

Original Research Paper

Investigation of some alloyed (SG) ductile irons

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In this work, we examined six grades of alloyed SG iron with bainitic – Martensitic and pearlitic matrix structure according to PN- 76/H83142- polish standard .The alloying elements were Ni ,Mo and Cu with moderate weight percentage . The chemical compositions of tested grades and metallographic examinations, also, hardness were tested, relative values of magnetic phase also tested. Investigation results and their discussions were included in this article the result showing the effects of those alloying elements on structure and properties of tested grades of ductile iron .

Aim of the research:

The main goals of this work were to indicate the results of each test such as chemical composition structural , hardness of alloyed SG iron , and relative magnetic phase, to increase the knowledge's dealing with that growing importance material in different applications .

Key Word : Ductile iron , alloying , investigation .

INTRODUCTION

Cast iron generally is one of the oldest ferrous metals used in construction.

It is primarily composed of Fe , C , and Si . But it may also contain traces of S and P and they have gray color due to free graphite. Ductile iron or SG iron was invented in 1943 and start production at (1951) with about five million ton /year . This material could contain many other alloying elements such as Ni, Cu , Cr ,Mo...etc. to get special specified properties required for applications either as cast or by heat treatment]4[The spherical shape of graphite can be obtained by (Mg) treatment .The microstructure of SG iron generally was shown in (fig1) Acicular matrix SG iron structure (Bainitic or bainitic – martensitic) could be obtained by alloying with certain elements with different percentages , which affect the phase transformation of SG iron and achieving the required structure by heating and cooling . According to the investigations , different properties can be obtained by useful heat treatment. Most varieties of cast iron are brittle , ductile iron has much more impact and fatigue resistance,due to its nodular graphite inoculation.

In ductile iron rounded nodules inhibit the creation of crack , thus providing the enhanced ductility that gives the alloy its name.

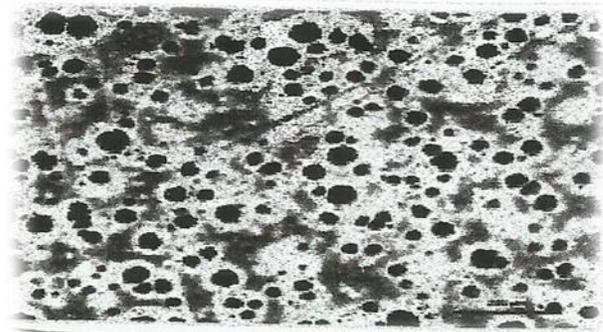


Fig.(1) ductile iron microstructure at 100× carbon islanding effect around nodules.

Element such as copper or tin may be added to increase tensile and yield strength while simultaneously reducing ductility . Improved corrosion resistance can be achieved

by replacing 15% to 30% of the iron in the alloy with varying amounts of nickel, copper, chromium or Mo.

Ductile cast iron properties are changed by adding alloying elements next to C & Si, is the most important alloyant because they force C out of solution Ni is one of the most common elements because it refines pearlite and graphite structure improve toughness, Cr and Cu are added to the ladle or to the furnace in (0.5-2.5)% by Wt to decrease chill, refine graphite and increase fluidity.

Mo is added in the range (0.3-1.0)% by Wt to increase chill and refine graphite and pearlite and increase fluidity. It is often added with Ni & Cu and Cr, to form high strength

A more recent development in nodular or ductile cast iron. Tiny amounts of magnesium or cerium added to those alloys slow down the growth of graphite precipitates by bonding to the edges of the graphite planes, along with careful control of other elements and timing, this allows the carbon to separate as spheroidal particles as the material solidifies. The properties are similar to malleable iron with higher ductility, but parts can be cast with larger sections.

New research programs aimed to improve production technology, solving its problems and providing better manufacturing economies. Exchange of technical and production knowledge take place by research and new technology.

Tech. and institution Manual, millions researches through the last century of investing improvement were done in manufacturing efficiency, productivity, and capacity these required more modification in the foundry of ductile and other grey cast irons.

Through the last century more modifications were required in the foundry of ductile iron and other grey iron. Metallurgical controls of (DI) production must test its chemical composition before treatment with Mg, it is

important to know S% in liquid iron, as it resists spheroidal graphite formation.

Addition of Mg is required to form spheroidal shape of graphite at temperature about 1450 °C. The Mg required for that treatment range (0.25-1.0)%.

The usual elements added to promote hardenability are Ni up to 2% and Mo up to 0.75%.

Cu has limited solubility in molten iron i.e. below 1.5%.

Ni is added to cast iron as graphitizer, it increases the toughness of matrix, and getting more unstable pearlite. Ni also makes it easier to heat treat to form martensitic structure. Cu is similar to Ni in many ways, but it is stronger in pearlite promoting. At 2% Cu matrix will be 100% pearlitic.

Mo is a pearlite stabilizer and promotes hardenability it is mostly used with Cu or Ni but in lower addition rate because of its segregation tendency.

Mo is added in the range (0.3-1.0)% to increase chill and refine graphite and pearlite and increase fluidity of DI. Small amount of Ni and Mo promote the formation of ferrite and increase ductility mainly with low alloying.

MATERIALS AND METHODS

The following tests were done in this work by investigating some alloyed ductile irons of bainitic SG iron with Ni, Mo and Cu additions.

Chemical composition of tested grades of SG iron:

Identification of phase transformations occurring in tested specimens of grades of bainitic SG irons according to above polish standards, have melted in the melting and crystallization workshop metal testing department, in the acidic lining induction furnace in Institute of Foundry Research, Cracow-Poland. Chemical compositions are given in table (1).

Table -1- Chemical composites of tested grades of bainitic SG iron

SG iron grades	Elements content %									
	C	Si	Mn	P	S	Mg	Ni	Mo	Cu	Cr
SG iron No1 (ZsNi2,7Mo)	3.36	2.75	0.49	0.105	0.012	0.048	2.75	0.82	0.02	0.06
SG iron No2 (ZsNi4,0Mo)	3.38	2.58	0.48	0.107	0.012	0.047	3.86	0.77	0.03	0.06
SG iron No3 (ZsNi3,2Cu1,1)	3.34	2.78	0.45	0.105	0.011	0.083	3.32	0.09	1.14	0.05
SG iron No4 (ZsNi4,5Cu1,1)	3.56	2.82	0.43	0.043	0.013	0.031	4.25	0.01	1.13	0.05
SG iron No5 (ZsNi2,2Cu1,1 Mo)	3.56	2.88	0.48	0.095	0.011	0.041	2.42	0.068	1.15	0.05
SG iron No6 (ZsNi3,2Cu1,1 Mo)	3.54	2.88	0.45	0.095	0.012	0.042	3.25	0.067	1.14	0.05

Applications:

Much of the annual production of ductile iron is in the form of ductile iron pipe, used for water and sewer lines. It competes with polymeric materials such as PVC, HDPE, LDPE and polypropylene, which are all much lighter than steel or ductile iron; being more flexible, these require protection from physical damage.

Ductile iron is specifically useful in many automotive components, where strength needs surpass that of aluminum but do not necessarily require steel. Other major industrial applications include off-highway diesel trucks, Class 8 trucks, agricultural tractors, and oil well pumps. In wind power industry, nodular cast iron is used

for hubs and structural parts like machine frames. Nodular cast iron is suitable for large and complex shapes and high (fatigue) loads.

Metallographic examination:

Metallographic examination to test microstructures in the testing Workshop. Examination of casted specimens having dimensions: $\text{Ø}32 \times 60$ mm, showed spheroidal graphite (SG) in acicular matrix of lower or higher bainite or martensite, traces of carbides appear on grain boundaries in figs. (2-7), microstructures of tested grades of ductile iron were presented.



Fig.2 structure of SG iron
No.1- Nital 3%-x250

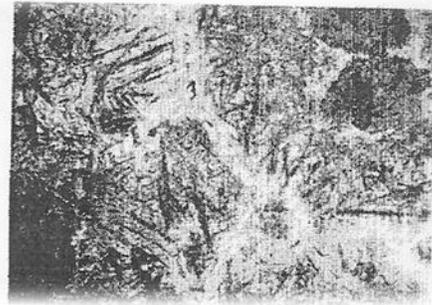


Fig.3 structure of SG iron
No.2- Nital 3%-x250



Fig.4 structure of SG iron
No.3- Nital 3%-x250

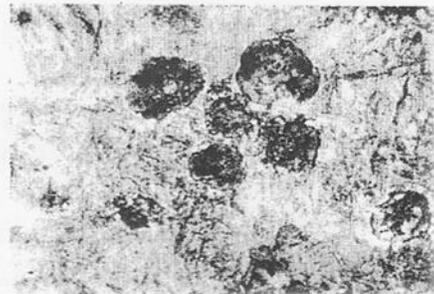


Fig.5 structure of SG iron
No.4- Nital 3%-x250

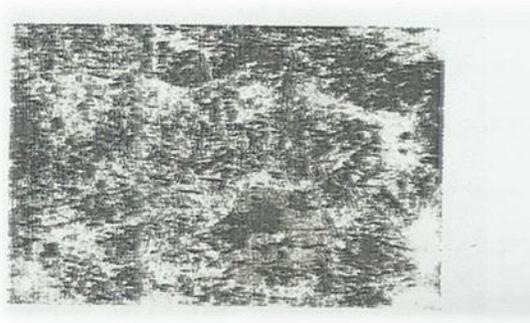


Fig.6 structure of SG iron
No.5- Nital 3%-x250



Fig.7 structure of SG iron
No.6- Nital 3%-x250

Hardness test:

For more precise characteristic of the structure of casted samples (CES) from the tested grades of SG iron, hardness tests were done by Brinell method . The hardness numbers were at Rockwell unite . Testing were done in the

workshop of strength of testing casting construction in Foundry research Institute -Cracow- Poland .Results of testing were listed in table -2.

Table -2- Results of hardness test (HRC) for tested grades of SG iron

Cast iron grade	Type of sample	Hardness Reading HRC					Average
		1	2	3	4	5	
Cast iron No1	CES	50.5	50.2	49.2	50.1	49.8	50.0
Cast iron No2	CES	50.0	51.3	52.1	50.7	50.7	50.96
Cast iron No3	CES	52.7	52.4	52.1	50.5	51.2	51.58
Cast iron No4	CES	47.8	47.3	48.2	48.4	50.0	48.34
Cast iron No5	CES	50.3	50.2	50.4	50.3	52.5	50.74
Cast iron No6	CES	51.0	50.1	52.0	52.7	52.4	51.64

Every result was the arithmetic mean value of six reading for CES sample using approximation given by O.L. Davies equation to calculate mean square of variation for hardness readings .

$S_x = R/d_n$ were: S_x - mean square variation , R - mean (value)
 d_n - coefficient depend on the quantity of equality of readings

According to O.L Davies equation :

For six readings – $d_6 = 2.534$

For four readings – $d_4 = 2.054$

By this method mean square of (value) calculated hardness

HRC: for sample CES – $S_x = 0.861$

Relative Values of magnetic phase test:

For exact identification of phases existed in the tested sample (CES), relative quantity of magnetic phase have measured . For this purpose , apparatus type Ferrikom II, was used . It was calibrated in such a way to give zero % reading for austenite SG iron (ZsNi 13Mn7) according to

polish standards (PN-76/H-83139) without Cr, and 100% for samples of SG iron No.4 of maximum value of magnetic phase .Testing was done at room temperature (20C°) and the results shown in table-3.

Table-3-Relative part of magnetic phase in tested samples from SG iron

Cast iron grade	(Relative part of magnetic phase*)%		
	Sample CES		
	Readings		
	1	2	Average
Cast iron No 1	88	88	88
Cast iron No 2	93	89	91
Cast iron No 3	91	90	90.5
Cast iron No 4	100	100	100
Cast iron No 5	90	87	88.5
Cast iron No 6	93	92	92.5

*) As an example (100%) considered part of magnetic phase in SG iron No4

RESULTS OBTAINED:

The main results of this work are :-

- 1- The chemical analysis showed that all types of tested alloyed SG ductile irons are nearly free of Cr. (0.05%) , low in S (0.012%) and high in C,(3.36%) and also high in Si (2.8%).With traces of Mg (0.045%) by weight %.
- 2- The alloying elements ranges are :Ni(2.42-4.25)% ,Mo(0.01-0.82)% and Cu (0.02-1.15)%.
- 3- Spherical shapes of graphite appears in the microstructure matrix of all types of tested alloyed ductile irons , due to the above compositions .
- 4- The hardness of the tested samples of SG alloyed ductile iron were high and range between (48.34)HRC for ductile iron No.4 to (51.64)HRC for ductile iron No.6 by using Brinell method .
- 5- The relative part of magnetic phase in tested samples of ductile irons ranged :between (88%) for iron No.1 and (100%) for iron No.4 , which was free of austenite phase as non-magnetic.
- 6- The microstructures of tested irons contains acicular (Martensite , bainite) and pearlite as shown in figs : (2-7) .

CONCLUSIONS AND RECOMMENDATIONS:

It was clear that the residuals of (Mg element) in the tested irons indicates that sufficient amount of that element were used to form the spherical shape of free graphite which presents in the tested irons . That was shown in the figs : (1-7). (High C% and Si%) low S% were very important in production of SG. Iron .The relatively low hardness for SG iron No.4 (48.34 HRC) was due to lowest Mo and highest Ni and Cu which are promoting pearlite formation , so lowering martensitic–or Bainitic structure ,which has higher hardness and strength. The presence of Mo in irons No.1 and No.2 about (0.8%)· which is also pearlite stabilizer used with Ni or Cu because of its segregation tendency, promoting hardenability , refining graphite and pearlite i.e. increasing hardness and strength . The highest relative magnetic phase (100%), indicates that all austenite was transferred into pearlite or martensite, which were magnetic phases , while the other tests still contain traces of retained austenite (non-magnetic) . Accordingly the structure and composition i.e. alloying elements also (C, Si , S ,Mg) % – must be controlled carefully in order to achieve the required properties and developing ductile iron production , manufacturing efficiency ,productivity and capacity .We hope that continuous researches in this field could be done for further development .

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