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Effect of small additions of vanadium and heat treatment on mechanical properties ductile iron

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Abstract

Results of investigations of influence of small vanadium additions (up to 0,15 % V) and heat treatment of 1080°C-24h/640 °C and 1080°C-24h/600 °C type on mechanical properties (tensile strength, yields strength and elongation) of ductile iron are presented in this work. It has been demonstrated that in ductile iron with 0,10÷0,15%V heat treatment of 1080°C-24h/640 °C type to a small extent decreases tensile strength and elongation, whereas essentially increases yields strength.

Key words: Mechanical properties; Ductile iron; Structure; Vanadium carbides; Heat treatment.

1. Introduction

Ductile iron is a modern construction material and offers wide range of mechanical properties with simultaneous high wear resistance and dumping capacity [1]. From foundry practice result that in many cases production of ductile iron ensure fulfillment the Standard regarding tensile strength as well as elongation but not always yield strength archives required value. Investigations enabling affirm whether the foregoing problem can be resolve by means of small additions of vanadium and heat treatment are the aim of this work.

2. Methodology

Ductile iron was obtained in an electric induction furnace of medium frequency and with 15 kg capacity. The raw materials were pig iron, steel scrap, ferrovanadium 80%. The metal was preheated at 1500 °C and then poured into sand mould to get normalized Y-shaped castings. Spheroidizing and inoculation process was made in gating system using Fe-Si-5%Mg alloy, and Foundrysil inoculant containing 0,5 % Ce in amounts 1,0 % and 0,8 % with relation to bath weight, respectively. Group of castings were heat treated, namely austenitized at 1080 °C for 24 hours followed by quick cooling to the temperature of 640 and 600 °C followed by cooling them together with furnace to ambient temperature. From castings samples with measurement diameter of 8 mm for mechanical testings were taken. Strength indicators of obtained ductile iron were: tensile strength R_m, yield strength $R_{0,2}$ and elongation A, which were determined using testing machine of INSTRON type.

3. Results

Chemical composition along with results of vanadium influence on mechanical properties of base and heat treated ductile iron are given in Tables 1 ÷ 5 and in Figures 1 and 2.

Table 1.
Chemical composition and structure indicators of ductile iron

Heat no.	C %	Si %	V %
w1	3,56	2,00	0,01
W2	3,62	1,98	0,02
W3	3,63	2,03	0,02
W4	3,77	2,22	0,04
W5	3,24	1,98	0,08
W6	3,45	2,02	0,12
W7	3,45	2,09	0,15
Mn ≈ 0,01 %, S = 0,005÷0,01 %; Mg = 0,040 ÷ 0,050 %			

In Table 3 there are put together regression equations between vanadium content in ductile iron and increment of tensile strength ΔR_m, yield strength $\Delta R_{p,0,2}$ and elongation decrease ΔA for base and heat treated ductile iron. Plot of these equations are shown in Fig. 1. Table 4 presents estimated regression increment of ΔR_m and $\Delta R_{p,0,2}$ as well as decrease in ΔA (expressed in %) for ductile iron containing 0,15 % V. It is worth noticing results for base and heat treated (1080°C/640 °C) castings. They show that such treatment hardly affects values of ΔR_m and ΔA while to a larger extent influences $\Delta R_{p,0,2}$. In other words heat treatment enable to maintain R_m and A at the level of base ductile iron and simultaneously increases $\Delta R_{p,0,2}$. In case of heat treatment of 1080°C/600 °C type increments of ΔR_m and $\Delta R_{p,0,2}$ are markedly but simultaneously ΔA falls essentially, what is unfavorable from a viewpoint of castings plasticity.

Table 3.
Mechanical properties of base iron and after heat treatment

Heat no.	Base ductile iron			Type of heat treatment					
				1080°C/640 °C			1080°C/600 °C		
	R_m MPa	$R_{0,2}$ MPa	A %	R_m MPa	$R_{0,2}$ MPa	A %	R_m MPa	$R_{0,2}$ MPa	A %
w1	420	262	23	400	275	24	408	285	20
w2	424	271	21	399	271	20	394	274	21
w3	421	275	22	400	275	21	393	275	20
w4	443	292	20	433	310	20	421	297	15
w5	455	297	20	432	303	18	438	305	13
w6	470	285	17	448	318	16	479	357	10
w7	499	310	17	466	348	16	482	368	12
1080°C/640 °C – austenitizing temperature /ferritizing temperature 1080°C/600 °C - austenitizing temperature /ferritizing temperature									

Table 3.
Regression equations

No. of curve in Fig.1	Type of heat treatment	Equation
1	-	ΔR_m=144,4V+53,2V^2
2	1080°C/640 °C	ΔR_m=165,7 V-311,4V^2
3	1080 °C /600 °C	ΔR_m=173,6V-75,6 V^2
1	-	$\Delta R_{p,0,2}$=144,3V-217,3 V^2
2	1080°C/640 °C	$\Delta R_{p,0,2}$=205,8V-125,6 V^2
3	1080 °C /600 °C	$\Delta R_{p,0,2}$=123,9V+802,9 V^2
1	-	ΔA=557,1V^2 - 557,1V
2	1080°C/640 °C	ΔA=873,3V^2 -349,4V
3	1080 °C /600 °C	ΔA=1815,1V^2-659,4V

Table 4.
Effect of heat treatment on mechanical properties of ductile iron with 0,15% V

Type of heat treatment	ΔR_m, %	$\Delta R_{p,0,2}$, %	ΔA, %
-	+20	+17	-26
1080°C/640 °C	+18	+28	-32
1080 °C /600 °C	+24	+36	-58

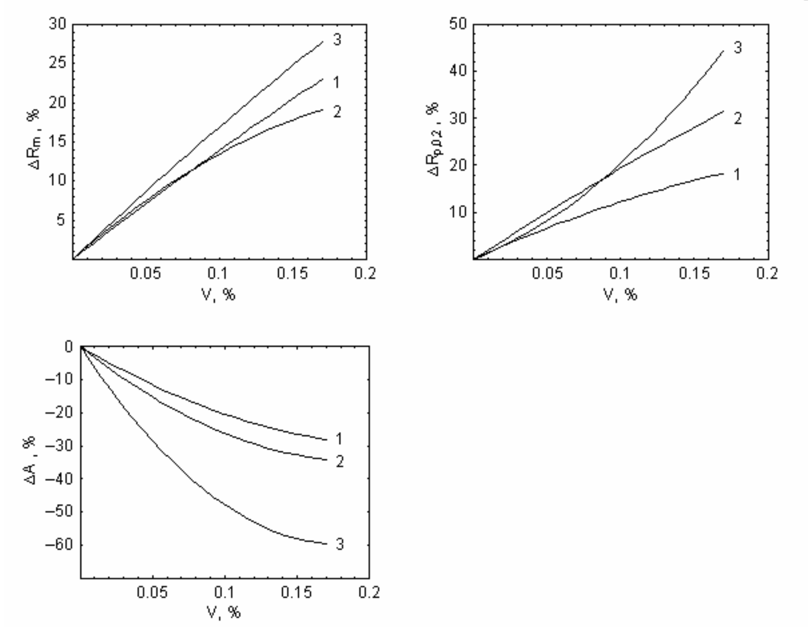

Fig.1. Influence of vanadium and heat treatment on changes of mechanical properties of ductile iron, curves: 1 - as cast, 2 and 3 after heat treatment 1080°C/640 °C and 1080 °C /600 °C, respectively

Table 5.
Regression equations

No. of curve in Fig.2	Type of heat treatment	Equation
1	-	R_m =410,2+592,2V-218,1V^2
2	1080°C/640 °C	R_m =392,6+649,0 V-1222,6V^2
3	1080 °C /600 °C	R_m =397,3+689,6 V+300,3V^2
1	-	$R_{p,0,2}$ =265,7+383,3 V-577,4 V^2
2	1080°C/640 °C	$R_{p,0,2}$ =267,3+550,2 V-355,9 V^2
3	1080 °C /600 °C	$R_{p,0,2}$ =273,1+338,1 V-2192,4 V^2
1	-	A=22,9 – 59,5 V+127,6 V^2
2	1080°C/640 °C	A=23,0 – 80,5 V+201,2 V^2
3	1080 °C /600 °C	A=22,8 – 150,9 V+415,3V^2

Table 5 gives regression equations between vanadium content and tensile strength R_m, yield strength $R_{p,0,2}$ and elongation A for the base and heat treated ductile iron. Plots of these equations are shown in figure 2, where regions of ductile iron from EN-GJS-350-22 grade up to EN-GJS-600-3 grade, according to PN-EN 1562 (Feb., 2000) are shown.

In general it can be state that heat treatment used in these investigations decreases tensile strength R_m and elongation A while yield strength $R_{p,0,2}$ increases and observed changes increases along with vanadium content in ductile iron (Fig.2). Interesting results were obtained for heat treated at 1080°C/640 °C ductile iron. As it turned out ductile iron with 0.02 % V fulfill requirements concerning tensile strength R_m and elongation A destined for ductile iron of EN-GJS-350-22 grade but simultaneously shows higher yield strength $R_{p,0,2}$, which are typical for higher grade of ductile iron that is EN-GJS-400-15 or EN-GJS-400-18. In case of ductile iron with V > about 0.1 % it is obtained from a viewpoint:

R_m, - ductile iron of EN-GJS-400-10 grade,
A - ductile iron with higher grade that is EN-GJS-400-15,
$R_{p,0,2}$ - ductile iron with higher grade that is EN-GJS-500-7.

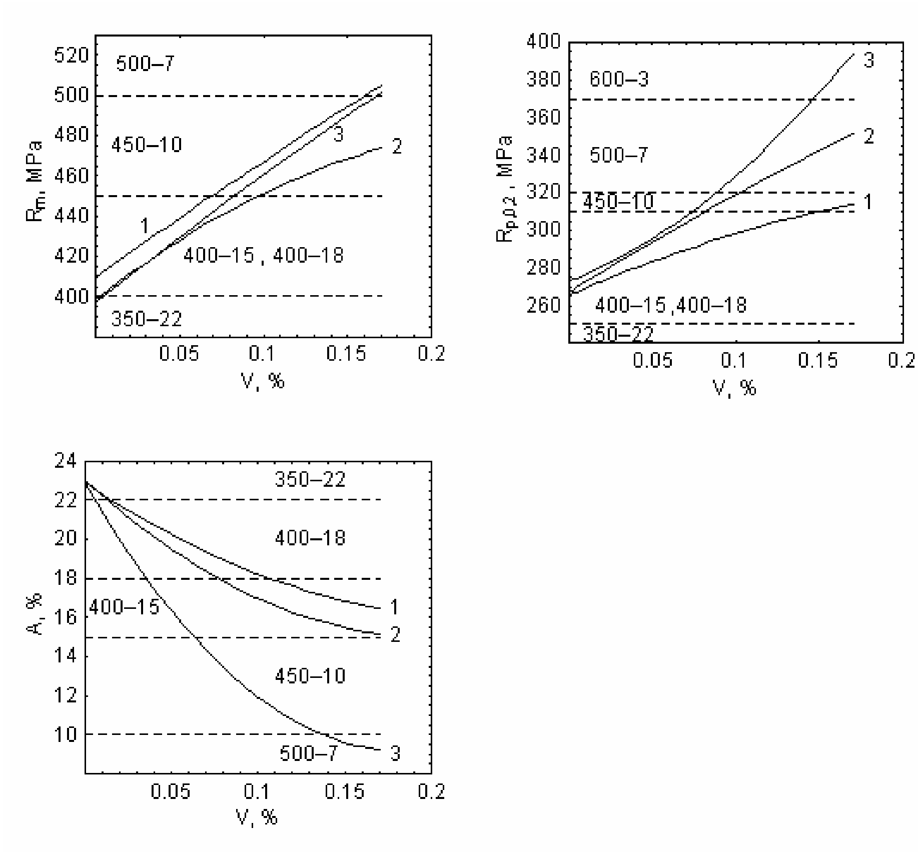

Fig.2. Influence of vanadium and heat treatment on mechanical properties of ductile cast iron, curves: 1 - as cast, 2 and 3 after heat treatment 1080°C/640 °C and 1080 °C /600 °C, respectively

4. Concluding remarks

1. Heat treatment of 1080°C/640 °C type of ductile iron with small addition of vanadium to a small extent lower tensile strength and elongation but simultaneously essentially increases yield strength.

2. Such heat treatment for ductile iron with 0,10÷0,15% V enable to obtain material, which from a viewpoint of tensile strength and elongation can be classified as a EN-GJS-400-10 and EN-GJS-400-15, respectively, while from a viewpoint of yield strength as a ductile with higher grade that is EN-GJS-500-7.

Acknowledgments

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