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ARCHIVES of FOUNDRY ENGINEERING

ISSN (2299-2944)
Volume 2021
Issue 4/2021

121 – 126

10.24425/afe.2021.139760

18/4

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

Influence of Tungsten on the Structure and Properties of Ductile Iron Containing 0.8% Cu

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Received 03.11.2021; accepted in revised form 10.12.2021

Abstract

The possibilities of producing ductile cast iron with the addition of 1 ÷ 3% of tungsten are presented. Tungsten from waste chips from mechanical processing was introduced into the liquid cast iron in the form of specially prepared cartridges. Correct dissolution of tungsten in the metal bath was found, and there were no casting defects in the alloy. The form of carbide precipitates in the microstructure of cast iron was determined and the influence of increasing tungsten content on the reduction of the number of graphite precipitates in the structure was determined. Impact tests show that this property degrades with increasing tungsten content as opposed to hardness which increases. It was found that the addition of tungsten from machining waste is a potential source of enrichment of cast iron with this element.

Keywords: Metallography, Mechanical properties, Tungsten, Cast iron

1. Introduction

Tungsten is one of the elements rarely used in cast iron metallurgy. Its very high melting point (3410°C) makes it difficult to incorporate into metal. It is chemically similar to molybdenum, but it is inferior to it in terms of use, and also in terms of its influence on the mechanical properties of cast iron. However, due to the rising price of molybdenum, it is being taken into account in special applications [1-3]. Tungsten, like molybdenum, is a carbide-forming and pearlitic element. Similarly, it favours the formation of a bainite matrix (Fig. 1) in the state after casting [4]. The comparison of these two elements (Fig. 2a) shows, however, that the effectiveness of the influence of tungsten is about two times lower than that of molybdenum [4]. Tungsten (next to: V, Mo, Cr) is one of the elements conducive to the solidification of cast iron according to the metastable system [4-8]. It is known that carbide-forming elements favour the crystallization of cast iron according to a metastable system, increasing its density. Tungsten and molybdenum particularly clearly increase the density of white cast iron (ρ_{Mo}=10,2 g/cm^3; ρ_W=19,3 g/cm^3) [1].

The influence of tungsten on the mechanical properties of gray cast iron is similar to that of molybdenum, but it is about two times weaker (Fig. 3). Until now, these elements have been designed in gray cast iron as perlitizing agents. Such an effect is caused by introducing different node elements with a diameter of atoms different from the diameter of iron atoms. Taking into account the ratio of the radii of the atoms of the alloying elements to the radius of the iron atom, tungsten, molybdenum, titanium and vanadium have the best effect on increasing the creep resistance (Table 1). The most popular are molybdenum and vanadium (up to 0.2 wt.%) Since titanium slightly dissolves in iron and binds mainly to carbides and nitrides, and tungsten is a relatively expensive element. It was found, however, that the introduction of tungsten in a much greater amount than other elements creates the possibility of significant solution strengthening and significantly increasing some mechanical properties, e.g. creep resistance of cast iron.

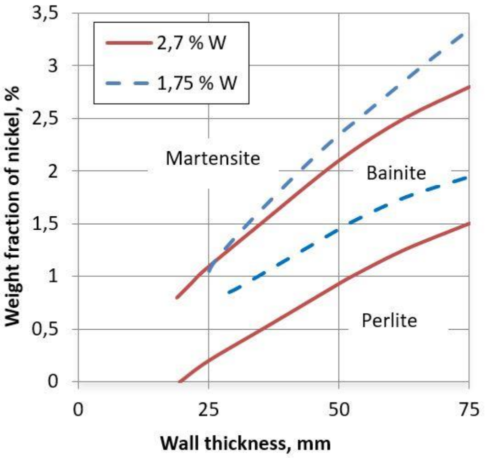

Fig. 1. Structural diagram of low-alloy gray cast iron containing Ni and W depending on the wall thickness; continuous line - 2.75%W; dashed line - 1.75%W [4]

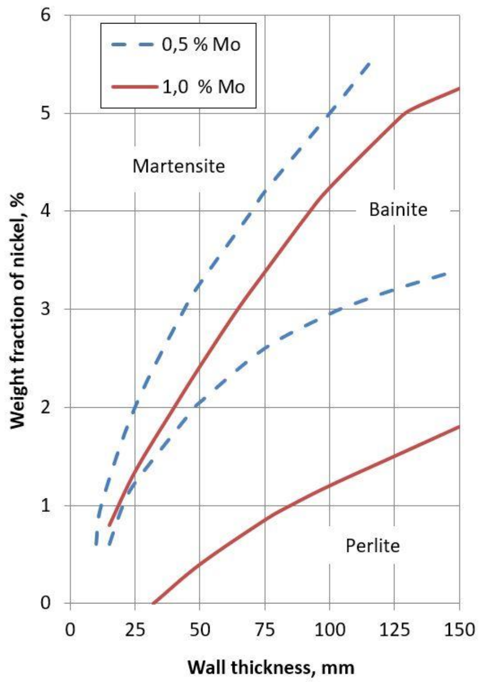

Fig. 2. Structural diagram of low-alloy gray cast iron containing Ni and Mo depending on the wall thickness; continuous line - 1.0% Mo; dashed line - 0.5% Mo [4]

The use of tungsten can only be justified when, due to its price or availability, it could be treated as a substitute element for molybdenum (tungsten increases the hardenability of cast iron). Today, the possibility of using tungsten from waste is a good source of this element in justified cases of producing special grades of cast iron, e.g. ausferritic cast iron [9]. Its metallurgical abilities must be determined by rigorous testing.

The research undertaken in this article is aimed at determining the influence of waste tungsten, recovered in other technological processes (most often machining), on the properties of ductile iron after casting. The article is an introduction to the research on the influence of tungsten on the hardenability and mechanical properties of ductile iron after heat treatment.

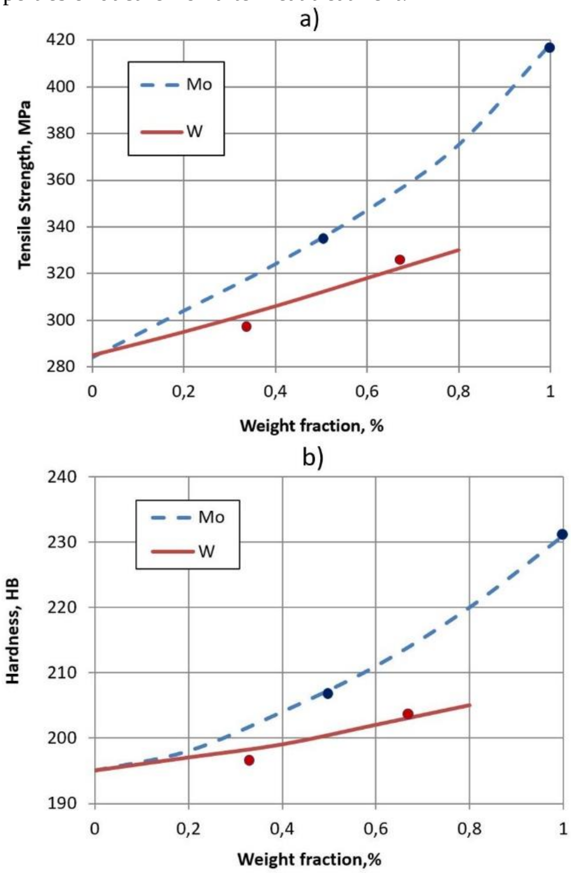

Fig. 3. The influence of molybdenum and tungsten on the tensile strength and HB hardness of grey cast iron [4]

Table 1
Comparison of the radii of the iron atom and atoms of various elements forming solid solutions with Fe.

Element	The radius of the atom	
	Absolute Å	Relative to the Fe atom, %
Ti	1,45	+114,1
W	1,42	+111,9
Mo	1,36	+107,1
V	1,29	+101,6
Fe	1,27	100

2. Methodology

Ductile iron was manufactured by remelting pig iron, steel, ferroalloys and alloying additives. Pure tungsten in a special cartridge made of a carbon steel cup filled with small chips was added as a modifier directly to the melting furnace. The metallurgical process was carried out in the PI35 medium frequency induction furnace with a capacity of 40kg. Spheroidization was carried out by the sandwich method with the use of FeSiMg added to the pouring ladle. The castings samples with the chemical composition as in Table 2 were poured into YII shape geometry mould cavities made of core mass. Specimens for the impact Charpy test and hardness test were cut from the lower part of the ingots according to Fig.5. The microstructure of the specimens etched with a solution of HNO_3 in C_2H_5OH was observed using a JSM 7100J scanning electron microscope. Metallographic images were analysed using the Image-J program. Standard deviation was determined for minimum 20 measurements in five randomly selected areas

Table 2.
Ductile iron chemical composition [wt.%] and characteristics of nodular graphite precipitates

Material	C	Si	Mn	P	S	Cu	W	Mg	Graphite share, %	Nodule count per mm^2
DI-Cu	3,59	2,52	0,21	0,040	0,012	0,72	0,02	0,05	11,8	288
DI-CuW1	3,66	2,41	0,08	0,046	0,009	0,67	0,97	0,05	9,3	164
DI-CuW2	3,37	2,35	0,19	0,039	0,018	0,65	1,88	0,04	10,7	189
DI-CuW3	3,47	2,38	0,15	0,036	0,008	0,73	2,89	0,05	8,9	122

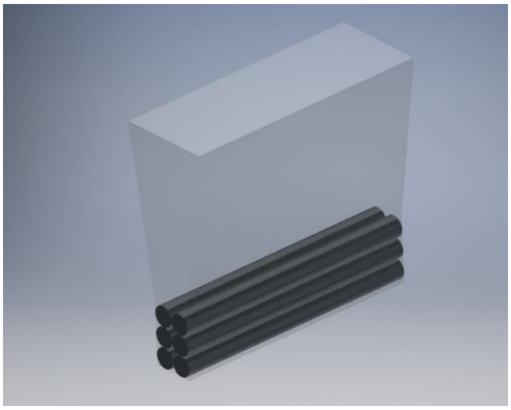

Fig. 5. YII shape casting with specimens for metallographic and mechanical properties examinations

3. Results and discussion

The introduction of pure tungsten into the liquid cast iron in the amounts of 1-3% resulted in a change in the structure of the ingots compared to the initial state (Fig. 6-9). The pictures of the microstructure of cast iron with the addition of tungsten show a microstructure with a predominant proportion of perlite (> 70%) compared to the starting cast iron (57% perlite). The effect on reducing the number of graphite spheres and increasing their volume was also noticed. In cast iron containing tungsten, the presence of tungsten carbides at the boundaries of eutectic cells is observed in each case (Fig. 7-9). These carbides take the characteristic form of stretched or compact skeletal structures (Fig. 7c and Fig. 8c) with a complex chemical composition based on tungsten (Fig. 10).

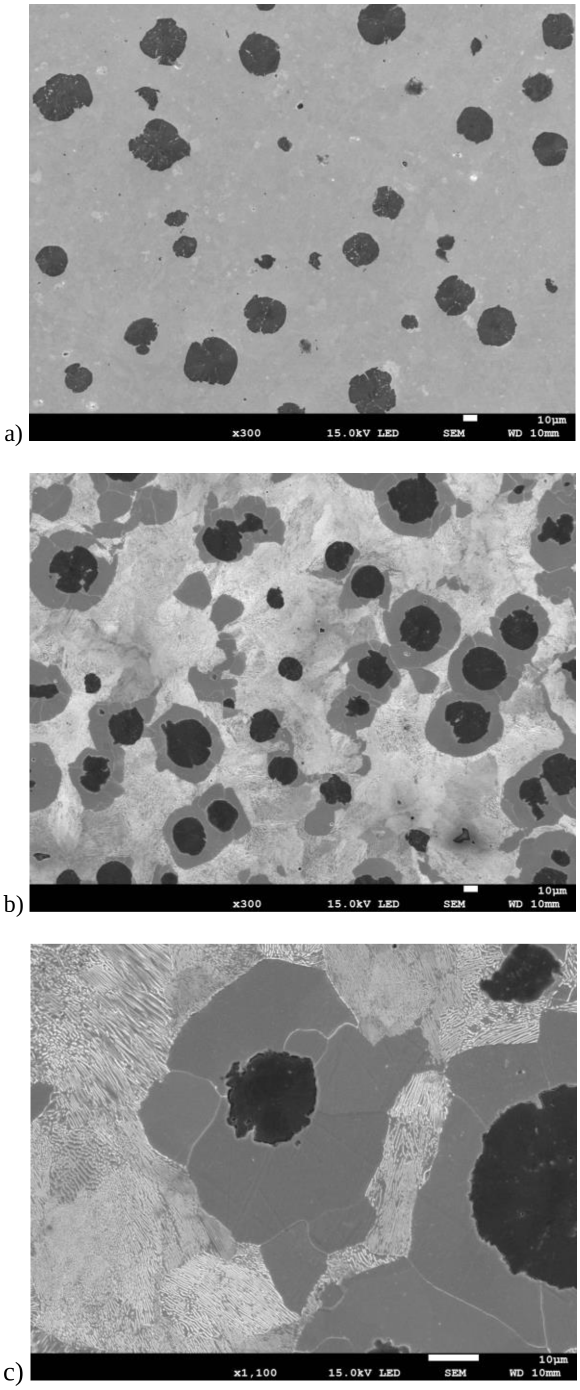

Fig. 6. Microstructure of DI-Cu ductile iron

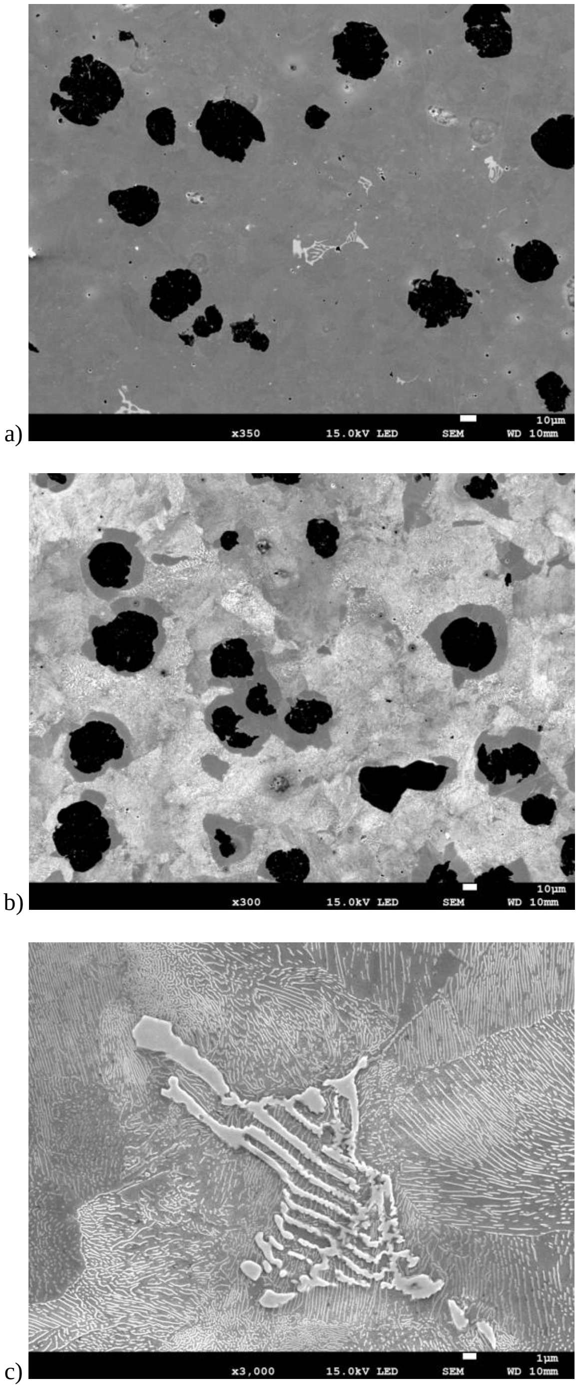

Fig. 7. Microstructure of DI-CuW1 ductile iron

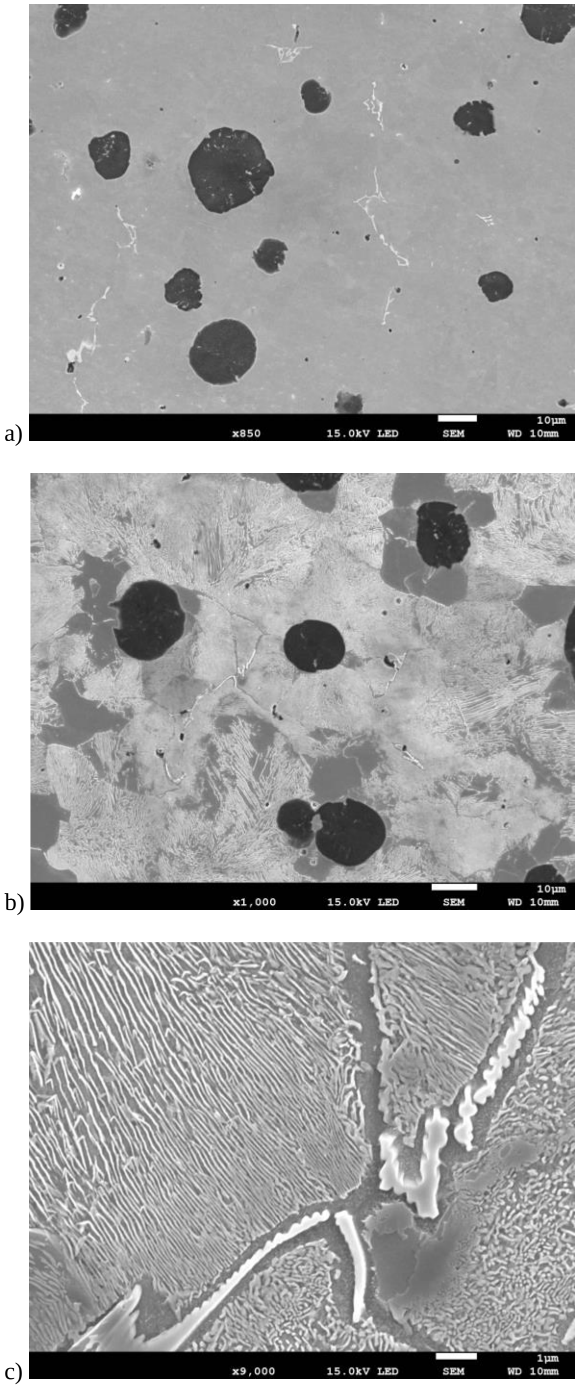

Fig. 8. Microstructure of DI-CuW2 ductile iron

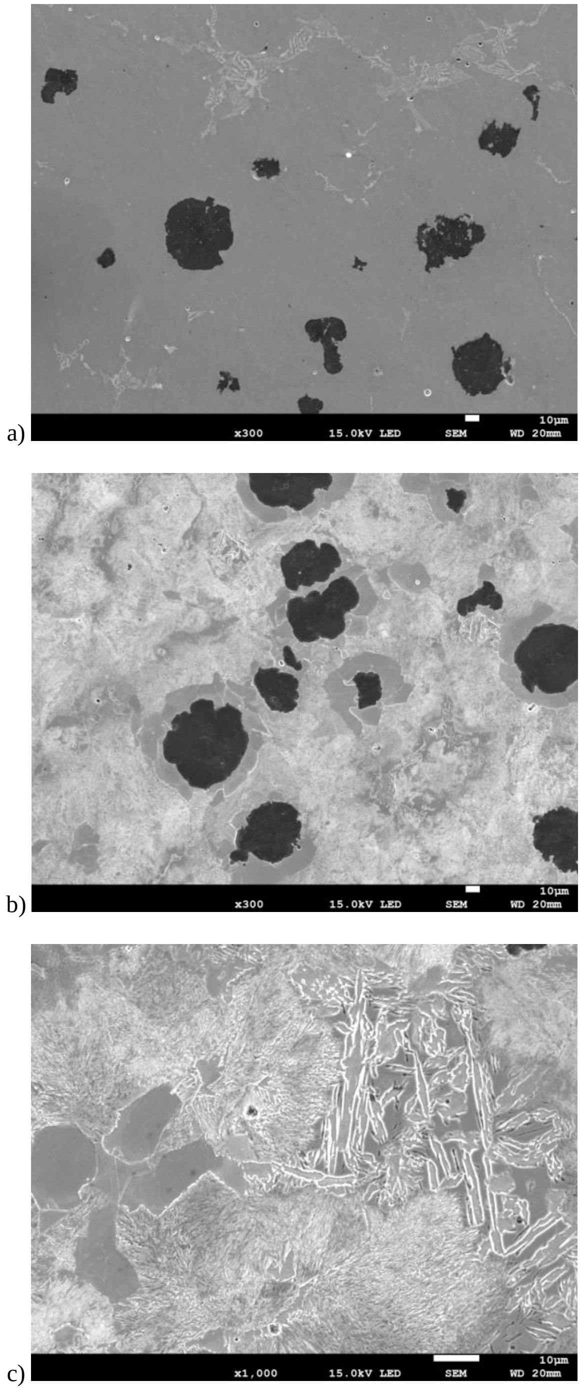

Fig. 9. Microstructure of DI-CuW3 ductile iron

The occurring carbide precipitations are the cause of brittle fractures and cracks that appear visibly at the carbide-matrix boundaries (Fig.10). The more carbide structures in a cast iron containing more than 1% W, the more brittle fractures. This is reflected in a significant decrease in the impact toughness of ductile iron reaching even 50% less than the initial value (Table 3).

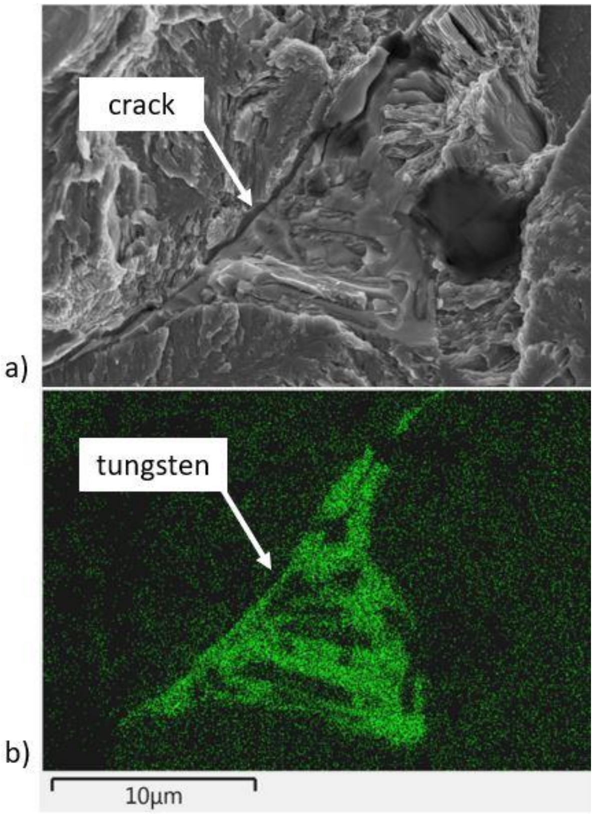

Fig. 10. Brittle fracture at the carbide-matrix interface in DI-CuW3 cast iron; a) SEM photo, b) indication of the presence of tungsten on EDS mapping

Table 3
Mechanical properties of ductile iron containing: 1÷3%W

Sample	Impact strength, J	Hardness, HB
DI-Cu	38,64	267
DI-CuW1	26,97	284
DI-CuW2	21,97	320
DI-CuW3	19,22	365

4. Conclusions

During the analysis of research results related to the introduction of tungsten additive to cast iron, it was found:

- Good solubility of tungsten chips in liquid cast iron;
- Lack of casting and structural defects in ductile iron with the addition of tungsten up to 3% by mass;
- Formation of complex carbide structures at the boundaries of eutectic cells in the structure of ductile iron;
- The addition of tungsten in the amount of 1% to 3% reduces the impact toughness and increases the hardness of ductile iron;
- The occurring carbide precipitation causes brittle fractures. The more carbide structures in a cast iron containing more than 1% W, the more brittle fractures.

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