ARCHIVES
of
FOUNDRY ENGINEERING
Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 9
Issue 1/2009
143-146

32/1

Thin wall ductile iron casting as a substitute for aluminum alloy casting in automotive industry

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Received 26.02.2009; accepted in revised form: 30.03.2009

Abstract

In paper it is presented thin wall ductile iron casting (TWDI) as a substitute of aluminium alloy casting. Upper control arm made of ductile iron with wall thickness ranging from 2 – 3.7 mm was produced by inmold process. Structure, mechanical properties and computer simulations were investigated. Structural analysis of TWDI shows pearlitic-ferritic matrix free from chills and porosity. Mechanical testing disclose superior ultimate tensile strength (R_m), yield strength ($R_{p0,2}$) and slightly lower elongation (E) of TWDI in comparison with forged control arm made of aluminium alloy (6061-T6). Moreover results of computer simulation of static loading for tested control arms are presented. Analysis show that the light-weight ductile iron casting can be loaded to similar working conditions as the forged Al alloy without any potential failures.

Key-words: Innovative materials and casting technologies, ductile iron, thin wall castings

1. Introduction

In a work [1] it has been proved that it is possible to produce super-thin wall castings made of ductile iron (TWDI) with wall thickness below 3 mm (without chills, cold laps and misruns). TWDI can be lighter than their substitute made of aluminium alloys [1-3] and characterized similar or better mechanical properties, definitely better dumping capacity. From an economics point of view costs involved in producing ductile iron is much lower than the ones corresponding to Al alloys.

All the technological aspects involved in the production of thin wall ductile iron castings (TWDI), with wall thicknesses below 3 mm should have been worked out before considering the development aluminum alloys castings as cast iron substitutes.

Recently, aluminium alloy has become a constituent material of the arm instead of steel in order to reduce the weight of the vehicle. The upper control arm is an important component and constrains the longitudinal and vertical movements of the wheel relative to the vehicle.

Numerous studies have been published on thin wall ductile iron, particularly on the solidification morphologies [5], microstructural characterization [6,7], mechanical properties [2,8-12], carbide formation factors [12,13], production [14,15] and mold filling [16]. Moreover, various experimental relationships have been developed between the chemical composition [6,13,15], pouring temperature[10], spheroidization and inoculation practice [13,14,17], casting geometry [8], plate thickness [13,14,16], and mold materials[18]. Yet, most of these works are limited to simple plate shaped castings. The aim of this work is to produce sound thin wall ductile iron casting which is lighter than counterparts made of Al alloys, but with improved mechanical strength, superior damping capacity and lower final costs. Accordingly, a forging control arm made of Al alloy was chosen to be replaced by a ductile iron casting as a counterpart.

2. Experimental

Molds were made of chemically bounded 75- silica sand. The melts were produced using an electric induction furnace and the raw materials were pig iron, steel scrap and commercially pure silicon. The metal was preheated at 1500 ^{o}C and then poured into the mold, which was equipped with a reaction chamber containing a mixture of 0.85 % spheroidizer (44-48% Si, 5-6% Mg, 0.25-0.4% La, 0.8-1.2% Al, 0.4-0.6 Ca) and 0.5% of inoculant (73-78% Si, 0.75-1.25% Ca, 0.75-1.25% Ba, 0.75-1.25% Al) connected to a mixing basin. In addition, post-inoculation occurs in the mixing basin by introducing 0.1 % of inoculant.

The role of the mixing basin is to ensure that complete mixing of the liquid iron occurs after dissolution of the magnesium and inoculant alloys. The mixing basin volume was designed as to be equal or exceed the volume of the casting and the gating system. Just after filling the mixing basin, a graphite plug is removed to enable metal flow into the mold cavity. The chemical composition of the produced ductile irons was 3.8 % C; 3.1 % Si; 0.10 % Mn; 0.02 % P; 0.01 % S; and 0.025 % Mg.

Fig. 1 shows the control arm made of forged aluminum alloy and the thin walled counterpart made of ductile iron.

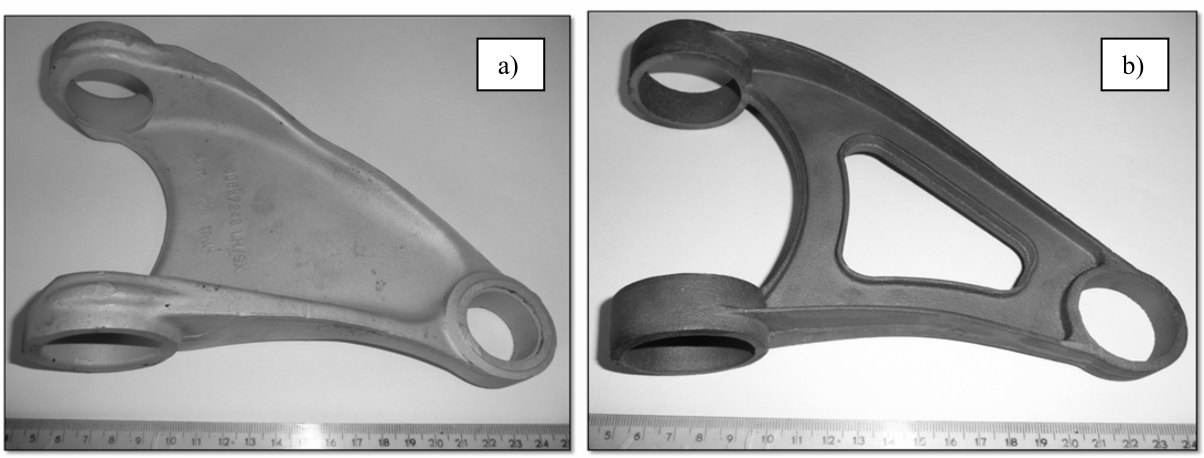

Fig. 1. Control arm, (a) forged aluminum alloy (weight 585 g) and (b) thin-walled ductile iron casting (weight 480 g)

From the microstructural point of view, Fig. 2 shows the reduction in nodule count (N) and the estimated increase in the absolute chilling tendency [19] (CT), including the time derivatives dN/dt and dCT/dt at various time-intervals after inoculation. From this figure it is found that fading is extremely rapid during the first minute following post inoculation. At the time of inoculation the liquid iron is in a “super-inoculated” state and exhibits the maximum nodule count and hence a minimal chilling tendency.

Metallographic determinations of the nodule count, as well as of the cementite and ferrite fractions were made on samples cut from the experimental casting. The average nodule count (average number of graphite nodules per unit area), N_F was measured using a Leica QWin quantitative analyzer at 200 x. The mechanical properties were determined using samples cut from control arms using an Instron universal testing machine. In addition, the stress distribution in the control arms made of the forged Al alloy and of thin wall ductile iron (TWDI) were determined using a SolidWorks program.

3. Results and discussion

3.1. Metallographic examinations

Figure 3 shows schematically locations where metallographic examinations were made. In addition, Table 1 gives the results from quantitative metallography such as nodule count and ferrite fraction. Notice that in the relatively thick cross sections of the control arm (hubs with a wall thickness of 3.7 mm) the nodule count is lower than in the thin cross sections. Moreover, from metallographic examinations it is found that the control arm matrix microstructure is of pearlitic-ferritic or ferritic-perlitic, free from chill formation and without porosity.

Table 1. Nodule count and ferrite fraction found in the control arm

Location	Wall thickness mm	Nodule count mm^{-2}	Ferrite fraction %
1	2.3	1510	60
2	2.0	2101	40
3	2.0	1925	40
4	2.1	1350	55
5	2.0	2050	40
6	3.7	1300	80

3.2. Mechanical testing

The results of mechanical testing for the forged Al alloy and TWDI counterpart are given in Table 2.

Control arms made of thin-walled ductile iron shows superior ultimate tensile strength (R_m), yield strength ($R_{p0,2}$) and hardness (HBW) and slightly lower elongation (E) than the parts made of forged Al alloy (6061-T6) (Table 2, Fig. 4). Hence, TWDI have a high potential for replacing Al alloy parts is diverse applications, particularly those that have high mechanical requirements.

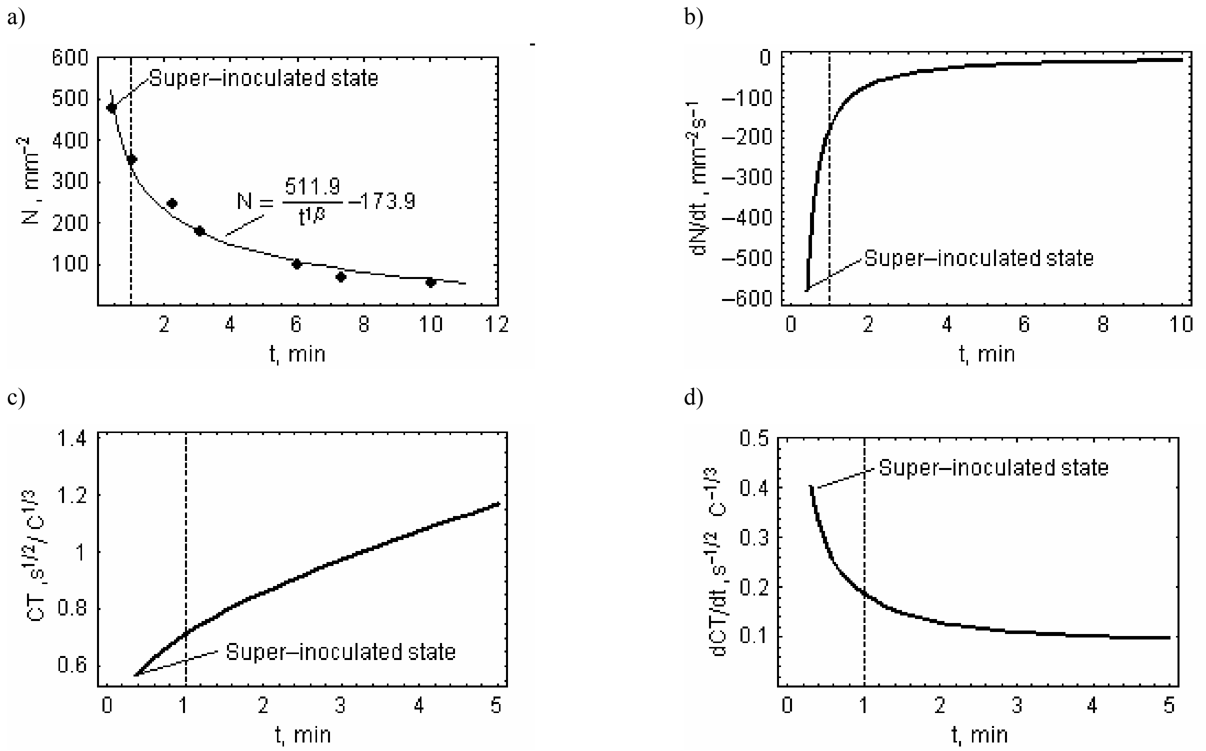

Fig. 2. (a) Fading of nodule count N, (b) Chilling tendency CT of cast iron, (c) dN/dt, and (d) dCT/dt.

Table 2. Mechanical properties of Al forged alloy and TWDI material

Material	R_m, MPa	$R_{p0,2}$, MPa	Strain, %	Hardness (EN ISO 6506)
Original control arm	290	149	8.2	118 (HBW 2,5/62,5)
TWDI control arm	530	325	7.1	188 (HBW 2,5/187,5)

In addition, strength to weight ratio, $R_{p0.2}/\gamma$ given for TWDI yields:

$$\frac{R_{p0.2}}{\gamma} = 46\,\text{MPa cm}^3/\text{g}$$

and for the Al alloy:

$$\frac{R_{p0.2}}{\gamma} = 53\,\text{MPa cm}^3/\text{g}$$

From the above $R_{p0.2}/\gamma$ ratios it is evident that TWDI and Al forged alloy characterize similar values. Therefore TWDI can substitute any Al made counterparts.

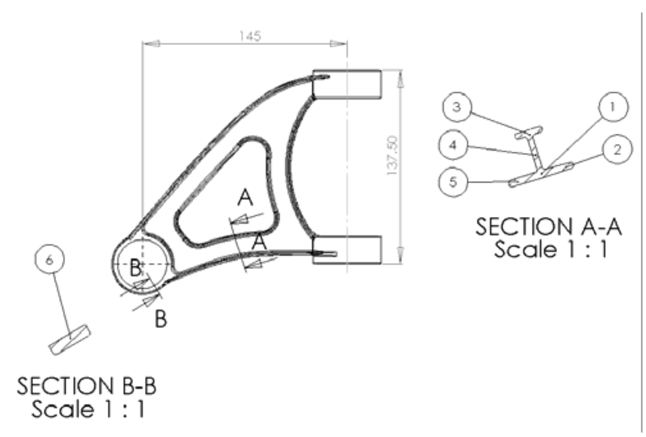

Fig.3. Thin-walled control arm showing the selected locations for metallographic examinations

3.3. Computer simulations

Computer simulations were performed by means of SolidWorks program. Simulations were made for original and for thin wall ductile iron casting. Analysis was done using the same static loading for tested control arms. Analysis shows that in case of aluminium alloy the von Mises effective stress has a maximum value of $7.56 \cdot 10^7$ N/m^2 = 82 MPa, which, compared with the material's yield strength of 149 MPa, results in a utilization factor of 51%.

In case of ductile iron the von Mises effective stress has a maximum value of $1.77 \cdot 10^8$ N/m^2 = 177 MPa, which, compared with the material's yield strength of 325 MPa, results in a utilization factor of 55 %. Thus analysis show that the light-weight ductile iron casting can be loaded to similar working conditions as the forged Al alloy without any potential failures.

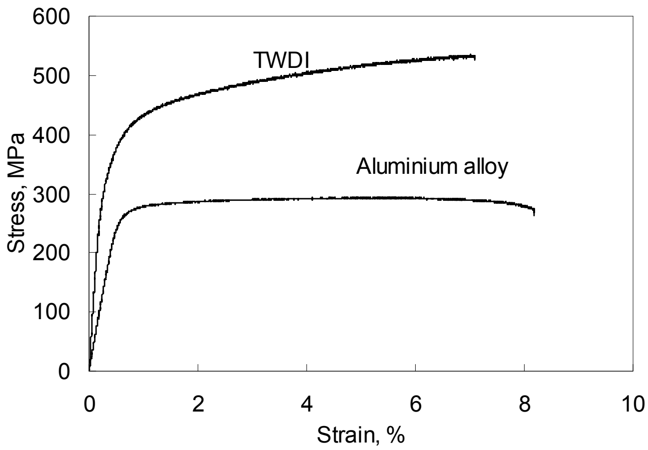

Fig. 4. Stress – strain curves for TWDI and aluminum alloy control arms

4. Conclusions

Through the super-inoculation of the liquid cast iron it is possible to produce thin wall control arms made of ductile iron without the development of chills, porosity, cold laps and misruns.

Thin wall control arms made of ductile (480 grams*)* can be lighter and with better mechanical properties than substitutes made of forged Al alloys (585 g). The ductile iron control arm is far less expensive and can bring substantial savings when replacing similar components made of Al alloys.

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