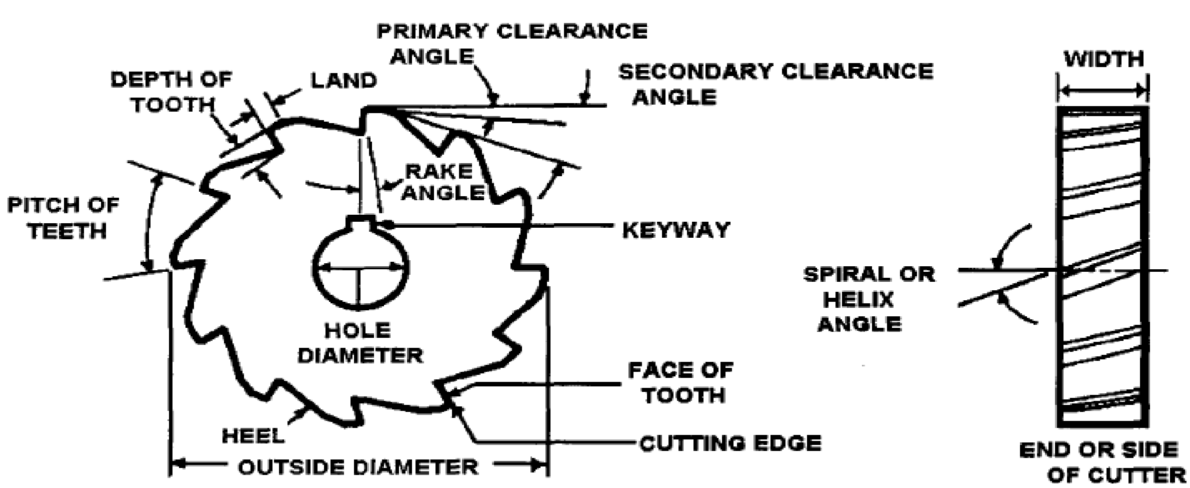


Figure 3.8: Milling cutter nomenclature.

bring this test various parameters described under were studied

- Cutting forces during horizontal milling.
- Surface roughness.
- Surface hardness.

Tool and material removal rates

Weight loss of tool as well as of the material ADI was measured using weighing machine of MJ-300 make & Type BL I 220H having capacity 310 grams with accuracy of 0.001 grams. The response variables to be evaluated are as follows:

Material removal rate (MRR) was calculated as follows:

$$\frac{\text{Reduction in weight of work piece}}{\text{Density of work piece} \times \text{machining time}}$$

Tool wear rate (TWR) was calculated as follows:

$$\frac{\text{Reduction in weight of tool}}{\text{Density of tool} \times \text{machining time}}$$

RESULTS AND DISCUSSIONS:-

The ductile iron, after its optimized austenitization is quenched immediately in salt bath maintained at preselected austempering temperature and hold in the bath for different austempering time periods before quenching these in water. The austempering temperature controls the microstructure morphology, the scale of phases developed, where as austempering time controls the amount of various phases developing during the process such as bainitic ferrite, retained austenite, martensite, carbide etc. Therefore, in the present work two austempering temperatures of 370°C and 320°C were selected to develop ADI with lower bainite / lower + upper bainite / upper bainite so that different grades of ADI could be developed. The austempering time was optimized from the processing window in an earlier work. 120 min. of austempering was therefore selected for the machinability testing in the present work. Also, study of microstructure with changing austempering time from 30 to 120 min. was carried out

Hardness Study

Figure 4.5 and Table 4.1 show the variation in hardness with austempering temperature and types for ADI developed by austenitization at 925°C for 120min. followed by austempering at 270°C, 320°C , 370°C and 420°C for 120 min.

Table 4.1: Variation in Hardness with austempering temperature and material composition

MATERIALS / Tγ (°C)	L1 (H.V)	L2 (H.V)	L3 (H.V)
420	254	309	327
370	262	327	350
320	299	354	369
270	342	388	394
D.I	242	281	297

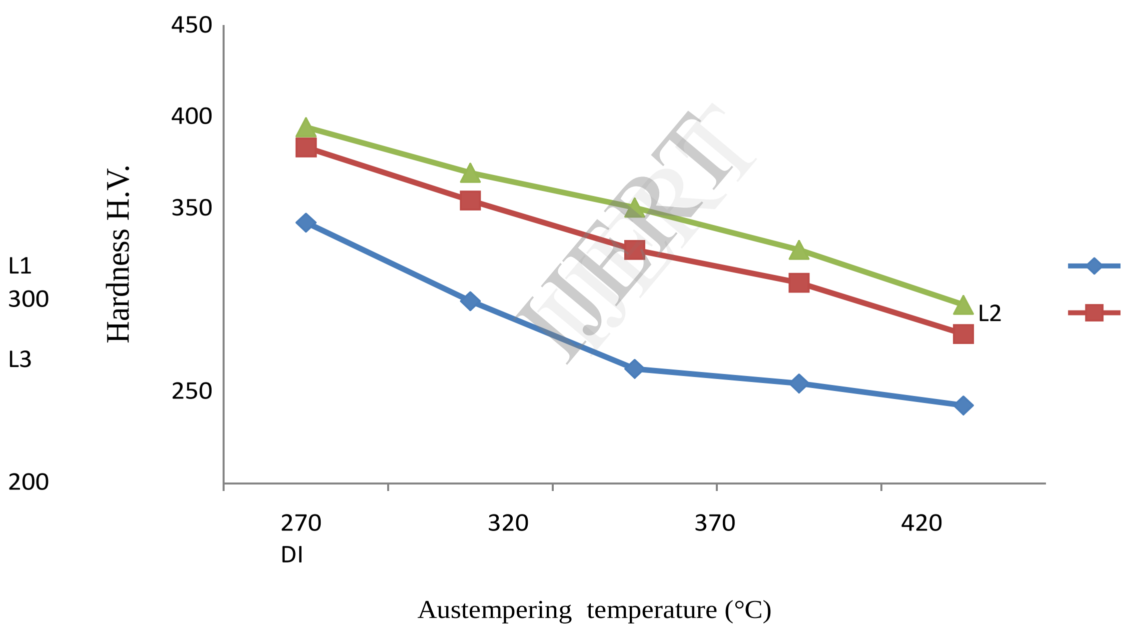


Figure 4.5: Variation in hardness with austempering temperatures and material composition.

From the graph three things are evident:

- Hardness decreases with the increase in austempering temperature, which means fine bainite is harder than coarse bainite.
- Material having greater nickel content has greater hardness.
- Increase in hardness is not proportional with the increase in nickel content, so there is a limit to addition of nickel to increase the hardness.

Analysis of cutting forces

A tri-axial dynamometer mounted on the horizontal milling machine and coupled to a multi-channel amplifier was used for measurement of cutting forces. Cutting forces during convectional horizontal milling operation on all the samples (3 different composition and 2 temperatures) were calculated.

Chips were collected after each cut and examined visually as shown in Fig.4.13.

Graph of cutting forces v/s austempering temperatures

The cutting forces required for milling operation on material L1, heat treated at different temperatures as shown in the Table 4.5.The variation of forces required for material heat treated at different temperatures are shown in Fig.4.10.

Table 4.5: Variation of cutting forces with austempering temperatures of material L1.

Austempering Temperatures(°C)	Cutting forces(N)
DI	15.276
370	16.538
320	18.874

Graph of cutting forces v/s austempering temperatures

The cutting forces required for milling operation on material L1, heat treated at different temperatures as shown in the Table 4.5.The variation of forces required for material heat treated at different temperatures are shown in Fig.4.10.

Table 4.5: Variation of cutting forces with austempering temperatures of material L1.

Austempering Temperatures(°C)	Cutting forces(N)
DI	15.276
370	16.538
320	18.874

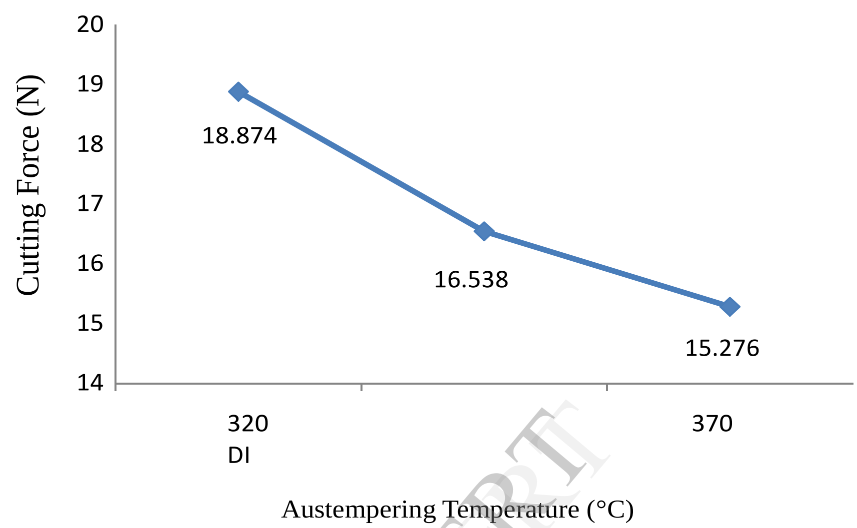


Figure 4.10: Variation of cutting forces with austempering temperatures of material L1.

The cutting forces required for milling operation on material L2, heat treated at different temperatures as shown in the Table 4.6.The variation of forces required for material heat treated at different temperatures are shown in Fig.4.11.

Table 4.6: Variation of cutting forces with austempering temperatures of material L2

Austempering Temperatures(°C)	Cutting forces(N)
DI	17.737
370	20.641
320	22.345

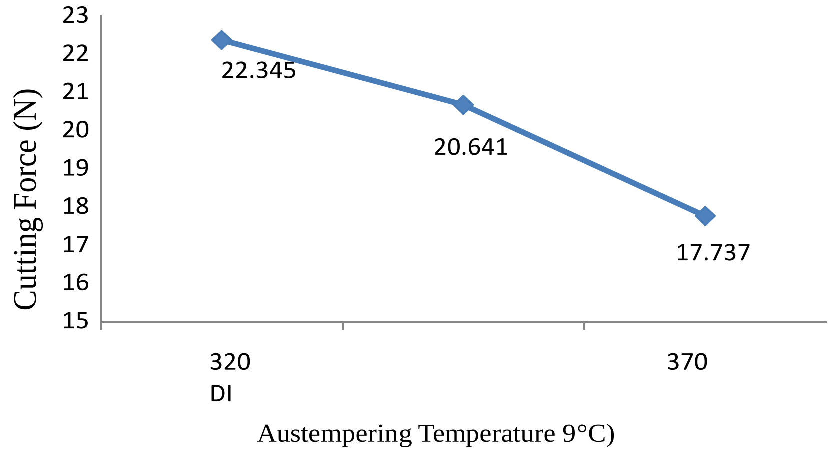
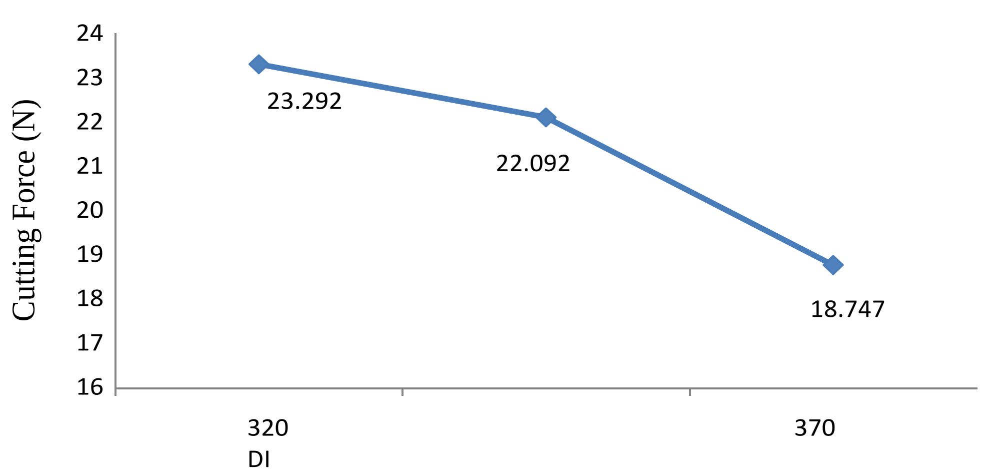


Figure 4.11: Variation of cutting forces with austempering temperatures of material L2.

The cutting forces required for milling operation on material L3, heat treated at different temperatures as shown in the Table 4.7.The variation of forces required for material heat treated at different temperatures are shown in Fig.4.12.

Table 4.7: Variation of cutting forces with austempering temperatures of material L3.

Austempering Temperatures(°C)	Cutting forces(N)
DI	18.747
370	22.092
320	23.292



Austempering Temperature (°C)

Figure 4.12: Variation of cutting forces with austempering temperatures of material L3.

Strain Induced phase transformation is a big problem in machining ADI i.e. when a high normal force is applied to ADI, a strain-induced phase transformation occurs on the surface of the part. The force exerted by the tool during milling, drilling, or turning can cause a localized phase change in the material in front of the tool. Austenite on the surface undergoes a transformation to martensite, which is harder and more brittle than the ausferrite structure. Therefore, while machining ADI, this transformation right in front of the tool face makes the material even more difficult to machine.

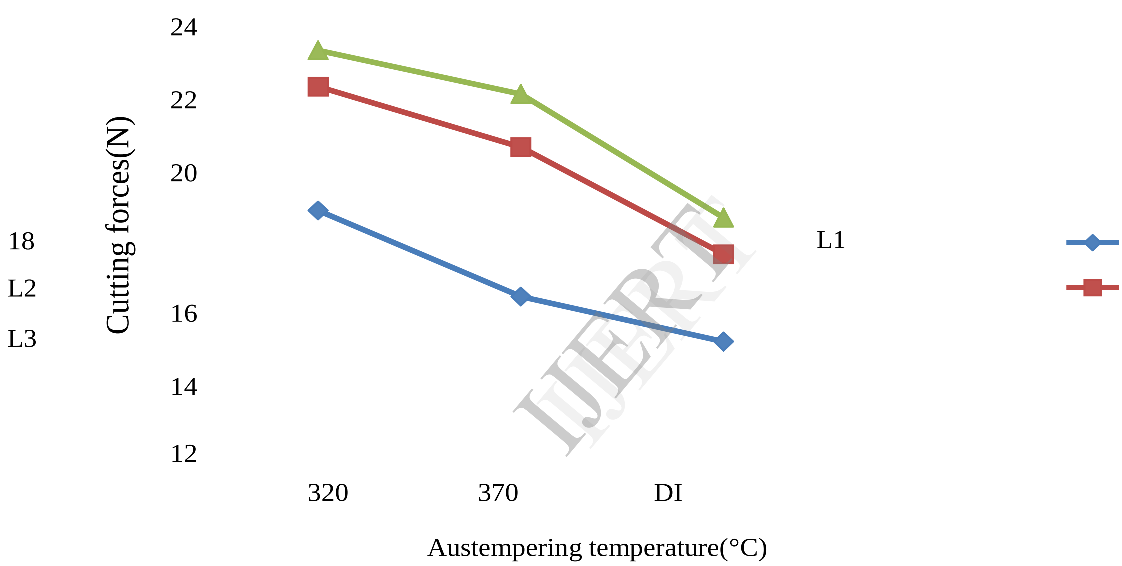


Figure 4.13: Variation in cutting forces with austempering temperatures and materials.

Figure 4.10 Shows that the cutting forces decreases with increase in temperature and is least for the material without heat treatment, for L1**.**Figure 4.11 and 4.12 also shows the same trend but for same austempering temperature cutting force of the material L2 is appreciably greater than that of material L1. Whereas the cutting forces variation between L3 and L2 at same austempering temperature is there but not as appreciable as between L1 and L3.

The morphology with the milling of the ductile iron and ADI of three different composition developed in the present work shows more discontinuous coarser chips with increase in the cutting force

Analysis of surface roughness

- **Material L1**

Table 4.8: Variation of surface roughness with austempering temperatures of material L1.

Austempering Temperatures(°C)	surface roughness(Ra-µm)
DI	3.50
370	2.92
320	1.42

- **Material L2**

Table 4.9: Variation of surface roughness with austempering temperatures of material L2

Austempering Temperatures(°C)	surface roughness(Ra-µm)
DI	3.25
370	2.75
320	1.39

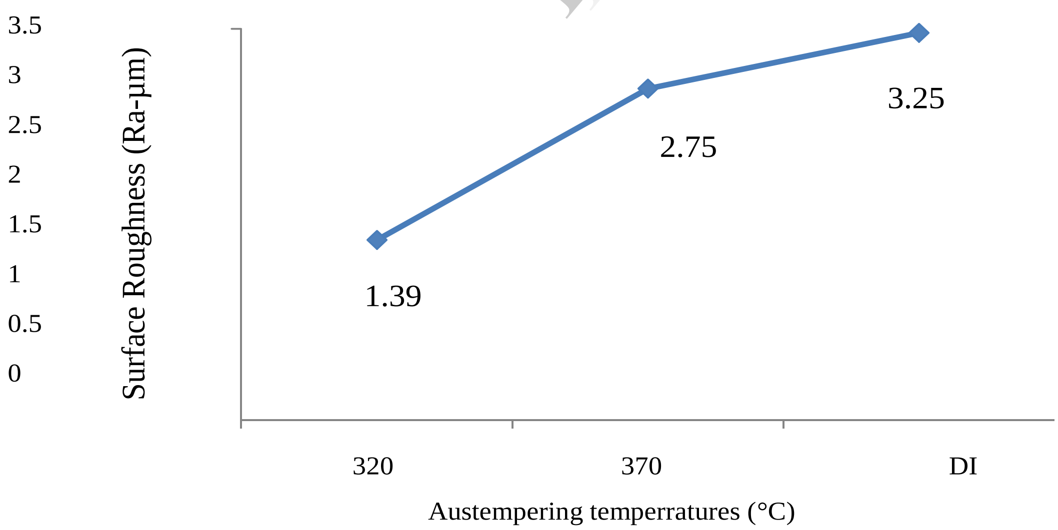


Figure 4.16: Variation of surface roughness with austempering temperatures of material L2.

- **Material L3**

Table 4.10: Variation of surface roughness with austempering temperatures of material L3

Austempering Temperatures(°C)	surface roughness(Ra-µm)
DI	3.15
370	2.69
320	1.35

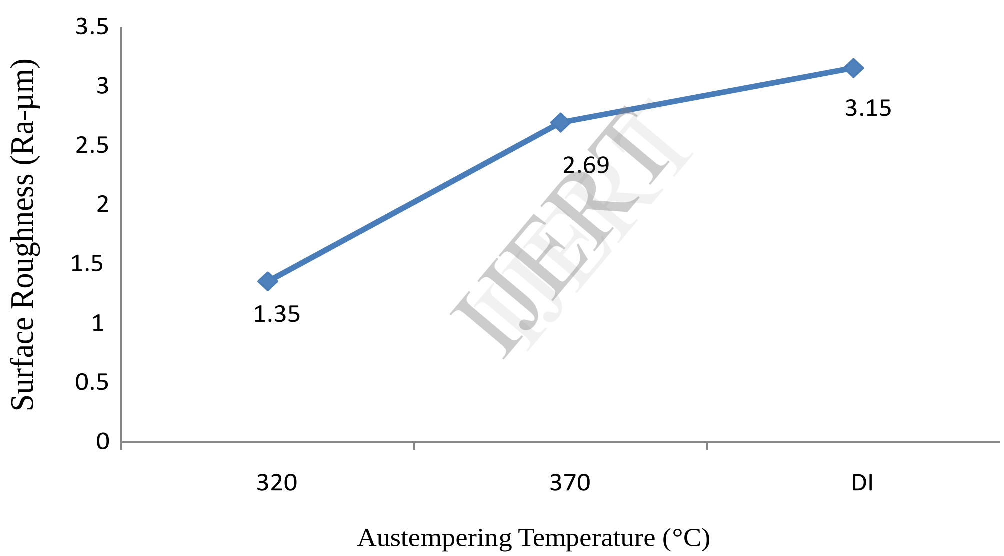


Figure 4.17: Variation of surface roughness with austempering temperatures of material L3

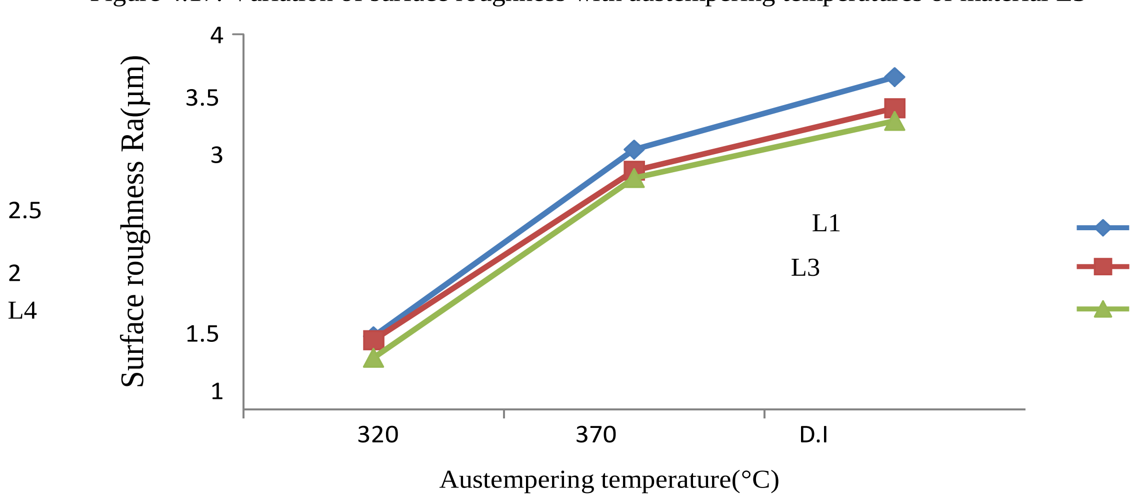
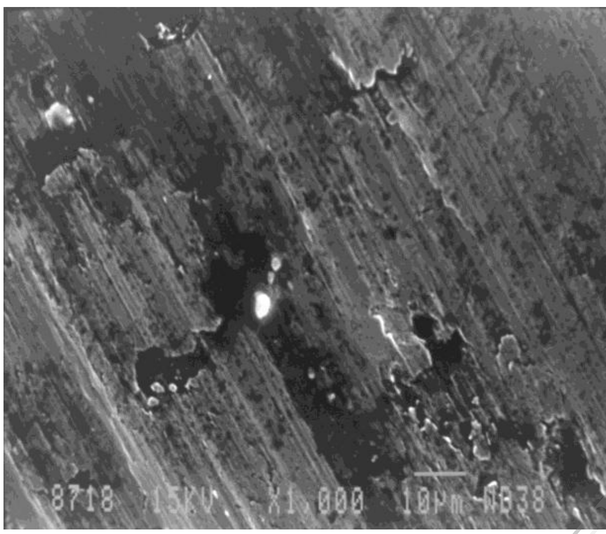
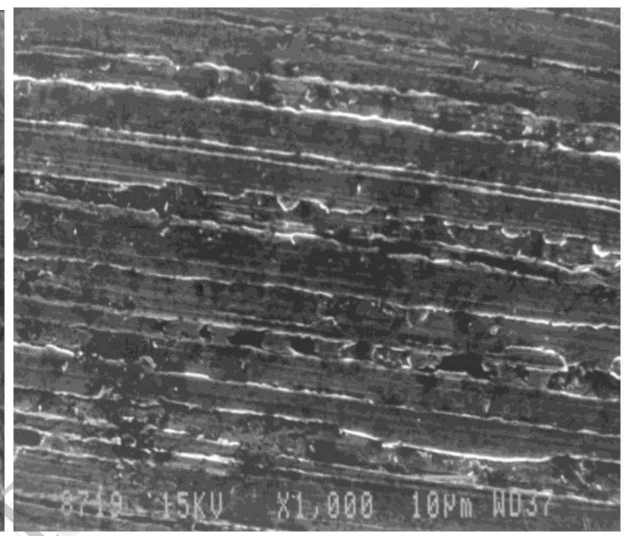


Figure 4.18: Variation in surface roughness with austempering temperatures and materials.

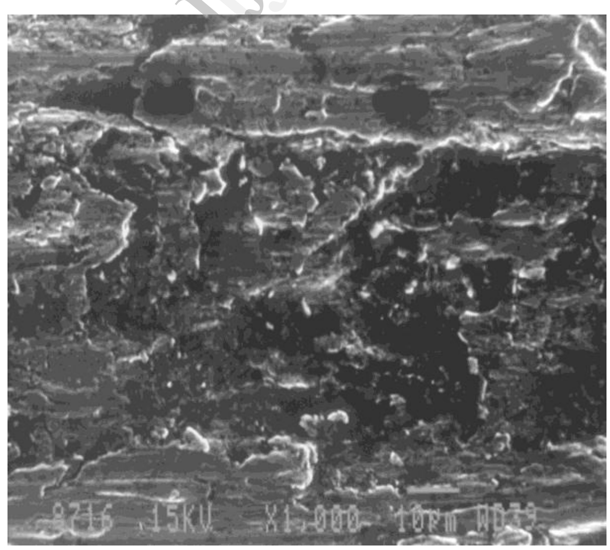
Figures 4.15, 4.16 and 4.17 shows the surface roughness increases with increase in austempering temperature, respectively, and is greatest for the material without austempering treatment. The same pattern is visible for all the three materials L1, L2 and L3.





a) 320-L1
L3

b) 370-



c) DI-L4

Figure 4.19: SEM microstructure of machined surfaces.

Graph of cutting forces v/s Materials

- **DI**

Table 4.11: Variation of cutting forces with materials of DI.

Material	Cutting forces(N)
L1	15.276
L2	17.737
L3	18.747

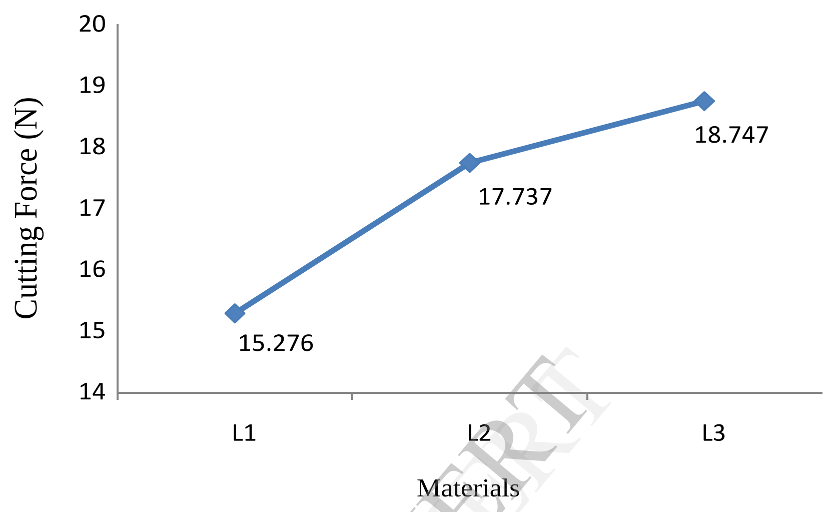


Figure 4.20: Variation of cutting forces with varying % of Ni of DI.

- **Austempering temperature 370°C**

Table 4.12: Variation of cutting forces with materials, austempered at 370°C.

Material	Cutting forces(N)
L1	16.538
L2	20.641
L3	22.092

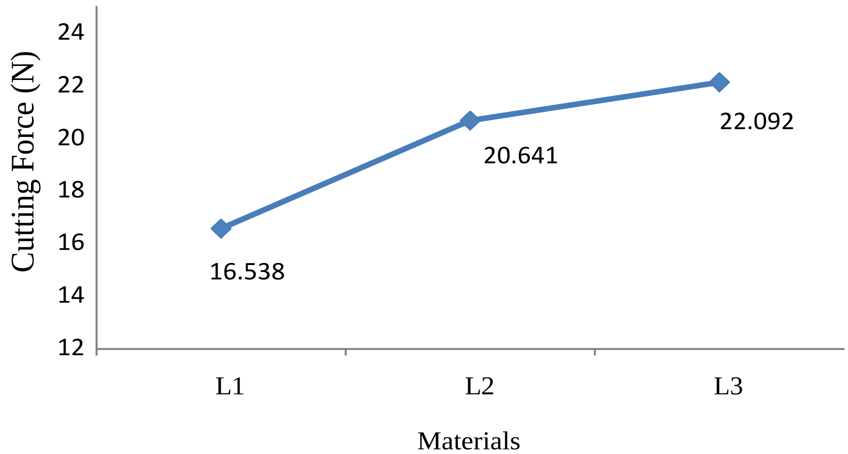


Figure 4.21: Variation of cutting forces with materials austempered at 370°C.

- **Austempering temperature 320°C**

Table 4.13: Variation of cutting force with materials, austempered at 320°C.

Material	Cutting forces(N)
L1	18.874
L2	22.345
L3	23.292

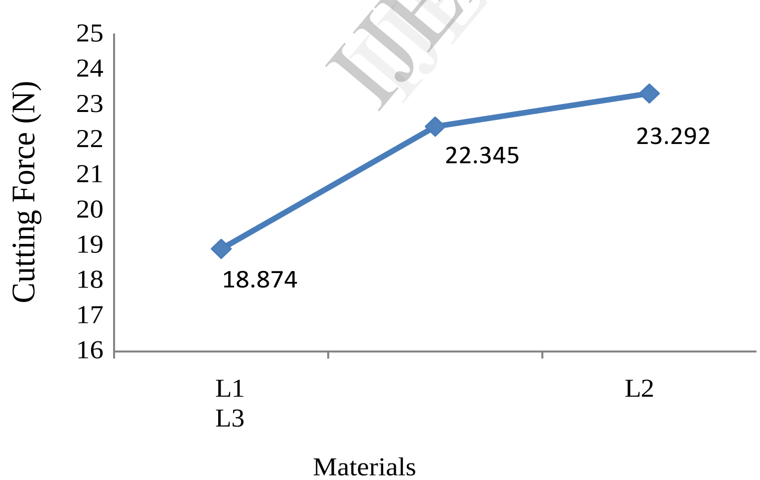


Figure 4.22: Variation of cutting forces with materials austempered at 320°C.

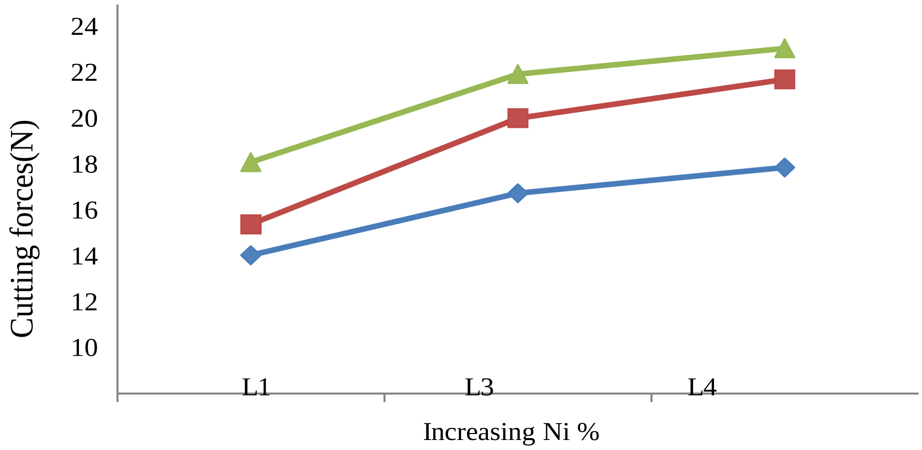


Figure 4.23 Variation of cutting forces with increasing % of Ni.

The Fig.4.20, 4.21 and 4.22 shows that for same austempering temperature, cutting forces increases with increase in nickel (Ni) content. This increase is appreciable when nickel content increases from 0% to 1.3% but not so varying between 1.3% and 1.6%.

Hardness values comparison before and after machining

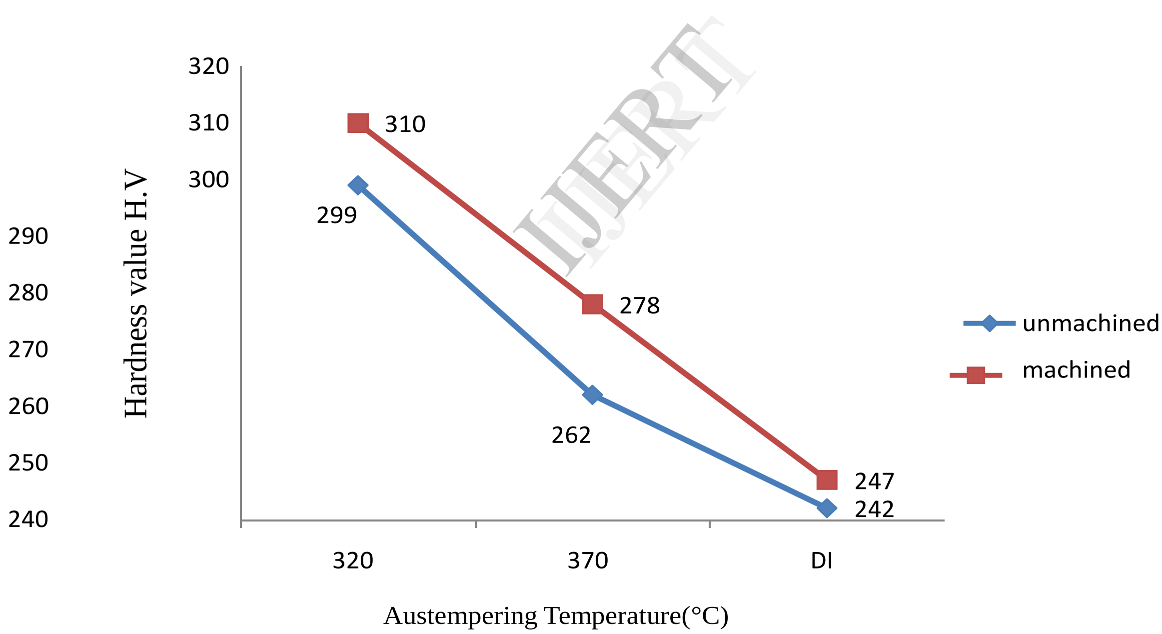
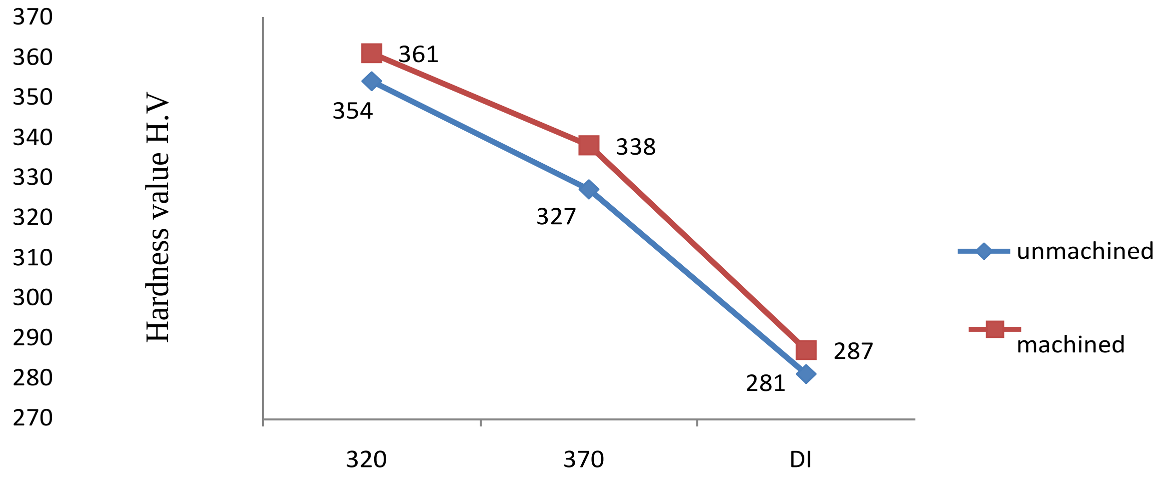


Figure 4.25: Comparison of hardness values of unmachined and machined material L1.



Austempering Temperature(°C)

Figure 4.26: Comparison of hardness values of unmachined and machined material L2.

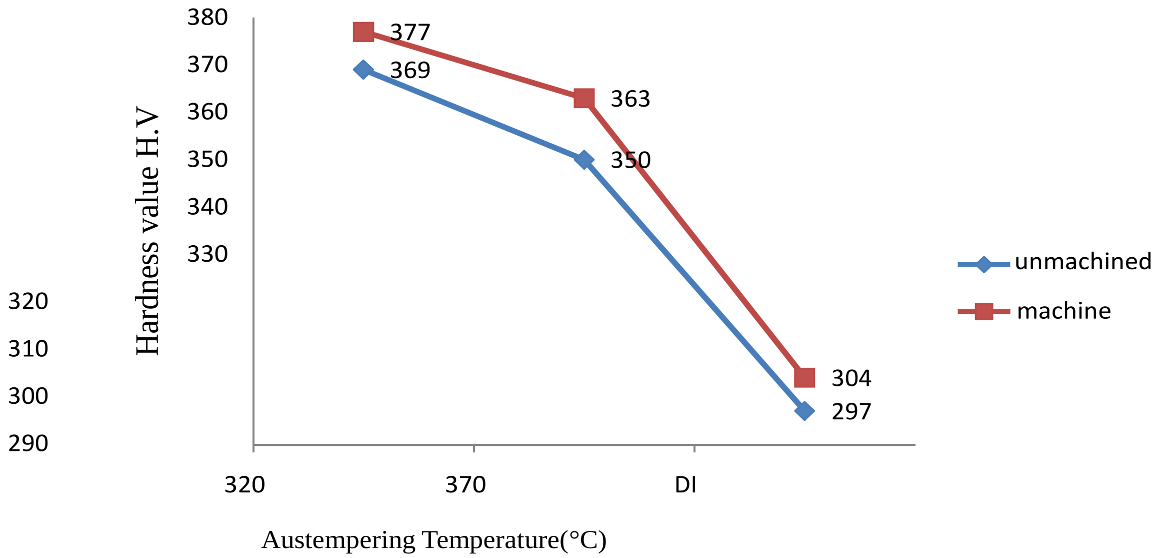


Figure 4.27: Comparison of hardness values of unmachined and machined material L3.

Figures 4.25, 4.26 and 4.27 shows that the hardness values of the material increased after machining, because retained austenite is converted into martensite due to phenomenon of strain hardening during the machining of the samples.

Conclusions

The aim of the work presented here is to study the machinability of ductile irons austempered at various temperatures for 2 hours. In order to do this cutting forces, surface qualities and power requirement were evaluated and the results were compared to each other.

Following conclusions can be drawn from the present work

1. Hardness increases from 254 H.V to 342 H.V of material L1, 309H.V to 388H.Vof L2 and 327H.V to 394H.V of L3 as austempering temperature decreases from 420°C to 270°C.
2. The amount of retained austenite in the matrix increases from 40.3% to 45.4% of L1, 38.4% to 44.6% of L2 and 35.3% to 43.8% of L3 with increase in austempering temperature from 320°C to 370°C.
3. During milling is at 320°C austempered ductile iron offer a cutting force of 22.3N as compared to 20.6N at 370°C.
4. Cutting forces increases from 23.3N to 17.7N with increase in hardness from 254 H.V to 394 H.V and increases with decrease in austempering temperature from 320°C to 370°C.
5. Surface roughness increases from 1.35µm to 3.50µm with increase in austempering temperature from 320°C to 370°C.
6. Power requirement is also increases from 0.0113W to 0.0172W with increase in hardness from 254 H.V to 394 H.V and increases with decrease in austempering temperature.
7. The retained austenite in the matrix of ADI decreased from 40.3% to 35.5% after machining considerably as compare to unmachined ADI.

REFERENCES

[1] Ductile Iron Data for Design Engineers, Rio unto Iron and Titanium Inc, (1990), pp. 4.1 - 4.44, 6.1 -6.10.

[2] Roy Elliot, –Cast Iron Technology", Jaico Publishing Rouse, (1996), pp. 1-36, 221-

235.

[3] Dai P.Q., He Z.R., Zheng C.M., Mao Z.Y., "In-situ SEM observation on the fracture of austempered ductile iron", journal of Materials Science and Engineering, Vol A319-321, (2001), pp. 531-534.

[4] Cakir M. Cemal, All Bayrarna, Yahya Isik, Bans Salar, "The effects of austempering temperature and time onto the machinability of austempered ductile iron", journal of Materials Science and Engineering, Vol A 407, (2005), pp. 147-153.

[5] Warrick Robert J., Althoff P., Druschitz Alan P., Lemke Jeffrey P. and Zimmerman K., "Austempered Ductile Iron Castings for Chassis Applications", Society of Automotive Engineers, Inc. , (2000-01), p.1290.

[6] Yescas M.A., Bhadeshia H.K.D.H., Mackay D.J., "Estimation of the amount of retained austenite in austempered ductile irons using neural networks", journal from Materials Science and Engineering, Vol A311, (2001), pp. 162-173.

[7] Eric 0., Rajnovi D., Leposava, Zec S. and Jovanov Milan T., "An austempering study of ductile iron alloyed with copper", Faculty of Technical Sciences, University of Novi Sad, Serbia and Montenegro, J. Serb. Chem. Soc., (2005), pp.1015-1022.

[8] Magalhaes L., Seabra J., Sac C., "Experimental observations of contact fatigue crack mechanisms for austempered ductile iron (ADI) discs", journal of Wear, Vol 246, (2000), pp. 134-148.

[9] Mazzaferro Petty C.C., Froehlich, Ronaldo A., Strohaecker, Reguly T.R., Alonso, "Devel6pment of a carbidic austempered ductile iron for wear applications", journal

of Wear, Vol 287, (2002), pp.194-211.

[10] Nadkarni, Behravesh G., Warda A.H., Davis R.D., Sahoo KG., tow-carbon equivalent Austempered Ductile Irons", Transactions of the American Foundrymen's Society, Volume 103, (1995), pp. 93-101.

[11] Lamer Y.S., Kingsbury G.R., "Wear Resistance Properties of Austennpered Ductile

Iron", 59th Annual ABM International Congress, Sao Paulo, Brasil, 19-22 July 2004. [12] Jianghuai Yang and Putatunda S.K., "Influence of a novel two-step austempering

process on the strain-hardening behavior of austempered ductile cast iron (ADO', journal of Materials Science and Engineering, Vol A 406, (2005), pp. 217-228.

[13] Marrow & Qetinel, "Short fatigue cracks in Austempered Ductile Cast Iron (ADI, journal of Materials Science, Vol 38, (2003), pp. 2971 — 2977.

[14] Bahmani M., Elliot R., Varahram N., "The austempering kinetics and • mechanical properties of an Austempered Cu-Ni-Mo-Mn alloyed ductile iron", Journal of Mining and Metallurgy, Vol 40B (1), (2004), pp. 11 - 19.

[15] Zimba J., Simbi D.J., Chandra T., Navara E., "A Dilatometry Study of the Austenitization and Cooling Behavior of Ductile Iron Meant for the Production of Austempered Ductile Iron (ADO", journal of Materials and Manufacturing Processes, Vol 19, (2004), pp. 907-920.