STUDIES ON MECHANICAL PROPERTIES AND DRY SLIDING WEAR PROPERTIES OF AUSTEMPERED DUCTILE IRON CASTINGS (CONFIRMING TO IS400/12,IS 600/3, IS700/2 GRADE DUCTILE IRON)

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Abstract

Now a days ductile iron has taken a leading position in various industrial applications in crank shaft, camshaft and other parts of automobiles, earth digging implements , power loom industries etc., and is replacing steel in almost all applications. Ductile iron when subjected to austempering treatment results in Austempered Ductile Iron. This has got a very great potential as it combines the properties of steel and cast iron. Hence, it is a very attractive material if properly harnessed. Lot of research work is going on at the International level and National level. In India researchers and foundrymen are continuously working in this direction.

In this paper, results of the investigation carried out on three grades of ductile iron castings conforming to Indian standards IS400/12, IS600/3 and IS 700/2 produced in three different moulds viz.,carbon dioxide sand moulds, no-bake sand moulds and metallic moulds is presented. Standard Y-block castings were produced in a regular production foundry following all the shop floor foundry practices. The castings after cooling were then subjected to standard austempering heat treatment cycle consisting of two stages, namely, austenitisation treatment carried out at $920^{o}C$ for 120 minutes duration, followed by quenching into austempering salt baths (consisting of Potassium nitrate and Sodium nitrate salts) maintained at $280^{0}C$, $310^{0}C$, $340^{0}C$, $370^{0}C$ for 120 minutes duration to bring about the changes in the microstructure and hence the properties.

The castings after heat treatment were cut and machined for carrying out different tests. Microstructure examination, mechanical property assessments like ultimate tensile strength, percentage elongation, and Brinell hardness measurements were carried out on as cast castings and austempered castings. Dry Sliding Wear studies were carried out using a standard instrumented type of pin–on-disc wear testing machine. Wear tests were carried for three different speeds viz.,300rpm,450rpm and 750rpm and for three different loads, viz.,1kg,1.5kg and2.5kgs.

The effect of austempering temperature on the structure, mechanical properties,dry sliding wear properties has been studied in detail. From the results of the investigation, it is found that graphite nodules are more are less uniform in size in ferritic matrix in the as cast condition. The structure of austempered heat treated castings reveals clearly the formation of bainite. Further, the castings made in metallic moulds exhibit better mechanical properties than those made in the other two sand moulds. From the dry sliding wear studies, it is observed that the wear resistance of austempered ductile iron (ADI) is superior to that of as cast ductile castings. Also castings austempered at $310^{0}C$, made in metallic moulds exhibit superior mechanical properties and better wear resistance properties as compared to other austempering conditions. The above trend is noticed for all the three grades of ductile iron castings made in different moulds.

(Key words; ductile iron, austempering, properties, wear)

Introduction: Ductile iron or S.G.iron refers to the cast iron consisting of graphite in the form of nodules dispersed (1) in a matrix of ferrite or pearlite. The matrix in the ductile iron can be suitably controlled by subjecting the iron to heat treatment cycle or by alloying additions. Several research works have been carried out ever since the discovery in the late 40's. The potential of S.G iron which has steel like mechanical properties, good casting property, good damping property comparable to cast iron (2,3) has made it a popular alloy for research work and industrial applications. Properties of ductile iron may be improved by subjecting it to austempering heat treatment cycle consisting of two stages namely austenitization (3,4) and austempering (4,5). Ductile Iron subjected austempering heat treatment is referred to as **Austempered Ductile Iron**. The heat treatment brings about the changes in the structure and the properties. Wear is a phenomenon which is observed whenever two materials in contact have relative motion. It is the progressive loss of material resulting from the surface of the materials in contact. Wear studies is finding importance now a days in characterising the material for different applications. In this study, detailed investigations have been carried out on the mechanical property assessments, dry sliding wear properties of different grades of ductile iron castings confirming to IS grades and subjected to different austempering heat treatment variables. The results are presented in this paper.

Experimental details:

Moulds used: Sand moulds and Metallic moulds.

Types of sand moulds used: 1) **Carbon dioxide sand mould;** Sodium silicate bonded carbon dioxide gas hardened sand was used as the moulding media.

Silica sand; 96% Co_2 gassing pressure; 600-700 kN/m^2

Sodium silicate; 4% CO_2gassing time; 30-50 seconds

Silica: soda gel: 2.6:1 Compression Strength developed; 10-20 kN/m^2

2) No bake sand mould; System consisting or 3-part (partA, part, part) alkyd system was used.Recommmended ratio of binder: catalyst; accelerator 3:8:18 was used.

Standard Y-block castings were produced in the above two types of sand moulds and test castings were cut, machined appropriately and used for evaluating various properties. **Figure 1** shows the details of the same.

Metallic moulds: Graphite powder coated and preheated cylindrical cast iron moulds were used. **Figure 2** shows the details of the same.

Melting and pouring: Melting of the charge was carried out using a 1.25 tone capacity, 200 Hz frequency induction furnace. Charge consisting of SG iron, grey cast iron returns, commercial pig iron (imported soral pig iron,-containing low sulphur content<0.05%), mild steel in the form of punching were used. Standard sandwich method method of treatment was employed. The carbon equivalent was aimed between 4.2-4.6 to meet IS400/2, IS600/3, and IS700/2 specifications. Typical composition of the different grades of ductile iron is shown in the **Table 1.**

Austempering heat treatment details: Standard austempering heat treatment cycle was employed. **Figure-3** shows the details of the same.

Austenitisation: 920^{0}C-2hours duration; salt baths used: sodium nitrate: potassium nitrate:: 55:45 by weight basis.

Austempering duration: 120 minutes; Austempering temperatures:280^{0}C,310^{0}C,340^{0}C, 370^{0}C.

Figure-4 shows the flow chart for the production of ADI.

Evaluation of castings: Test specimen required for the microstructure examination, tensile strength measurements, hardness measurements and wear properties were machined from the as cast and heat treated castings.

Microstructure examination; Specimen for structure examination were machined and standard metallographic procedure was employed. The number of nodules for a given area was measured in the as cast condition and the heat treated ones were etched with 3% natal solution, using SEM the matrix examination was carried out.

Mechanical properties:

UTS and percentage elongation: Standard tensometer specimen was tested for UTS and percentage elongation values using ASTME-E8 universal testing machine of capacity 40 tonnes.

Hardness measurements: Brinell hardness tester was used (10mm diameter ball and 3000kg load). The average value of 4 measurements at different locations was taken as a measure of the hardness of the specimen.

Dry sliding wear tests: Sliding wear tests were carried out using an instrumented type pin on disc wear testing machine. **Figure-5** shows the details of the same. The procedure employed is described below:

1. Cylindrical specimen of 8mm diameter and 15mm length was used.

2. Wear disc was cleaned thoroughly to remove dust, grease; the specimen surface was also cleaned with acetone.

3. Initial weight of the specimen was noted down; The specimen fixed in the specimen holder was made to contact the rotating wear disc.

4. Initial running in time of two minutes was given to ensure the perfect contact between the specimen surface and the wear disc.

5. The specimen was then loaded by applying the weights in the pan.

6. The test was conducted for 60 minutes; At the end of every 10 minutes, the specimen was removed from the specimen holder, the surface was thoroughly cleaned with acetone, dried and was weighed precisely in an electronic balance.

7. The loss in weight of the specimen after conducting the test was taken as a measure of wear.

Wear tests were carried out for 3 different levels of speeds and 3 different levels of load as given below:

Speeds investigated	**Loads investigated**
N1 = 300 rpm	P1 = 1 Kg
N2 = 450 rpm	P2 = 1.5 Kg
N3 = 750 rpm	P3 = 2.5 Kg

RESULTS AND DISCUSSION:

Microstructure examination: Following photographs shows the details of the microstructure examination of the as cast and austempered ductile iron **Photo 5** shows the details.

In the as cast condition, graphite nodules are more or less uniform in size and distributed evenly in the matrix. Upon austempering, the microstructure shows the formation of bainitic matrix in the iron. The above behaviour is observed in all the different grades of ductile iron studied and austempered for different condition.

Mechanical properties: Table 2-4 summarises the results of the mechanical properties of the different grades of ductile iron austempered for different conditions.

UTS versus Austempering Temperature

From the table it can be seen that austempered specimens exhibit higher UTS values compared to the as cast ones for all the grades of ductile irons studied and also for all the austempering conditions. UTS values of the castings made in metallic mould specimen show higher values in the as cast condition and for all austempering temperatures as compared to the specimen made in sand moulds. UTS values increases with increase in austempering temperatures upto 310^0C and then decreases with further increase in austempering temperature.

Percentage elongation versus austempering temperature

From the table, it can be seen that austempered specimens exhibit higher UTS values compared to the as cast ones for all the grades of ductile irons studied and also for all the austempering conditions. UTS values of the castings made in metallic mould specimen show higher values in the as cast condition and for all austempering temperatures as compared to the specimen made in sand moulds. UTS values increases with increase in austempering temperatures upto 340^0C and then decreases with further increase in austempering temperature.

Hardness versus austempering temperature

From the table, it can be seen that austempered specimens exhibit higher UTS values compared to the as cast ones for all the grades of ductile irons studied and also for all the austempering conditions. UTS values of the castings made in metallic mould specimen show higher values in the as cast condition and for all austempering temperatures as compared to the specimen made in sand moulds. UTS values increases with increase in austempering temperatures upto 310^0C and then decreases with further increase in austempering temperature.

Wear versus austempering temperature

Sliding wear at 300 rpm and 1 Kg load; The discussion has been highlighted for 300 rpm at different loads. However the consolidated results have been shown in the form of **Table 5-7.**

The variation of weight loss versus time are shown in **Figures 6-10**. It can be observed that weight loss increases steadily with increase in time of testing. Weight loss is found to be more in as cast specimens compared to the austempered specimens. Specimens austempered at 310^0C seems to show least weight loss compared to those austempered at other austempering temperatures. Specimens made in metallic moulds exhibit lower weight loss compared to those made in sand moulds for all the conditions studied.

Conclusions: The results of the investigation carried out on different grades of ductile irons subjected to different austempering conditions indicate the following:

1. In the as cast condition, graphite nodules are more or less uniform in size and distributed evenly in the matrix. Upon austempering, the microstructure shows the formation of bianatic matrix in the iron. The above behaviour is observed in all the different grades of ductile iron studied and austempered for different condition.

2. Ductile iron made in metal moulds show higher ultimate tensile strength, percentage elongation and hardness values in austempered and austempered conditions.

3. By austempering heat treatment of ductile iron the properties gets improved and optimum strength values and hardness values are realised in the ductile iron austempered at 310^0C.

4. From the wear studies it is observed that wear of the specimens increases with increase in time of testing for all the conditions.

5. By austempering the castings the wear of the material is reduced.

6. Castings made in sand moulds show higher wear compared to the ones made in metallic moulds both in as cast and austempered conditions.

7. By austempering the castings at 310^0C, the wear of the specimen can be reduced appreciably.

References:

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Table 1 Composition of different grades of iron

Grades	%C	%Si	%Mn	%Cu	%P	%S	Residual Mg%
IS400/2	3.6-3.7	2.7-2.8	0.35max	-	0.03max	0.01max	0.03min
IS600/3	3.4-3.5	2.5-2.6	0.5max	0.3-0.5	0.03max	0.01max	0.03min
IS700/2	3.4	2.5-2.6	0.5-0.6	0.5-0.8	0.03max	0.01max	0.03min

Table 2 Mechanical properties of IS 400/12 ductile iron made in different moulds:

Ultimate Tensile Strength values (N/mm^2)

		Austempering Temperature			
Moulds used	**As cast**	**280^{0}C**	**310^{0}C**	**340^{0}C**	**370^{0}C**
CO_2 sand mould	390	480	620	570	520
No Bake mould	430	570	680	620	560
Metallic mould	450	630	780	750	700

Elongation values (%)

		Austempering Temperature			
Moulds used	**As cast**	**280^{0}C**	**310^{0}C**	**340^{0}C**	**370^{0}C**
CO_2 sand mould	13	14.8	18	21	19
No Bake mould	13	16.5	19	22.5	20
Metallic mould	14	18	23.5	24	23

Hardness Values (BHN)

		Austempering Temperature			
Moulds used	**As cast**	**280^{0}C**	**310^{0}C**	**340^{0}C**	**370^{0}C**
CO_2 sand mould	250	262	256	250	242
No Bake mould	252	265	278	263	262
Metallic mould	260	278	298	276	270

Table 3 Mechanical properties of IS 600/3 ductile iron made in different moulds:

Ultimate Tensile Strength values (N/mm^2)

		Austempering Temperature			
Moulds used	**As cast**	**280^{0}C**	**310^{0}C**	**340^{0}C**	**370^{0}C**
CO_2 sand mould	588.6	735.7	784.8	765.1	706.8
No Bake mould	609.1	784.8	875.5	824.0	784.8
Metallic mould	690	936.8	1139.9	1030	963.3

Elongation values (%)

		Austempering Temperature			
Moulds used	**As cast**	**280^{0}C**	**310^{0}C**	**340^{0}C**	**370^{0}C**
CO_2 sand mould	3	3.75	4.15	4	3.6
No Bake mould	3	4.4	5.5	5.45	4.75
Metallic mould	3.3	4.7	6.4	6.35	5.5

Hardness Values (BHN)

		Austempering Temperature			
Moulds used	**As cast**	**280^{0}C**	**310^{0}C**	**340^{0}C**	**370^{0}C**
CO_2 sand mould	252	266	282	280	278
No Bake mould	268	275	294	288	280
Metallic mould	274	286	320	305	286

Table 4 Mechanical properties of IS 700/2 ductile iron made in different moulds:

Ultimate Tensile Strength values (N/mm^2)

		Austempering Temperature			
Moulds used	**As cast**	**280^{0}C**	**310^{0}C**	**340^{0}C**	**370^{0}C**
CO_2 sand mould	700	840	960	920	820
No Bake mould	710	890	1090	960	880
Metallic mould	730	1040	1180	1020	970

Elongation values (%)

		Austempering Temperature			
Moulds used	**As cast**	**280^{0}C**	**310^{0}C**	**340^{0}C**	**370^{0}C**
CO_2 sand mould	2.6	6	8.6	8.6	8.2
No Bake mould	2.8	6.5	9.6	9.2	9
Metallic mould	3.2	7.6	12	11	9.6

Hardness Values (BHN)

		Austempering Temperature			
Moulds used	**As cast**	**280^{0}C**	**310^{0}C**	**340^{0}C**	**370^{0}C**
CO_2 sand mould	250	248	260	247	230
No Bake mould	252	261	275	265	260
Metallic mould	260	280	315	305	298

Table 5 Consolidated results of dry sliding wear for different speeds and loads investigated

Grade IS 400/12 specification-CO_2 mould

Speeds RPM	Condition	Weight Loss in Grams		
		Load		
		1 Kg	1.5 Kg	2.5 Kg
300	As cast	0.0430	0.0420	0.650
	Austempered at 280^{0}C	0.0160	0.0368	0.565
	Austempered at 310^{0}C	0.0128	0.0315	0.498
	Austempered at 340^{0}C	0.0138	0.0318	0.540
	Austempered at 370^{0}C	0.0141	0.0370	0.595
Speeds RPM	Condition	Weight Loss in Grams		
		Load		
		1 Kg	1.5 Kg	2.5 Kg
450	As cast	0.0101	0.07125	0.1315
	Austempered at 280^{0}C	0.0918	0.0650	0.1135
	Austempered at 310^{0}C	0.0731	0.0555	0.9500
	Austempered at 340^{0}C	0.0832	0.0600	0.1085
	Austempered at 370^{0}C	0.0750	0.0575	0.1070
Speeds RPM	Condition	Weight Loss in Grams		
		Load		
		1 Kg	1.5 Kg	2.5 Kg
750	As cast	0.1400	0.1260	0.1340
	Austempered at 280^{0}C	0.1135	0.1115	0.1185
	Austempered at 310^{0}C	0.1035	0.1110	0.1065
	Austempered at 340^{0}C	0.1110	0.1110	0.1085
	Austempered at 370^{0}C	0.1125	0.1140	0.1145

Table 6 Consolidated results of dry sliding wear for different speeds and loads investigated Grade IS 400/12 specification-No bake sand mould

Speeds RPM	Condition	Weight Loss in Grams		
		Load		
		1 Kg	1.5 Kg	2.5 Kg
300	As cast	0.0420	0.0415	0.0675
	Austempered at 280^{0}C	0.0155	0.0400	0.0575
	Austempered at 310^{0}C	0.0125	0.0318	0.0475
	Austempered at 340^{0}C	0.0125	0.0300	0.0550
	Austempered at 370^{0}C	0.0151	0.0390	0.0565
Speeds RPM	Condition	Weight Loss in Grams		
		Load		
		1 Kg	1.5 Kg	2.5 Kg
450	As cast	0.0950	0.0682	0.1350
	Austempered at 280^{0}C	0.0881	0.0617	0.1085
	Austempered at 310^{0}C	0.0667	0.0505	0.8450
	Austempered at 340^{0}C	0.0795	0.0575	0.1150
	Austempered at 370^{0}C	0.0887	0.0605	0.1115
Speeds RPM	Condition	Weight Loss in Grams		
		Load		
		1 Kg	1.5 Kg	2.5 Kg
750	As cast	0.1310	0.1175	0.1260
	Austempered at 280^{0}C	0.1100	0.1065	0.1145
	Austempered at 310^{0}C	0.0920	0.1050	0.1040
	Austempered at 340^{0}C	0.1145	0.1065	0.1115
	Austempered at 370^{0}C	0.1110	0.1110	0.1110

Table 7 Consolidated results of dry sliding wear for different speeds and loads investigated Grade IS 400/12 specification-metallic mould

Speeds RPM	Condition	Weight Loss in Grams		
		Load		
		1 Kg	1.5 Kg	2.5 Kg
300	As cast	0.0385	0.0395	0.0610
	Austempered at 280^{0}C	0.012	0.0315	0.0515
	Austempered at 310^{0}C	0.0112	0.0272	0.0425
	Austempered at 340^{0}C	0.0115	0.0265	0.0465
	Austempered at 370^{0}C	0.0124	0.0325	0.0475
Speeds RPM	Condition	Weight Loss in Grams		
		Load		
		1 Kg	1.5 Kg	2.5 Kg
450	As cast	0.0925	0.0645	0.1255
	Austempered at 280^{0}C	0.0825	0.0575	0.1250
	Austempered at 310^{0}C	0.0592	0.0450	0.7750
	Austempered at 340^{0}C	0.0723	0.0512	0.0935
	Austempered at 370^{0}C	0.0600	0.0575	0.0930
Speeds RPM	Condition	Weight Loss in Grams		
		Load		
		1 Kg	1.5 Kg	2.5 Kg
750	As cast	0.1260	0.108	0.1170
	Austempered at 280^{0}C	0.0985	0.0925	0.1120
	Austempered at 310^{0}C	0.0835	0.0925	0.1120
	Austempered at 340^{0}C	0.0940	0.0985	0.0985
	Austempered at 370^{0}C	0.1025	0.1045	0.1055

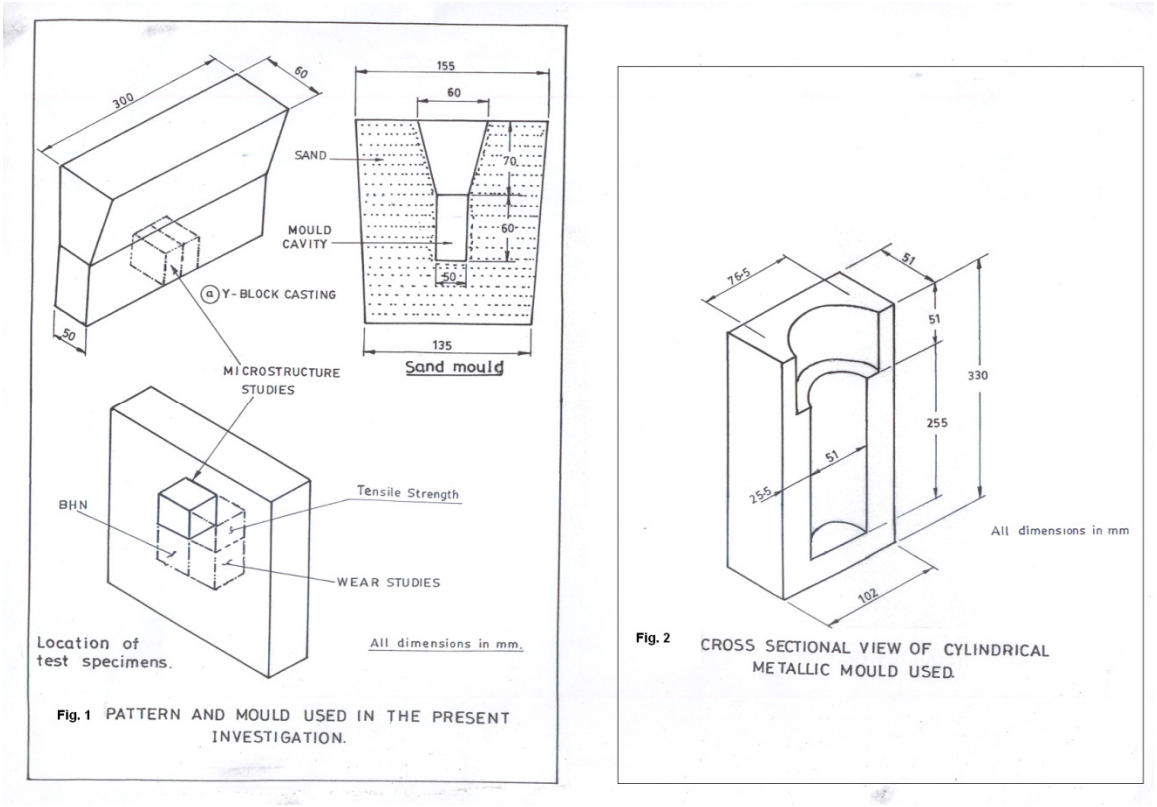


Fig. 1 PATTERN AND MOULD USED IN THE PRESENT INVESTIGATION.

Fig. 2 CROSS SECTIONAL VIEW OF CYLINDRICAL METALLIC MOULD USED.

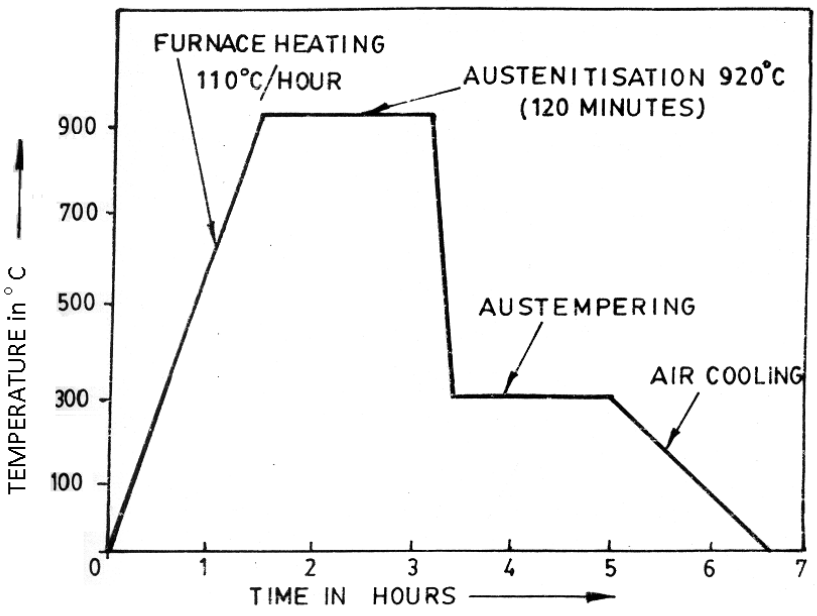


Fig. 3 AUSTEMPERING HEAT TREATMENT CYCLE EMPLOYED

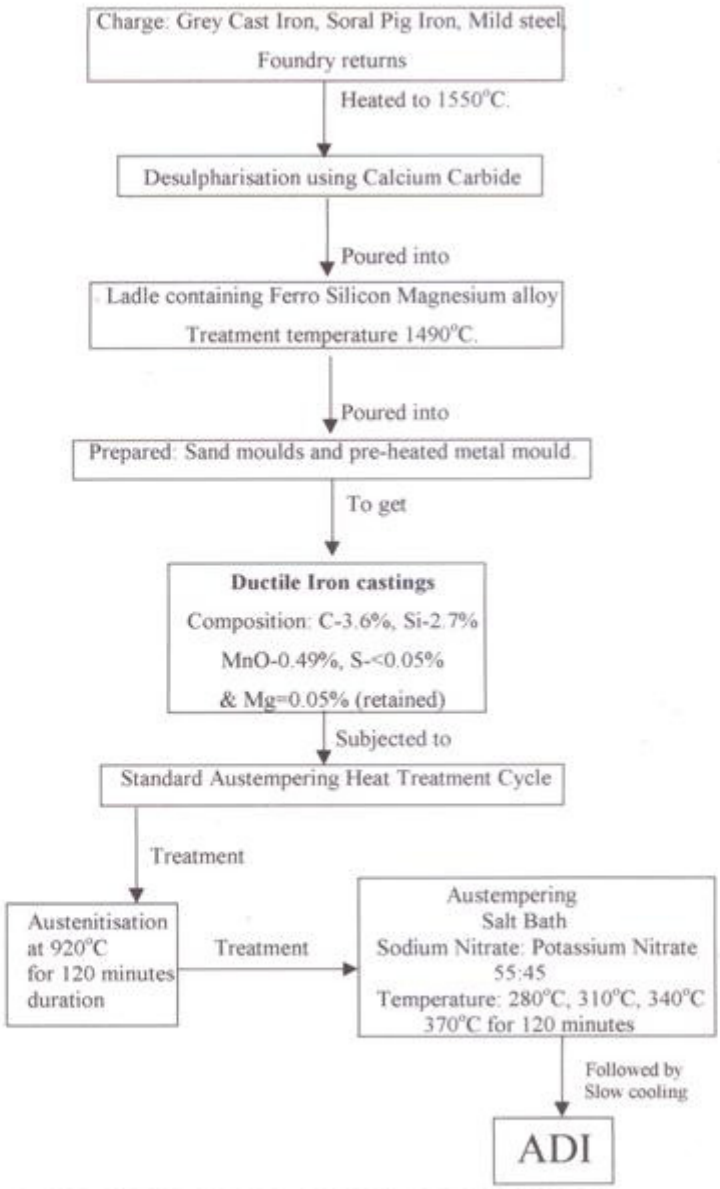


Fig. 4 FLOW CHART FOR THE PRODUCTION OF ADI

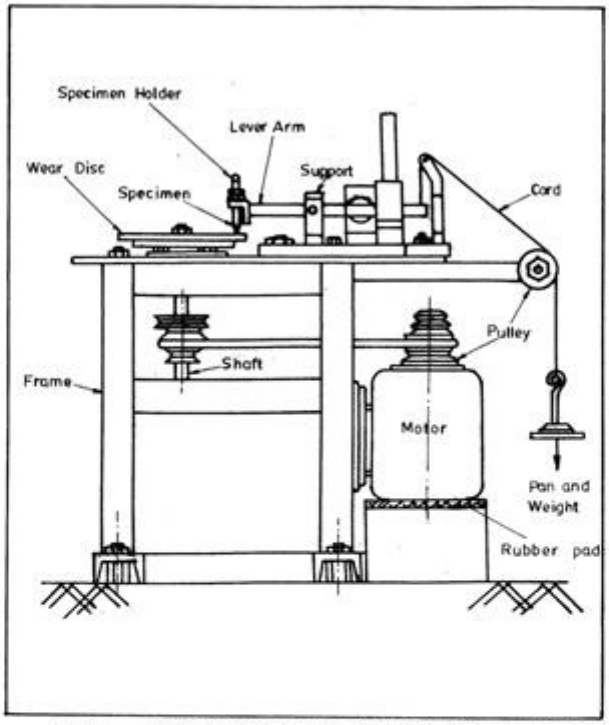
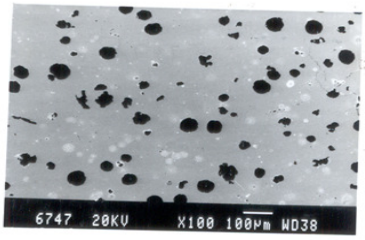
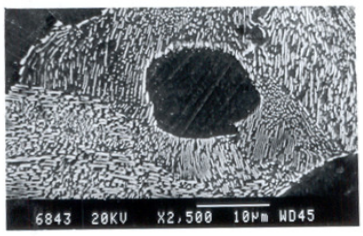


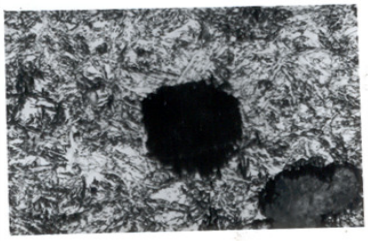
FIG 5 SCHEMATIC DIAGRAM OF DRY SLIDING WEAR TESTING MACHINE



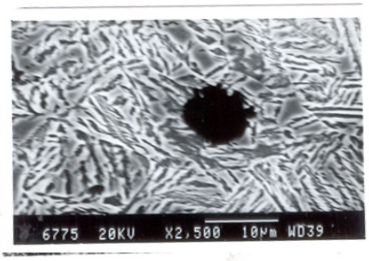
Ascast
X100



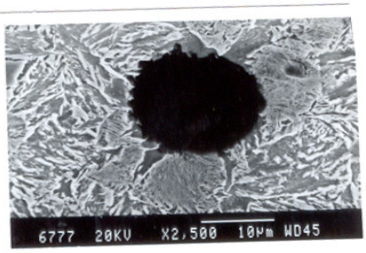
Austempered at 280 °C



Austempered at 310 °C



Austempered at 340 °C



Austempered at 370 °C

X 2500, etched with 3% nital

PHOTO 5 Microstructure of IS 400/12 Grade Ductile Iron Cast in Carbon dioxide sand mould

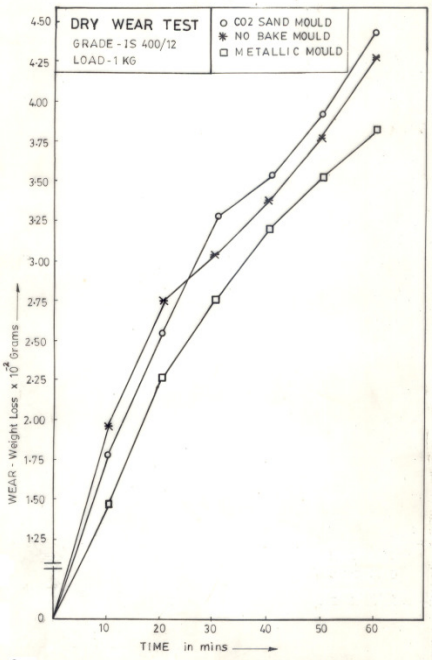


FIG 6 : VARIATION OF WEIGHT LOSS WITH TIME FOR SPECIMENS ASCAST CONDITION SLIDING WEAR AT 300 RPM

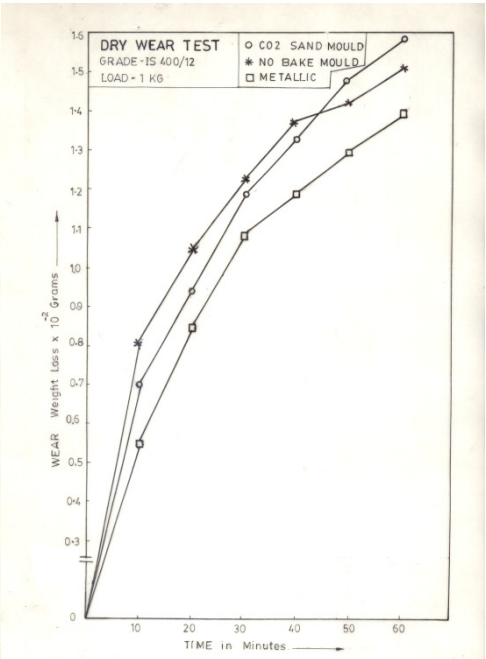


FIG 7 : VARIATION OF WEIGHT LOSS WITH TIME FOR SPECIMENS AUSTEMPERED AT 280°C - SLIDING WEAR AT 300 RPM

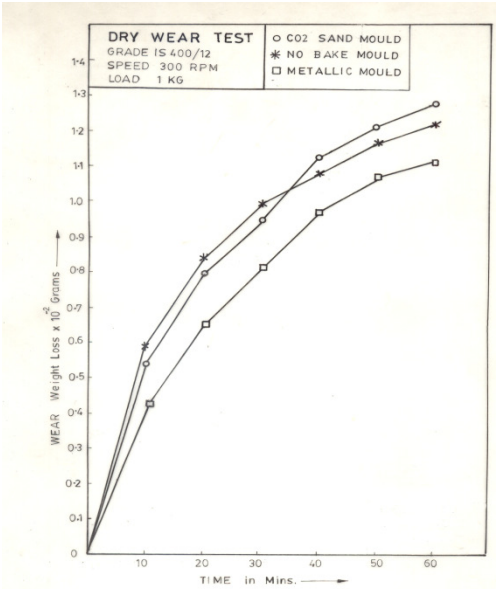


FIG 8 : VARIATION OF WEIGHT LOSS WITH TIME FOR SPECIMENS AUSTEMPERED AT 310 °C SLIDING WEAR AT 300 RPM

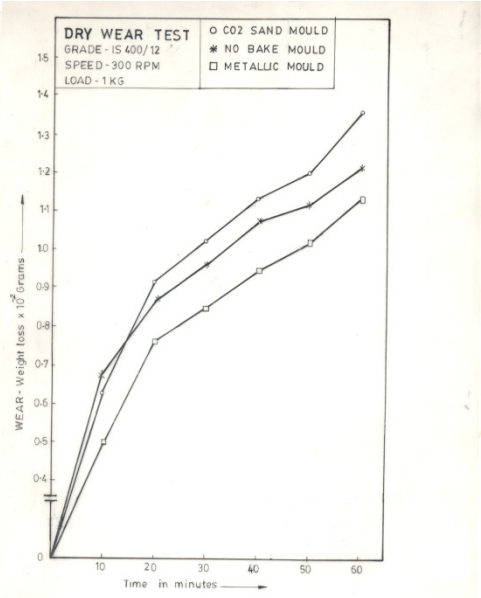


FIG 9 : VARIATION OF WEIGHT LOSS WITH TIME FOR SPECIMENS AUSTEMPERED AT 340°C SLIDING WEAR AT 300 RPM

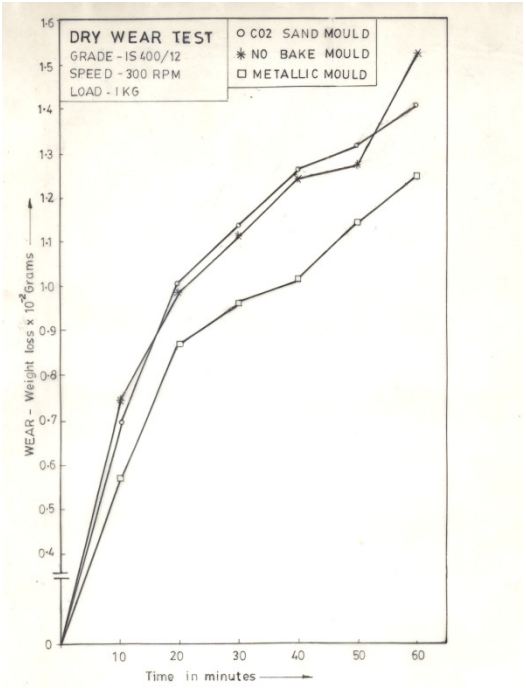


FIG. 10 :VARIATION OF WEIGHT LOSS WITH TIME FOR SPECIMENS AUSTEMPERED AT 370 °C SLIDING WEAR AT 300 RPM