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## Impact strength of thin wall ductile iron with dual matrix structure

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In this work the effects of thin wall and the temperature of heating in the intercritical region ( $\alpha + \gamma$ ) on the impact strength of ductile cast iron (unalloyed and 0.5Ni-0.2Mo alloyed) was investigated. For this purpose, step plate casting with wall thickness of 3 and 6 mm were produced using ductile iron chemistry. After, the casting were heating to the austenitizing temperature in the range of 790 to 850°C for 60 minutes and then quenched into salt bath held at austempering temperature of 370 or 315°C for 60 minutes to obtain austempered ductile iron with duplex structure consisting of pro-eutectoid ferrite and ausferrite. These microstructures of thin wall ductile iron casting were characterized quantitatively using an image analyzer. In as-cast condition, pearlite content, nodule count and nodularity increased with decreasing wall thickness, whereas the nodule size decreased. For heat-treated samples, the reduction of thin wall combined with an increase in the intercritical heating and austempered temperatures, results in better values on the impact strength.

*Keywords:* Ductile iron; thickness thin; austempering; impact strength.

En este trabajo se estudió el efecto del espesor de la pared y la temperatura de calentamiento en la región intercrítica ( $\alpha + \gamma$ ), sobre la resistencia al impacto de dos hierros dúctiles: no aleado y aleado al 0.5Ni-0.2Mo. Para ello, se elaboraron piezas en forma de escalón con espesores de 3 y 6 mm, que se produjeron mediante una práctica común de fabricación de hierros dúctiles. Para generar una estructura bifásica consistente en ferrita proeutectoide y ausferrita, las piezas fueron calentadas a temperaturas comprendidas entre 790 a 850°C por 60 minutos, seguido de temple en baño de sales a la temperatura de austemperizado de 370 o 315°C por 60 minutos. La microestructura de las piezas de pared delgada fue caracterizada cuantitativamente usando análisis de imágenes. En la condición de colada, el contenido de perlita, la cuenta de nódulos y la nodularidad mostraron un incremento con la disminución en el espesor de la pieza, mientras que, el tamaño del nódulo decrece. Para las muestras tratadas térmicamente, la reducción en el espesor de la pared combinado con un incremento en la temperatura de calentamiento intercrítica o mayor temperatura de austemperizado, resulta en mejores valores de resistencia al impacto.

*Descriptores:* Hierro dúctil; paredes delgadas; austemperizado; resistencia al impacto.

PACS: 81.05.Bx; 81.40.Gh; 81.70.Bt

### 1. Introduction

Ductile irons are Fe-C-Si alloys that are known for their low cost in production, high capacity of recycling and a wide range of mechanical properties which are in function of the metallic matrix, as well as size, form and amount of graphite [1-3]. The applications of these alloys have been expanded in the last years, particularly, in the automotive industry due to recent development of thin wall casting less than 5 mm. Recent studies have shown that ductile irons of thin walls are comparables on the resistance/weight ratio with aluminum alloys of automotive use, therefore, these alloys are considered as a light alloy [3,4].

Due to cooling velocity imposed during the solidification in pieces of small thickness, increases the nodular count, since it promotes the activation of greater amount of nucleation sites that generates a refine microstructure. Basic aspects in the fabrication of thin plates have been the reason of study between scientists and technologists on the last years. There are excellent results that showed the obtaining structures without microporosities and practically free of carbides [5], also it has been shown that the mechanical behavior can be improved by the application of austempering heat treatment [1,6,7]. The austempering is a thermal cycle

that consists of a heating at austenitization temperature (850-900°C), holding to austempering temperatures in the interval between 280-450°C, and cooling end at room temperature in a water bath. During the holding of the isothermal temperature, the austenite of high temperature ( $\gamma$ ) is decomposing in a product of acicular morphology formed by ferrite ( $\alpha$ ) and high carbon austenite ( $\gamma_{hc}$ ), known as ausferrite ( $\gamma = \alpha + \gamma_{hc}$ ).  $\gamma_{hc}$  is unstable thermodynamically and with long period of holding times at the isothermal temperature, it decomposes according to the reaction  $\gamma_{hc} = \alpha + carbides$ . Ausferrite is the structure responsible of the good combination of properties that exhibit the austempering ductile irons (ADI), whereas the development of the second reaction leads to a decreasing on mechanical properties, in particular, ductility and toughness.

The objective of this work is to study the impact behavior of thin walls (3 and 6 mm) of duplex ductile irons in function of heating intercritical region ( $\alpha + \gamma$ ) and austempering temperatures.

### 2. Experimental procedure

Unalloyed and Ni-Mo alloyed ductile irons Table I were melted in an induction furnace using steel scrap, ductile iron

returns, graphite, Fe-Si, Fe-Mo and electrolytic Ni as raw materials. The spheroidizing treatment was performed using Tundish-cover process with Fe-Si-5%Mg. The metal was poured after inoculation treatment with Fe-75%Si in sand molds to obtain step plate casting with wall thicknesses of 3 and 6 mm. Un-notched impact specimens were machined from each plate according to the ASTM E23-94b “Charpy subsize”. The rough surfaces in the samples were completely eliminated.

The heat treatment for all of the ductile irons consisted of heating at the intercritical temperatures of 790,

TABLE I. Average chemical composition of ductile irons.

Cast iron	Chemical composition, wt.%								
	C	Si	Mn	S	P	Mg	Mo	Ni	
Unalloyed	3.64	2.35	0.47	0.011	0.016	0.034	—	—	
0.5Ni-0.2Mo	3.70	2.56	0.52	0.011	0.018	0.036	0.22	0.54	

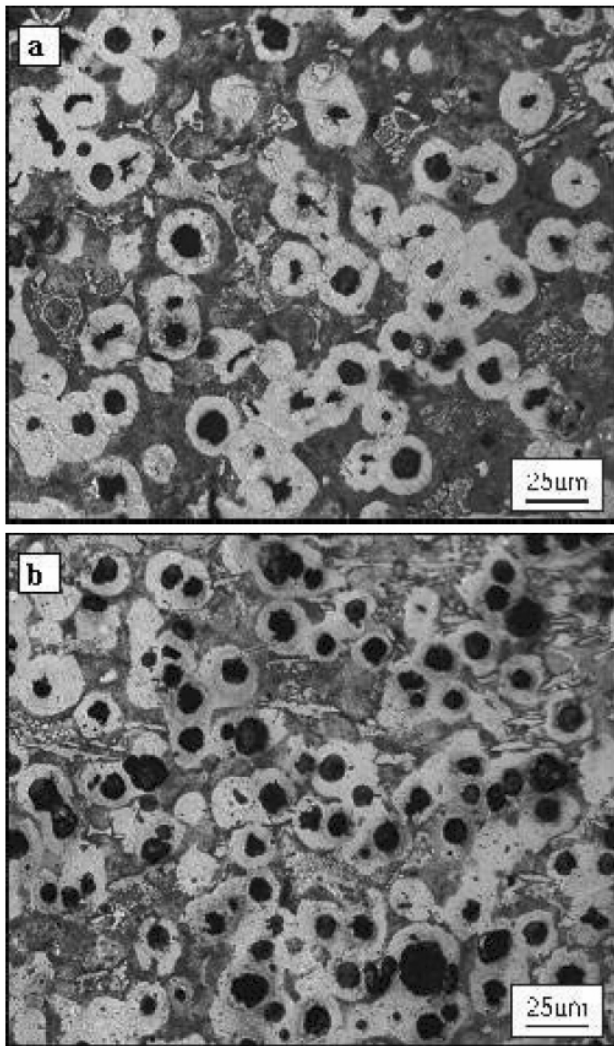


FIGURE 1. As-cast microstructure of 0.5Ni-0.2Mo ductile iron a) 3 mm and b) 6 mm of thick plate.

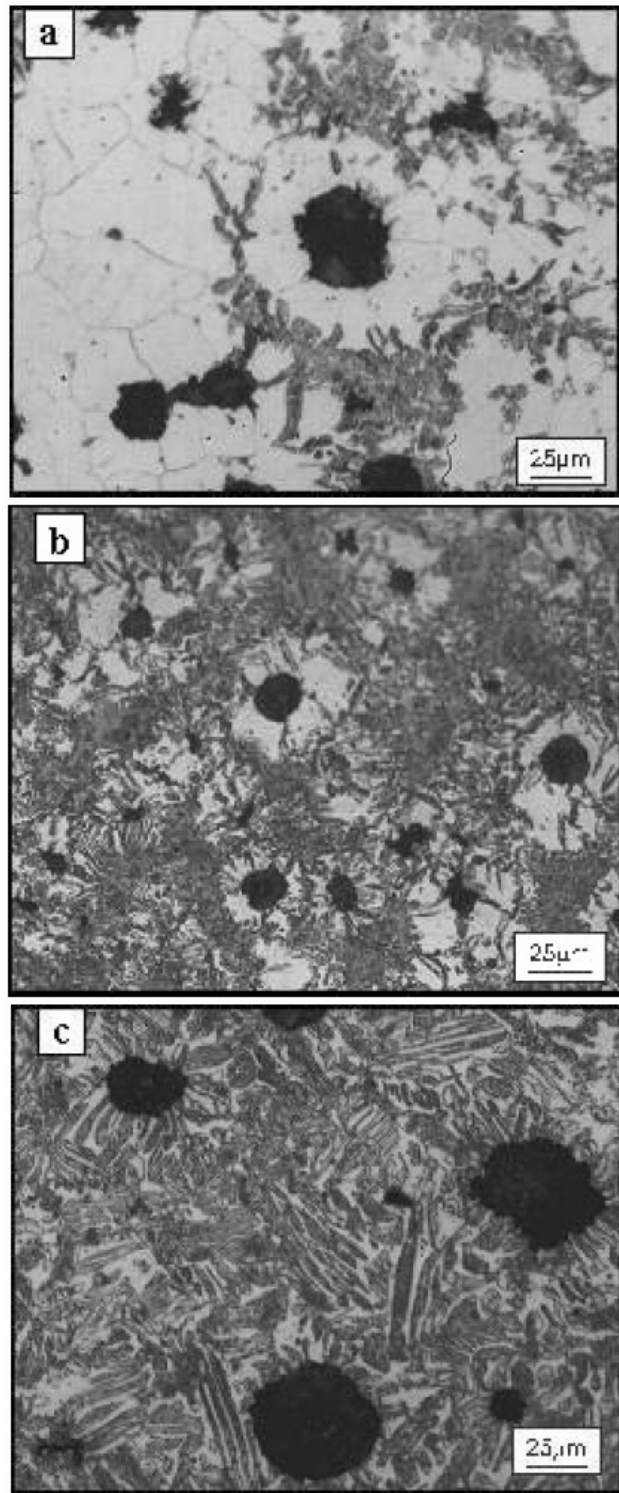


FIGURE 2. Microstructural changes of 3 mm thin wall in 0.5Ni-0.2Mo austempered ductile iron at 370°C as a function of intercritical heating a) 790°C, b) 820°C and c) 850°C.

820 and 850°C for 60 minutes followed by austempering at 370 or 315°C for 60 minutes and then water quenching. Impact testing was carried out in a Charpy machine of 325 J capacity and a minimal of three specimens were tested in each

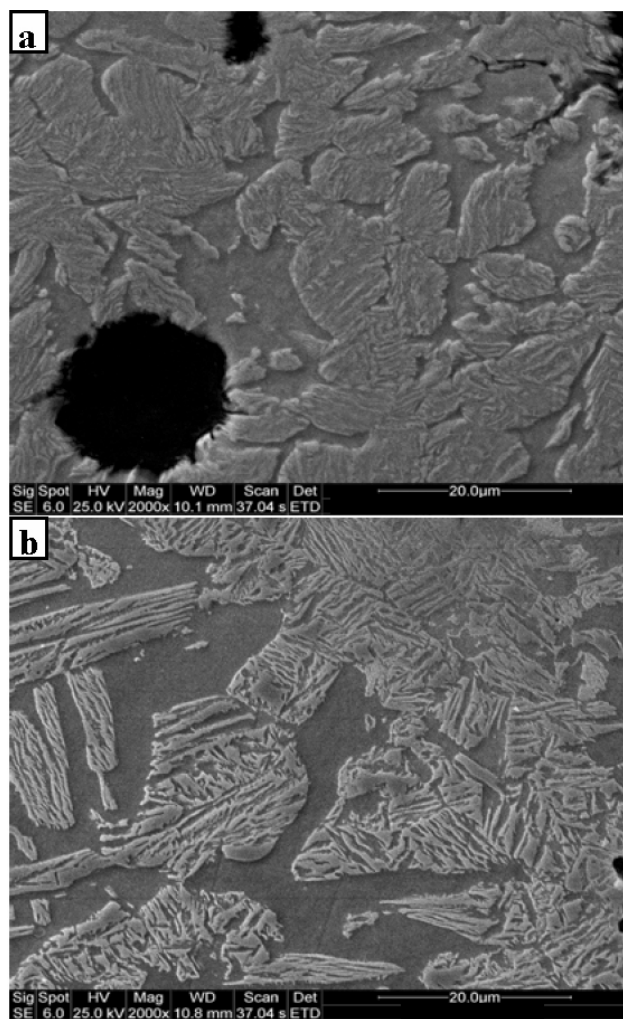


FIGURE 3. SEM micrographs of 0.5Ni-0.2Mo alloyed ductile iron of 3 mm thin plates, heating at 820°C and austempering at a) 315°C and b) 370°C.

heat treated condition. Image analysis was employed to quantitatively evaluate the microstructure using Image-Pro software in conjunction with optical microscope. Typical measurements included nodule count, graphite size and amount phases (graphite, ferrite and pearlite) in as-cast condition and volume fractions of pro-eutectoid ferrite ( $\alpha_p$ ) and ausferrite in heat treatment samples.

### 3. Results and discusión

#### 3.1. As-cast microstructure

In the as-cast condition, the samples showed a ferritic-pearlitic microstructure (known as bull eye type), where the pearlite content varies with the wall thickness. Fig. 1 shows the bull eye structure in alloyed ductile iron, it consists of graphite nodules surrounded by ferrite in a pearlitic matrix. In general, volume percent of pearlite decreases by increasing the thickness of the piece Table II. As it is shown on the table, the graphite content tends to decrease as the wall thickness

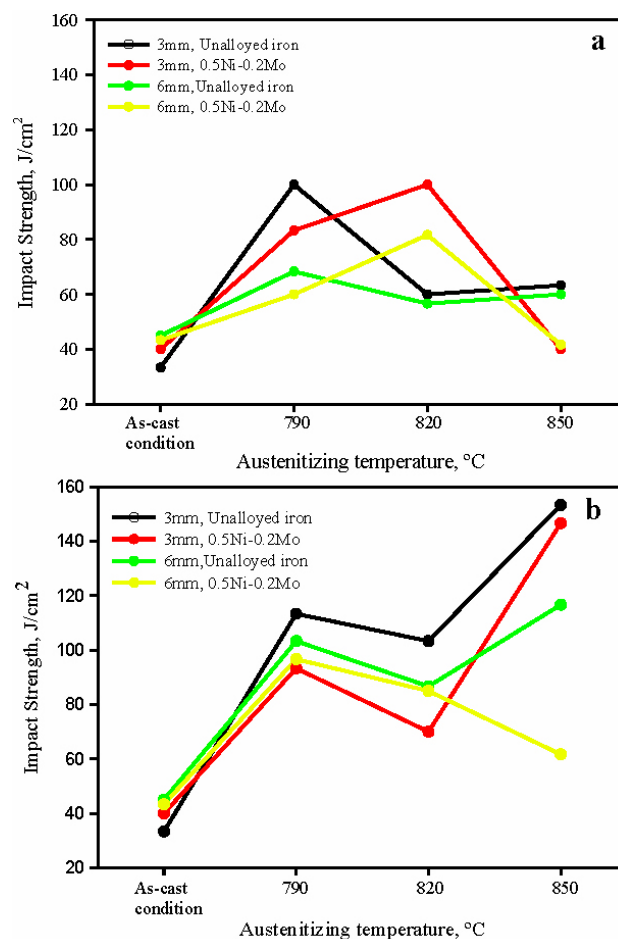


FIGURE 4. Impact strength of ductile irons as a function of austempering temperature a) 315°C and b) 370°C.

increases. Unalloyed and 0.5Ni-0.2Mo alloyed irons presented a percent of graphite volume between 9-13% and 12-19%, respectively; the latter associated with a greater amount of C and Si, which are elements that favor the formation of graphite. The graphite nodularity varied between 80 to 95%, literature [2,8,9] reports that this phenomenon is associated to the inoculation process efficiency. With respect to the account of nodules, it was observed a reduction on this parameter by increasing the wall thickness Table II. When the nodules account decrease, the volume percent of ferrite increases due to slower cooling rates above eutectoid temperature (723°C) in thick samples (6 mm).

#### 3.2. Heat treatment microstructure

Heating at austenitizing temperatures of 790, 820 and 850°C gave rise to an initial structure consisting of pro-eutectoid ferrite and high temperature austenite ( $\alpha_p + \gamma$ ), with various amounts of  $\alpha_p$  in each ductile iron Table III, which it depends on the heating temperature and chemical composition. During heating, the austenite phase nucleates and grows at the  $\alpha/Fe_3C$  interfaces of the pearlite structure. Apparently, the presence of higher amounts of pearlite in the ductile iron

TABLE II. As-cast microstructure of ductile iron as a function of thickness plate.

Cast iron	Thickness, mm	Pearlite, %	Ferrite, %	Graphite, %	Nodule count, Nod/mm <sup>2</sup>	Nodularity, %
	6	40	51	9	277	90(85)
0.5Ni-0.2Mo	3	65	24	11	358	95
	6	44	44	12	308	80

TABLE III. Microstructure of ductile iron as a function of heat treatment.

Cast iron	Intercritical , temperature °C	Thickness, mm	Austempering temperature at 315 °C		Austempering temperature at 370 °C	
			$\alpha_p$ , %	Ausferrite, %	$\alpha_p$ , %	Ausferrite, %
			Unalloyed	790		85
	820	3	15	85	18	82
	850		3	97	2	98
	790		67	33	70	30
	820	6	7	93	5	95
	850		3	97	2	98
0.5Ni-0.2Mo	790		66	34	61	39
	820	3	18	82	15	85
	850		1	99	4	96
	790		55	45	58	42
	820	6	5	95	4	96
	850		1	99	3	97

promotes that the amounts of austenite increases during heating and ferrite volume percent decreases, the same occurs when the austenitization temperature increases. During holding at isothermal temperatures of 375 or 315 °C, the high temperature austenite is decomposed in ausferrite. The ausferritic structure is a mixture of ferrite and high carbon austenite with an acicular morphology ( $\gamma = \alpha + \gamma_{hc}$ ). It can be appreciated that as the heating temperature increases, the volume percent of ausferrite increases gradually until the metallic matrix is totally ausferritic. It happens when a heating was achieved at 850 °C. The increase on the amount of ausferrite is associated to a decrease of volume percent of pro-eutectoid ferrite in the matrix Table III. It is important to notice that in all the cases where the  $\alpha_p$  is presented, ausferritic phase is localized fundamentally in the eutectic cell boundary until it completely occupied at high temperatures see Fig. 2. Austempering temperature affects the coarse morphology of the ausferritic structure see Fig. 3. At low temperatures of austempering (315 °C), the greater overcooling leads to an enhanced nucleation and highly refined ausferrite. On the other hand, when the transformation was carried out at temperatures of 370 °, the overcooling falls and the diffusivity of carbon increases which it helps to the growth of needles of

ferrite and high carbon austenite. It results in a coarse ausferrite structures.

#### 4. Impact strength

Figure 4 depicts the absorbed energy at room temperature for samples of 3 and 6 mm of thickness at different conditions of heat treatment. With the purpose to evaluate the effectiveness of the heat treatment, graphs in Fig. 4 included values of impact strength on the as-cast samples (each point represents an average of three tests). With exception on the Ni-Mo alloyed iron austempered at 370 °C, it is observed that the impact strength decreases as samples thickness increases from 3 to 6 mm. These results showed that the values of energy absorbed for different cross sections can not be comparable because these are different. For example, in 3 mm samples thickness, which have a cross section of 30 mm<sup>2</sup>, presented an average impact strength of 100 J/cm<sup>2</sup> (intercritical heating at 820 °C and austempered at 315 °C), while 6 mm thickness samples, with a 60 mm<sup>2</sup> area, had a average value of 80 J/cm<sup>2</sup> (intercritical heating at 820 °C and austempered at 315 °C). In addition, a higher austempering temperature (370 °C), the values of impact energy are 20 to 50% higher than those at

austempering temperatures of 315°C, due to the presence of greater amounts of high carbon austenite into ausferrite structure [10]. The variations in impact strength can be attributed to the type and volume percent of presents phases. Apparently, the best impact strength in ductile iron is due to with dual matrix structures.

## 5. Conclusions

In this work, the microstructures change and the impact strength in unalloyed and alloyed ductile irons were inves-

tigated as a function of thin wall and heat treatment conditions. in the as-cast condition was found that the increases of graphite nodule count and pearlite content are associated with the increased cooling rates (3 mm thickness).

Lower intercritical heating temperatures (790 and 820°C) produced dual matrix structures, composed of pro-eutectoid ferrite and ausferrite. The amounts of ausferrite were increased with the presence of alloyed elements (Ni-Mo) and thin wall increased. Also, it indicated that as the austempering temperature increases, the impact strength increases due to the coarse morphology of the ausferritic structure.

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