TEKA. COMMISSION OF MOTORIZATION AND ENERGETICS IN AGRICULTURE – 2012, Vol. 12, No. 2, 189–193

Testing ADI properties when used for cast agricultural tools operating in soil

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Summary. The paper discusses the influence of heat treatment parameters on selected properties of austempered ductile iron (ADI). The studies involved two grades of low-alloyed ductile iron: nickel-molybdenum and nickel-copper. The results of laboratory tests were used in the selection of material for cast agricultural tools operating in soil: subsoiler coulters and cultivator duckfoot.

Key words: iron alloys, ductile iron, ADI, mechanical properties, agricultural tools.

INTRODUCTION

Austempered ductile iron (ADI) is increasingly used for cast parts operating in different machines and equipment, including cast agricultural tools for soil cultivation [1-3, 9, 10, 14]. The problem in selecting the best type of this cast iron as regards the operational requirements of the tools is to obtain the mechanical/plastic properties relationship consistent with the operating conditions of a casting [4-8, 11-13, 20, 21]. The purpose of this study has been to identify the obtainable properties of ADI based on the heat treatment parameters (isothermal cooling temperature) [15-17]. The study involves low-alloyed ductile iron of nickel-molybdenum type and nickel-copper type used for the manufacture of cast subsoiler coulters and cultivator duckfoot, respectively.

CHOICE OF DUCTILE IRON CHEMICAL COMPOSITION

Austempered ductile iron was selected as a test material. As a base cast iron for further heat treatment, two grades of ductile iron were chosen. They differed in the type and content of the introduced alloying elements improving the hardenability of this material (nickel, copper, molybdenum) [12,14,18,19]:

– first - low-alloyed nickel-molybdenum ductile iron containing about 1.6 wt.% nickel and about 0.4 wt.% molybdenum,
– second - low-alloyed nickel-copper ductile iron with nickel content of about 1.9 wt.% and copper in an amount of about 0.9 wt.%.

MELTING PROCEDURE

Melting was carried out in a PIT 150 medium frequency induction furnace made by ZAM Kęty with a 150 kg metallic charge capacity crucible and neutral lining. The following stock was used as charge materials: foundry pig iron, steel scrap, FeMn82 ferromanganese, FeSi75 ferrosilicon, metallic nickel, electrolytic copper, FeMo60 ferromolybdenum.

The spheroidising treatment and inoculation were performed by the technique of elastic wire, using two wires: the first one containing an FeSiMg17 magnesium master alloy (1.5% respective of molten metal weight), and the second one containing an FeSi75T inoculant (1% respective of molten metal weight). The treatments were performed in a slender ladle at 1400°C.

From the melts, samples were taken for laboratory testing and prototype utility castings were made (pilot agricultural tools for soil cultivation).

Samples for chemical analysis were poured in metal moulds (copper dies), pilot castings and samples for other laboratory tests were poured in bentonite sand moulds.

CHEMICAL ANALYSIS

Chemical analysis of melts was performed by emission spectrometry on a POLYVAC 2000 (Hilger Co., UK) apparatus in accordance with the certified test procedures developed by the Foundry Research Institute in Cracow. The results are summarised in Table 1.

Table 1. Chemical analysis of melts

Ductile iron	Chemical composition; wt.%								
	C	Si	Mn	P	S	Mg	Ni	Mo	Cu
nickel-molybdenum	3,85	2,90	0,61	0,050	0,010	0,080	1,50	0,47	-
nickel-copper	3,60	2,45	0,32	0,035	0,020	0,065	1,90	-	0,93

METALLOGRAPHIC EXAMINATIONS OF AS-CAST SPECIMENS

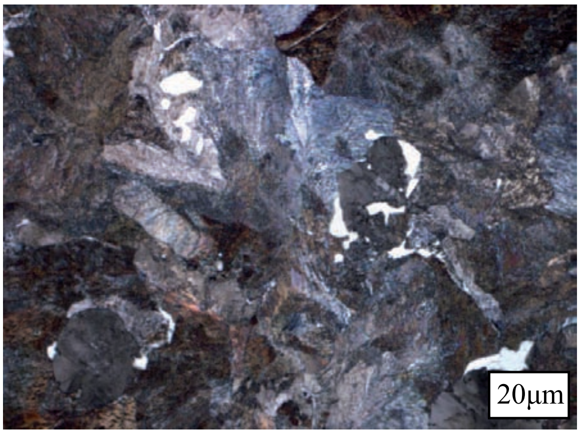
Metallographic examinations were performed in accordance with the procedure specified in a TBS/P/002/02: 2008 Instruction Manual. Graphite microstructure was determined comparing the microstructure of unetched specimens with reference standards shown in PN-EN ISO 945:1999. Microstructure of the metallic matrix was examined comparing the microstructure of etched specimens with reference standards shown in PN-75/H-04661. Polished sections were etched with Mi1Fe reagent (4% nital) according to PN-61/H-04503.

Microscopic observations and photographs were taken with an AXIO OBSERVER Z1M metallographic microscope.

The results of metallographic observations are summarised in Table 2, and examples of microstructure images are shown in Figure 1.

Table 2. The results of metallographic observations conducted on as-cast specimens

Ductile iron	Graphite microstructure	Metallic matrix microstructure
nickel-molybdenum	80% VI6 + 20% V6	P45-Pd0,5
nickel-copper	90% VI5 +10% V5	Pf1-P96-Pd1,0



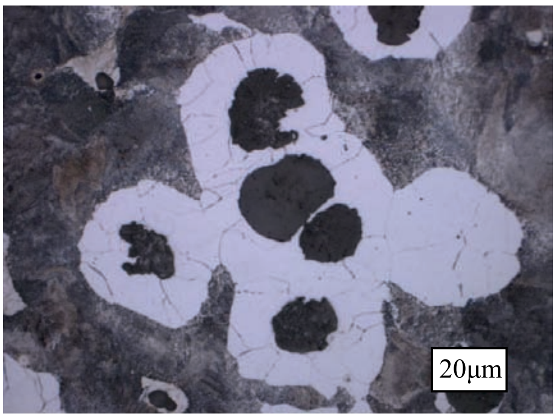


Fig. 1. Microstructure of nickel-molybdenum (up) and nickel-copper (down) ductile iron, sections etched with Mi1Fe

TESTING AS-CAST IRON MECHANICAL PROPERTIES

Testing of mechanical properties included hardness measurements and static tensile test at ambient temperature. Hardness was measured on the Rockwell C scale in accordance with PN-EN ISO 6508-1:2007. The tensile test was performed according to PN-EN 10002-1:2004 using an EU-20 testing machine made by FEB Werkstoffprufmaschinen Leipzig, Germany. The stress increase rate during the test was 1.59 MPa/s, the loading force was 1471 N, and the nominal load operation time was 4 sec. The obtained results of the mechanical tests are summarised in Table 3.

Table 3. The results of mechanical tests carried out on as-cast specimens

Ductile iron	Results of mechanical tests				
	HBS 5/750 [-]	R_m [MPa]	$R_{p0,2}$ [MPa]	A [%]	Z [%]
nickel-molybdenum	360	936	657	1,8	0,4
nickel-copper	257	764	479	2,5	2,0

HEAT TREATMENT

Specimens were undergoing the heat treatment in a Multitherm N41/M Nabertherm furnace (Germany) with an air-tight retort and inert gas (argon) protective atmosphere to avoid surface decarburising.

In this furnace, the operations of austenitising treatment were carried out, keeping the same regime for all the batches:

– heating with furnace to a temperature of 900°C,
– holding at this temperature for 2 h.

The isothermal cooling treatment was carried out in a PEW-2 electric bath-type furnace using salt bath (a mixture of potassium nitrate and sodium nitrite).

The salt bath temperature and the isothermal cooling times were as follows:

– for nickel-molybdenum ductile iron specimens:
  - 370 °C / 2 h – cycle „A1",
  - 320 °C / 2 h – cycle „B1",
  - 270 °C / 3 h – cycle „C1",
– for nickel-copper ductile iron specimens:
  - 375 °C / 2,5 h – cycle „A2",
  - 330 °C / 2,5 h – cycle „B2",
  - 270 °C / 3 h – cycle „C2",

After heat treatment, specimens from each cycle were subjected to laboratory testing.

METALLOGRAPHIC EXAMINATIONS OF HEAT TREATED SPECIMENS

Metallographic examinations of the austempered ductile iron specimens were performed in accordance with the procedure specified in a TBS/P/002/02:2011 Instruction Manual.

Microscopic observations and photographs were taken with an Axio OBSERVER Z1M metallographic microscope, metallographic sections were prepared in accordance with the procedure specified in a TBM/001 Instruction Manual.

To reveal the microstructure of the metallic matrix, the metallographic sections were etched in modified BM reagent of the following chemical composition: 100 ml stock solution (5 parts by vol. H_2O, 1 part by vol. concentrated HCl), 2 g NH4Fe • HF, 1 g $K_2S_2O_5$. This reagent did not colour the austenite and carbides, but coloured bainite and tempered martensite in brown and martensite in blue. Sometimes fine martensite needles were not coloured in blue but in light brown, and then in the microstructure evaluation their morphology should be taken into account.

Microstructures of the examined specimens of ductile iron after heat treatment are shown in Figures 2 - 7, while descriptions of the structure are compared in Table 4.

Table 4. The results of metallographic observations conducted on heat treated specimens

Ductile iron		Graphite microstructure	Metallic matrix microstructure
Type	Heat treatment cycle		
1. nickel-molybdenum	A1	80% VI6 + 20% V6	B + M (about 2%)
	B1	80% VI6 + 20% V6	B + M (about 2%)
	C1	80% VI6 + 20% V6	B
2. nickel-copper	A2	90% VI5 +10% V5	B + M (about 15%) + A (traces)
	B2	90% VI5 +10% V5	B + M (traces, <1%) + A (traces)
	C2	90% VI5 +10% V5	B +F (traces) +A (traces)

B – bainite (ausferrite), M – martensite on boundaries of eutectic cells, F – ferrite, A – retained austenite

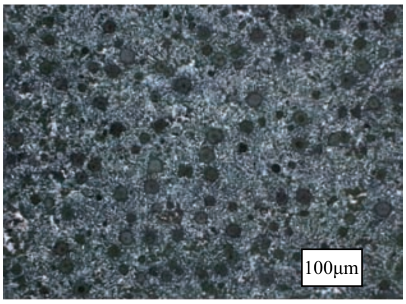


Fig. 2. Microstructure of specimen A1, metallic matrix, etched section

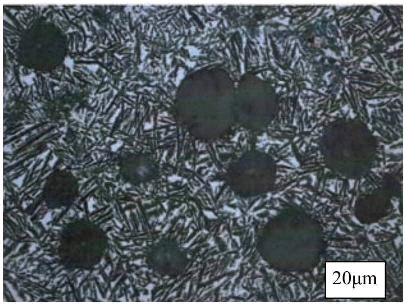


Fig. 3. Microstructure of specimen B1, metallic matrix, etched section

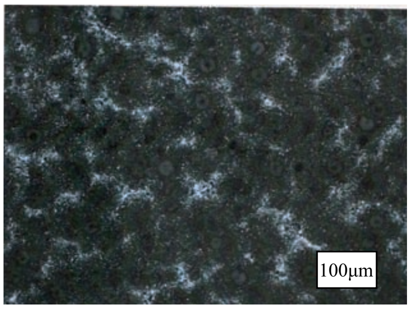


Fig. 4. Microstructure of specimen C1, metallic matrix, etched section

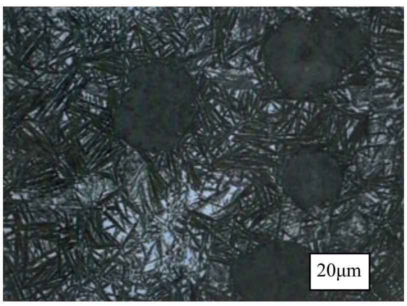


Fig. 5. Microstructure of specimen A2, metallic matrix, etched section

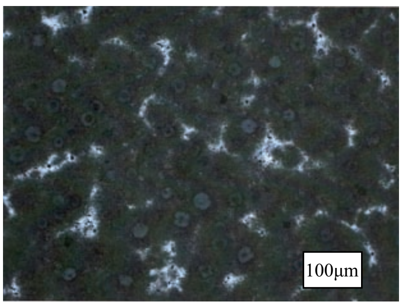


Fig. 6. Microstructure of specimen B2, metallic matrix, etched section

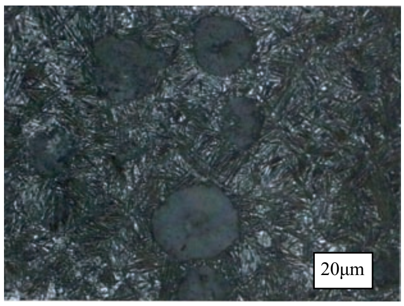


Fig. 7. Microstructure of specimen C2, metallic matrix, etched section

TESTING THE MECHANICAL PROPERTIES OF HEAT-TREATED DUCTILE IRON

As in the case of as-cast condition, testing of mechanical properties included the measurement of hardness and static tensile test at ambient temperature, as well as Charpy impact test at ambient temperature conducted in accordance with PN-EN 10045-1:2007. Hardness was measured on the Rockwell C scale in accordance with PN-EN ISO 6508-1:2007. The tensile test was performed in the same manner as for the as-cast condition.

The results of mechanical tests obtained on heat-treated specimens are compared in Table 5.

Table 5. The results of mechanical tests carried out on heat-treated specimens

Ductile iron		Results of mechanical tests					
Type	Heat treatment cycle	HRC [-]	R_m [MPa]	$R_{p0,2}$ [MPa]	A [%]	Z [%]	KCV [J/cm^2]
1. nickel-molybdenum	A1	28	875	460	6,2	6,9	9,6
	B1	38	1161	512	3,0	5,2	8,3
	C1	44	1275	687	1,5	1,9	7,3
2. nickel-copper	A2	27	950	575	8,2	7,1	9,9
	B2	36	1168	827	5,6	5,5	8,6
	C2	43	1485	1133	2,4	2,4	7,9

CONCLUSIONS

Tests conducted on austempered ductile iron helped to quantify the effect of alloy cooling temperature on the selected mechanical and plastic properties of ADI, obtained under given conditions.

Comparing the results obtained for nickel-copper and nickel-molybdenum cast irons it was found that, at comparable strength parameters, the former of these alloys offers slightly higher plastic properties than the latter one.

In the case of nickel-copper ductile iron, under comparable heat treatment parameters, higher mechanical properties were obtained than in the case of nickel-molybdenum cast iron.

The collected information enabled choosing the type of alloy and heat treatment parameters best for the production of cast agricultural tools operating in soil. Consequently, nickel-molybdenum cast iron was used for subsoiler coulters and nickel-copper cast iron was used for cultivator duckfoot. The design, technology and operational tests performed on these castings will be described in subsequent articles.

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The study was performed within the framework of a EUREKA E! 4102 MEDHIAL Project

BADANIA MATERIAŁOWE ŻELIWA ADI PRZEZNACZONEGO NA ODLEWY NARZĘDZI ROLNICZYCH PRACUJĄCYCH W GLEBIE

S t r e s z c z e n i e. W pracy omówiono wpływ parametrów obróbki cieplnej na wybrane właściwości żeliwa sferoidalnego hartowanego z przemianą izotermiczną. Przedmiotem badań były dwa rodzaje sferoidalnego żeliwa niskostopowego: niklowo-molibdenowe i niklowo miedziowe. Uzyskane rezultaty badań laboratoryjnych wykorzystane zostały przy doborze tworzywa na odlewy narzędzi rolniczych pracujących w glebie: redlice głębosza i gęsiostópki kultywatora.

S ł o w a k l u c z o w e: stopy żelaza, żeliwo sferoidalne, ADI, właściwości mechaniczne, narzędzia rolnicze.