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RESEARCH

Connection Between Tribological and Metallurgical Properties of ADI*

Connections between tribological and metallurgical properties of Austempered Ductile Iron (ADI) were subject of investigation in last years at Laboratory for Metal Cutting and Tribology, at Mechanical Engineering Faculty in Kragujevac, Yugoslavia.
The main goal of this investigation was getting acquainted with optimum conditions of isothermal treatment of Austempered Ductile Iron from tribological aspect.
In this paper are presented the part of investigation results which show the influence of several parameters of microstructure discs made of several kind of ADI.

Keywords: austempered ductile iron, metallurgical properties

1. INTRODUCTION

Connections between tribological and metallurgical properties of Austempered Ductile Iron (ADI) were subject of investigation in the last years at Laboratory for Metal Cutting and Tribology, at Mechanical Engineering Faculty in Kragujevac, Yugoslavia.

The main goal of this investigation was to get acquainted with optimum conditions of isothermal treatment of Austempered Ductile Iron from tribological aspect.

A few kinds of ADI is treated during investigation. Besides traditional thermal treatment several different conditions of isothermal treatment were used.

Tribological properties were obtained by measurement of the friction force to refer to friction coefficient in the contact zone between Block and Disc and of wear scar on Block contact surface. For tribological measurements, Tribometer "Block on Disc" TPD-95 produced in Yugoslavia was used.

Metallurgical measurements was realized at Technological-Metallurgical Faculty in Belgrade by application of standard instrumentation from this area.

In this paper are presented the part of these investigation results which show the influence of several parameters of discs microstructure made of several kind of ADI.

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2. EXPERIMENTAL TESTS AND RESULTS

Differences in tribological properties of nodular cast iron of the same kind, but thermally treated in different conditions, which were established by measurements of the friction force, namely the friction coefficient, and magnitude of the wear parameter on Tribometer "Pin (Block) on Disc", required searching for the cause of this phenomenon.

Metallurgical investigations on numerous samples, made of several kinds of nodular cast irons and thermally treated by various procedures, were performed at Technological Metallurgical Faculty of University of Belgrade. Bigger part of investigations were done on the apparatus for semi-automatic picture analysis MOP - videopla manufactured by KANTRON.

Investigations were done with 10 samples, out of which three were in the raw condition, made of nodular cast irons NL 500, NL 600 and NL 700.

Four samples were made in the form of Disc of nodular cast iron NL 500 and thermally treated in accordance with previously explained procedures .

Results of metallographic investigations enabled:

- presentation of microstructure of all samples and
- quantitative evaluation of the samples microstructure

* *The paper was published at The First Mediterranean Conference on Tribology in Israel.*

In Figure 1. is shown the Ferritic-pearlitic substrate of NL 500 in raw condition (magnification 100x).

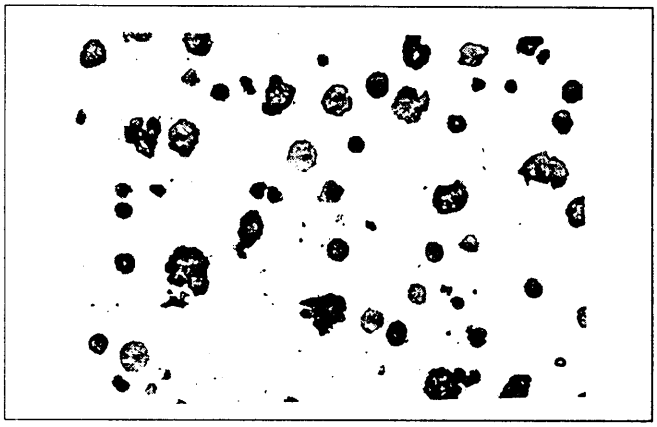

Figure 1.

Three structure parameters were selected for quantitative evaluation of microstructure of thermally treated Discs made of nodular cast irons NL 500 (marks a, b, c and d) and NL 700 (marks A, B and C). Those parameters are:

- Size of graphite inclusions (nodules and vermicular graphite)
- Graphite form expressed by factor F and
- Volume share of micro-constituents.

Size of graphite nodules is determined by the average value of cross section $\overline{A}$ in μm, average value of the maximum diameterin $\overline{D}_{mam}$ mm, average value of the circle diameter $\overline{D}_{circ}$ in μm and average value of parameter L_p in μm.

Graphite form is expressed by the factor F that is defined by expression:

$$F = \frac{4\pi A}{L_p^2}$$

where:

- A - is the cross section area of the graphite inclusion, and
- L_p - is the parameter, which represents the ratio between the graphite inclusion diameters measured along the longest and the shortest axes.

Volume shares of graphite (G), pearlite (P) and free cementite (SC) are given for the nodular cast irons in the raw condition, while for the thermally treated nodular cast irons NL 500 and NL 600 (Discs) the volume shares of graphite, ferrite (F) and free cementite were determined by measurements.

Number of measurements was sufficiently large to achieve satisfying reliability of the measurement results. Size and form of graphite was determined by measurements of 1000-1150 inclusions.

In Tables 1 and 2 are shown average values of all the measured variables.

Table 1. Volume share of micro-constituents

ADI quality	Condition	Sample mark	V* V G	V** V GV	V V G+T	V V F vol %	V V P	V V SC	V V MO
1	2	3	4	5	6	7	8	9	10
NL 500	Raw		9.20	-	-	46.76	43.75	0.29	-
NL 600		5759-13	10.38	-	-	3.00	86.11	0.51	-
NL 700		NL-70	9.88	-	-	1.49	88.58	0.05	-
NL 500	Thermally treated	a	9.36	2.67	-	-	-	0.07	90.58
		b	11.98	3.42	0.06	-	-	-	88.02
		c	9.22	2.35	1.95	-	-	-	90.78
		d	9.13	-	3.12	-	-	-	90.87
NL 700	Thermally treated	A	11.01	-	2.00	-	-	0.34	88.65
		B	4.84	-	0.45	-	-	0.64	94.52
		C	8.29	-	2.82	7.39	-	0.69	83.63

* In case of nodular cast irons NL 500 and NL 700, in thermally treated condition, shares of pure carbon inclusions and those with slag are given summarily.

** Shares of vermicular graphite and graphite with slag are given separately in columns 5 and 6.

Table 2. Geometrical parameters of the Discs microstructure

Casting quality	Condition	Sample mark	NA mm^2	$\overline{A}$ mm^2	$\overline{D}_{max}$ mm	$\overline{D}_{circ.}$ mm	$\overline{L}_p$ mm	F	d_{min}/d_{max}
1	2	3	4	5	6	7	8	9	10
NL 500	Raw		76.86	1344.4	45.14	37.56	144.29	0.729	0.728
NL 600		5759-13	122.45	787.9	31.51	28.45	97.02	0.866	0.783
NL 700		NL-70	188.72	335.1	21.10	19.41	63.47	0.923	0.803
NL 500	Thermally treated	a	84.54	981.9	36.02	29.74	111.30	0.807	0.727
		b	110.96	1034.1	36.81	31.72	117.50	0.818	0.759
		c	96.93	1121.3	38.44	33.06	12.10	0.817	0.752
		d	99.47	949.9	36.13	30.45	112.90	0.803	0.751
NL 700	Thermally treated	A	72.98	1388.8	40.64	36.77	126.20	0.865	0.786
		B	7.52	486.1	25.10	21.28	75.10	0.832	0.711
		C	65.74	1472	42.20	38.03	130.70	0.859	0.786

Marks A,B,C,a,b,c and d are for different condition of thermally treated.

Experimental results obtained by measurement of individual microstructure parameters of isothermally treated Discs and the friction coefficients in the zone of contact between the Pins made of carbon steel and grey cast iron and Discs made of NL 500 and NL 700, enable several basic conclusions:

1. *With increase of the number of graphite nodules per mm^2 of the Disc area, the friction coefficient decreases for about 10 %. This means that tribological characteristics, from the aspect of friction of the nodular cast iron is increasing with the number of graphite nodules per mm^2 of the contact surface of the tribo-mechanical systems elements.*

   Energy consumption in tribo-mechanical system will be lower if one of the elements of the system is made of nodular cast iron with higher number of graphite nodules per contact zone unit area.

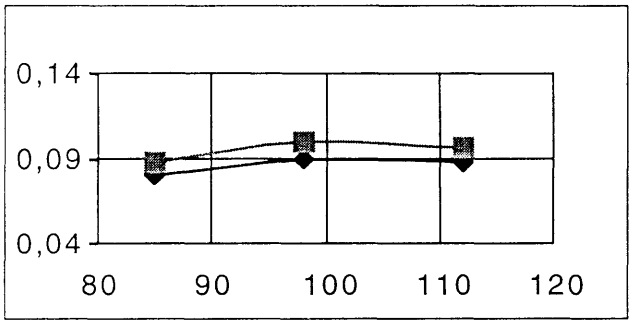

Figure 2. Experimental functions $\mu = f(N_A)$ Disc - NL 500, Pin: ♦- SL 250, ■- Č 1531, F_N = 20 daN, v = 1.3 m/s

In Figure 2 are shown, as an example, two experimental functions $\mu = f(N_A)$ obtained through realization of a program for investigations the tribological characteristics of a group of nodular cast irons.

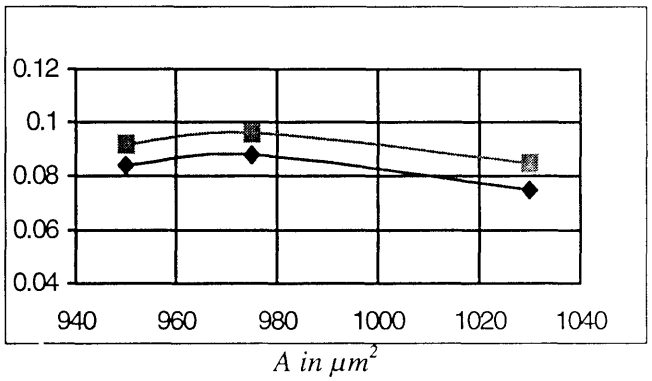

Figure 3. Experimental functions $\mu = f(A)$ Disc - NL 500, Pin: ♦- SL 250, ■- Č 1531, F_N = 20 daN, v = 1.3 m/s.

In Figure 3 are shown two experimental functions $\mu = f(A)$ obtained during realization of contact between Discs made of NL 500 and Pins of Č 1531 and SL 250.

2. *The friction coefficient decreases with increase of the average value of the graphite cross section area A (mm^2) on the contact surfaces of Discs. Influence of the average value of the graphite cross section area is, however, smaller than the influence of the number of nodules per unit area. It is assumed that this is caused by decrease of*

number of nodules per unit area, which occurs with increase of the average area of nodules.

These are two of several conclusions only.

Influence of the microstructure parameters of nodular cast irons, thermally treated in different conditions, on their tribological characteristics, determined from the standpoint of wear, is also noticed through realization of the investigation program.

At the end of performing the experimental operations on Tribometer "Pin on Disc", the lubricating oil from the oil bath was distributed, by rule, in three original containers of the Pikometer PQ 2000. Measurements were done ten times and average values of the PQ indices were calculated. In the following figures the influence of several basic parameters of the nodular cast iron NL 500 structure on its tribological characteristics determined by the PQ index, which points to the quantity of the wear products created during the realization of contact between the Pin and the Disc, is presented.

In Figures 4 and 5 are shown the influence of the number of the graphite nodules per mm^2 and grafite noduled area A in μmm^2 on the magnitude of the PQ index.

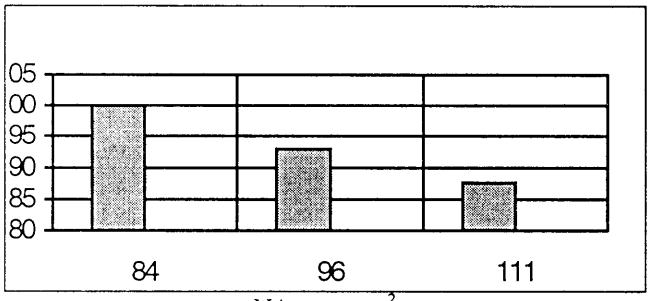

Figure 4. PQ index as a function of N_A, Disc - NL 500, Pin - SL 250, F_N = 20 daN, v = 1.3 m/s.

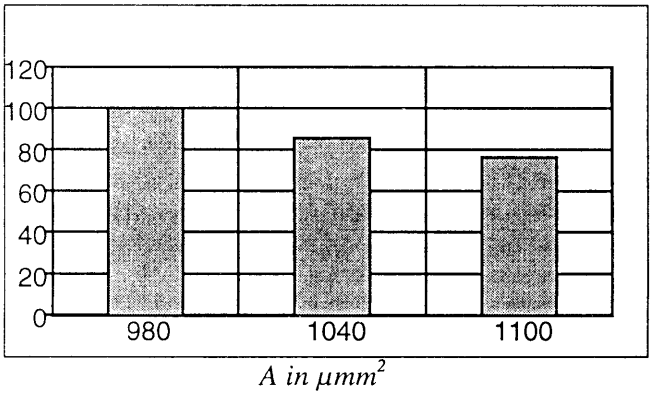

Figure 5. PQ index as a function of A, Disc - NL 500, Pin - SL 250, F_N = 20 daN, v = 1.3 m/s.

4. CONCLUSION

The basic conclusion that can be stated, based on considerations of relationships between the individual parameters of the thermally treated nodular cast irons microstructure, is the following:

Tribological characteristics of elements of the tribo-mechanical systems made of nodular cast irons, that are determined from the aspect of friction and wear, depend, to a great extent, on their microstructure, realized by application of various procedures of thermal treatment.

Isothermal tempering procedure that lasts 60 minutes was shown, in the largest number of cases, as the optimal one, for almost all types of nodular cast iron.

Derived conclusions are referring to realization of contact between nodular cast irons with carbon steel and grey cast iron. Further investigations in this area would enable obtaining more complete information about contacts of nodular cast iron.

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