Testing of heating and cooling process of ADI cast iron with use of ATND method

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Abstract

ADI (Austempered Ductile Iron) cast iron, owing to its unique combination of high tensile strength and abrasion resistance with very good plasticity, founds implementation in many branches of industry as a substitute of alloy cast steel and carburized or heat treated steels. In spite of its solid position among producers and recipients of castings, there are still undertaken studies aimed at perfection of its properties and recognition of mechanisms enabling obtaining such properties. The paper presents implementation of thermal-voltage-derivative (ATND) method to registration of heating and cooling course of ADI cast iron with EN-GJS-1200-2 grade. ADI cast iron with EN-GJS-1200-2 grade underwent the study. Heat treatment of the cast iron was performed in Foundry Institute with use of LT ADI-350/1000 processing line. Results obtained from the testing illustrate in graphic form registered heating and cooling curves of investigated cast irons obtained with use of the ATND method.

Keywords: Austempered ductile iron; Heat treatment; ATD; ATND

1. Introduction

The ADI "Austempered Ductile Iron" cast iron belongs to one from the most up-to-date cast structural material [1]. It is cast iron with metallic matrix consisting of bainitic ferrite needles and stable austenite saturated with carbon. Such microstructure enables to obtain tensile strength up to 1600 MPa [2], yield point from 500 to 1200 MPa and elongation in range of 1 to 16% [3,4].

Castings made from ADI cast iron enjoy great success in automotive industry (steering rods, camshafts, crankshafts, conrods, timing gears, suspension elements, friction components of brake systems), agricultural industry (edges of ploughs, elements of movable couplings, components of fertilizer seeders, towing hooks, eye bolts, wheel hubs, steering shafts, steering rods), railway industry (hub cups, brake pads, wheels of maintenance trucks, hooks to coupling devices, shock absorbers, engine components, track elements), armaments industry (missiles, armours, rocket bodies, alloys for caterpillar links, rotors of motors) and construction industry (excavator teeth, sorting machine blades, crushing mill components, carrying rings, brackets, slideways and shafts, gears, housings, structural elements).

Counting over per kilogram of material, the ADI cast iron costs less than steel or aluminum. Moreover, in every stage of manufacturing process a component made from ADI can generate a savings of order of 20% in comparison with forged steel and up to 50% comparing with aluminum [3,5]. In many applications ADI cast iron surpasses: steel forgings, welded elements, products from carburized steel and aluminum. Strength of ADI cast iron is nearly twice higher at equivalent elongation, comparing with traditional brands of spheroidal cast iron [6].

In the Fig. 1 is shown a comparison of tensile strength and elongation obtained for ADI cast iron, casting alloys of aluminum and wrought aluminium.
Bainitic-austenitic structure of castings requires implementation of heat treatment, consisting on quenching with isothermal transformation.

The heat treatment is composed from a few stages (Fig. 2) [8,9,10]:
- Heating of castings up to austenitizing temperature, suitable for a given chemical constitution, in the limits of 830÷950°C (line 1-2)
- Soaking of the castings in austenitizing temperature during time which assures equalization of temperature on cross-section of the casting, decomposition of constituents of initial cast iron (pearlite, ferrite, possibly carbides) and saturation with carbon (line 2-3),
- Cooling of the castings with a rate assuring avoidance of pearlite formation, up to temperature of isothermal soaking in limits of 230÷400°C (line 3-4),
- Isothermal soaking of the castings during time which assures formation ausferrite structure of metallic matrix in spheroidal cast iron (line 4-5),
- Cooling of the castings to ambient temperature (line 5-6).

To parameters of the heat treatment belong [12,13]:
- austenitizing temperature 820÷950°C,
- austenitizing time 0,5÷5 h,
- temperature of isothermal transformation 230÷400°C,
- time of isothermal transformation 0,5÷5 h.

The above parameters depend on chemical constitution of cast iron, quantity, shape of graphite release, geometry and method of production of castings.

2. Methodology of the research

Investigated materials were prepared in Krakow Foundry Institute with use of LT ADI-350/1000 processing line (Fig. 3) to heat treatment of cast iron [14].

The processing line comprises [3]:
- Chamber furnace of B-4-ENL type,
- Salt bath of WS-4/450EL type – serving to isothermal cooling of castings from iron alloys in temperature range of 250÷480°C,
- WPSD-4EL device for washing and drying of the charge—destined for removal of salt from castings after salt bath,
- LW-4E loader of the charge – mobile loader serving for transport of the charge to load bottoms of devices positioned in the processing line,
- Loading-unloading stand – consisted of two supply stands to load and unload of the charge.

The tests were carried out with use of ATND method. The method consists on permanent measurement of temperature and electric voltage generated on probes during crystallization and phase transformations of solidifying alloy. In course of the measurement there are registered generated voltage and temperature of tested specimen. The method enables also to registration of heating and cooling processes of alloys. Course of the process is illustrated in form of diagram in which are shown thermal curves (t and dt/dt) supplemented with voltage ones (U and dU/dt) [15].

Test stand (Fig. 4) consists of tubular silit furnace, two millivoltmeters and computer with operating software.

Suitably prepared specimens were put into the furnace’s chamber, where melting and crystallization occurred. In course of these processes there occurred permanent, simultaneous registration of specimen’s temperature change and potential difference on measuring probes. Cooling occurred after removal of the specimen from furnace.
As a testing material were used:
1) Initial cast iron with chemical composition (% weight):
   C = 3.5, Si = 2.35, Ni = 1.0, Cu = 0.95, Mn = 0.13, Mg = 0.065,
   P = 0.045, S = 0.015.
2) ADI cast iron, brand 1200-2 having composition:
   C = 3.7%, Si = 2.3%, Ni = 1.34%, Cu = 0.30%, Mn = 0.11%,
   Mg = 0.07%, P = 0.035%, S = 0.010%.

Fig. 4. View of the test stand

ADI cast iron was characterized by tensile strength of
$R_m = 1250$ MPa, elongation of $A_5 = 3.2\%$ and hardness of $HB = 350$.
The cast iron was austenized in temperature of 900°C during
period of 2 hours. Isothermal transformation was performed in
salt baths with temperature of 340°C. Duration of the isothermal
transformation amounted to 2 hours.

3. Description of achieved results of own research

In the Fig. 5 is shown a run of heating and cooling of initial
cast iron, registered with use of ATND method.

Specimen from investigated ADI 1200-2 cast iron was heated
to temperature of 1126°C (point P1 in the Fig. 7), and next,
cooled down. Eutectoid transformation proceeds in area of the
Point P3 (temperature of 760°C). Austenization process occurs in
temperature of 810÷980°C (scope from P4 to P5). Next, the
voltage curve “U” falls to the Point P7 (temperature of 1126°C),
from which occurs its growth. It is result of completion of heating
stage and commencing of cooling of the specimen. Point P7
(temperature of 647°C) corresponds to refraction of the curve „T”.
Underneath the Point P8 (with temperature of 340°C) there occurs
isothermal transformation. Point P8 corresponds to the Point P2,
occurring in course of heating of the specimen.

In the Fig. 6 is presented a heating and cooling process of the
ADI cast iron, brand 1200-2, registered with use of ATND method.

Fig. 5. Curves of ATND method for initial cast iron

Fig. 6. ATND method curves for ADI 1200-2 cast iron

Fig. 7. ATND method curves for ADI 1200-2 cast iron with
marked characteristic points
In the Fig. 8 is shown a run of ATND method curves (voltage and temperature) for initial cast iron and ADI 1200-2 cast iron. Obtained character of temperature curves points at similarity of course of the process, whereas voltage curves show a differences between run of heating and cooling process of initial cast iron and ADI 1200-2 cast iron.

4. Conclusions

Basing on obtained results from preliminary tests, one can ascertain that the ATND method can be used in registration of heating and cooling processes of metal alloys.

The ATND method for initial and ADI 1200-2 cast iron shows differences resulted from quenching before isothermal transformation.

On the voltage curve there are present a characteristic points, to which correspond on thermal curve a temperatures connected with phase transformations of the ADI 1200-2 cast iron in solid state.

References