Design and Control of Cooling rate for improving The strength of Gray cast iron

การออกแบบและควบคุมอัตราการเย็นตัวเพื่อเพิ่มสมบัติความต้านทานแรงดึงของเหล็กหล่อเทา

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ABSTRACT

The quality of cast iron was enhanced by controlling the cooling rate of cast iron in the manufacturing process. We have designed the gray cast iron process by modifying the thickness of a sand mold to get the proper tensile stress of the cast iron with regular structure. The mold was a cylindrical shape and made of sand. The process of heat transfer of the materials was investigated. The heat transfer rate was considered as the radial thickness of the mold wall. Three gray cast irons with the mold wall thickness of 0.7, 1.5, and 2.8 inches were casted and tested for tensile strength. The results show that the specimen made of 1.5 inch radial mold thickness yields the highest tensile strength.

บทคัดย่อ

ในกระบวนการหล่อเหล็กหล่อเทาจะสามารถปรับคุณภาพของเหล็กหล่อโดยใช้วิธีการควบคุมอัตราการเย็นตัวของเหล็กหล่อ เราจึงได้ทำการออกแบบความหนาของแบบหล่อทรายในการหล่อเหล็กหล่อเทาเพื่อควบคุมอัตราการเย็นตัว ที่จะส่งผลให้ได้ความต้านทานแรงดึงที่ดีและมีโครงสร้างภายในของเหล็กที่สม่ำเสมอ มีโครงสร้างของแกรไฟต์ตามความต้องในการใช้งาน ซึ่งการควบคุมอัตราการเย็นตัวนั้น เราได้ศึกษาจากกระบวนการถ่ายโอนความร้อนของวัสดุและวัสดุที่ใช้ในการศึกษาเป็นรูปทรงกระบอก ซึ่งจะมีอัตราการถ่ายโอนความร้อนตามแนวรัศมีของความหนา งานวิจัยนี้จึงได้ออกแบบการหล่อเหล็กหล่อเทาที่ใช้ความหนาแบบหล่อทราย 3 ขนาดตามแนวรัศมี โดยมีรัศมี คือ 0.7 นิ้ว 1.5 นิ้ว และ 2.8 นิ้ว ใช้ทำการหล่อ ผลการทดสอบได้ว่า ค่าความต้านทานแรงดึงตัวอย่างที่หล่อด้วยแบบหล่อทรายผนังหนา 1.5 นิ้ว มีค่าความต้านทานแรงดึงที่ดี

Key Words: Cooling rate, Tensile strength, Gray cast iron

คำสำคัญ: อัตราการเย็นตัว ความต้านทานแรงดึง เหล็กหล่อเทา

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Introduction

Gray cast iron has become a popular cast metal material which is widely applied in modern industrial manufacture because of its good castability, wear resistance, machinability, low melting point, high damping capacity, and low cost. The microstructure of gray cast iron is characterized by graphite flakes dispersed into the matrix. Industrial castings practice can influence nucleation and growth of graphite flakes, so that type and size increase the desired properties.The amount of graphite and size, morphology and distribution of graphite lamellas are essential in determining the mechanical quality of gray cast iron (Colliniet *al.,* 2008; Davis *et al.,* 1985). Thus,it is important to control the flake graphite morphology that has a direct influence on the properties of gray cast iron (Pluphrach, 2010). The structure of gray cast iron depends on chemical composition, inoculants and physical properties. Some researchers have studied the unidirectional solidification process to improve the mechanical properties of gray cast iron. For example, Ceccarelli*et al.* (2004) andGiacchi*et al.* (2007)have modified the morphology of graphite flakes by inoculating the iron melt to improve the fracture toughness or impact toughness and applying austempering heat treatments to improve the fracture toughness or impact toughness of monolithic gray cast iron.

High cooling rates in producing fine structures results in increase of high-strength cast alloys. The undercooling of a melt to a lower temperature increases the number of effective nuclei relative to the growth rate and the final being restricted by the rate at which the latent heat of crystallization can be dissipated (Aver, 1987; Kakani*et al.,* 2004). The refining influence of an enhanced cooling rate applies to grain size and to substructure.

This work presents the effect of the design of the cooling rate control on the tensile strength, morphology, and microstructure of the specimens extracted from industrial castings made of gray cast iron and produced by different wall thickness of the sand molds. The cooling rate was used to control the flake graphite morphology. Then, the mechanical properties of the gray cast iron were tested.

Experimental

Materials and casting procedure

The specimens of gray cast iron were casted bymolds 0.7, 1.5, and 2.8 inch wall thickness to obtain different cooling rates. The specimens with the composition (mass percent) of: C 3.141%, Si 2.657%, Mn 0.366%, P 0.079% and S 0.057%. The melting point of 1350-1400 °C. The molds were designed in cylindrical shape and made of river sand. K-type thermocouples were mounted in the middle of mold to measure real cooling rate temperatures. After the melted cast iron was poured into the molds, the cast iron samples were cooled to room temperature. The temperatures of thermocouples were collected as a function of time.

Mechanical properties

1. The specimens of tension tests were carried out according to ASTM E8-04 standard as shown in Fig 1.

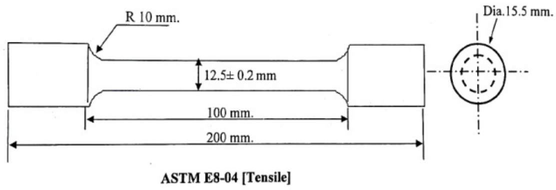

Fig 1 Dimensionsof the tension test specimen.

The engineering stress on the bar is equal to the average uniaxial tensile force on the bar divided by the original cross-section area of bar.

$$\sigma = \frac{F}{A}$$

where σ is Engineering stress (MPa).

F is Average uniaxial tensile force (N).

A is Original cross-sectional (m^2).

2. Elongation is inversely proportional to tensile strength and hardness. The amount of elongation is expressed as a percentage of the original gauge length. given by

$$\text{Percentage elongation} = \frac{L - L_o}{L_o} \times 100$$

where L is Final gauge length.

L_0 is Original gauge length.

3. The Rockwell test is used to determine the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload.

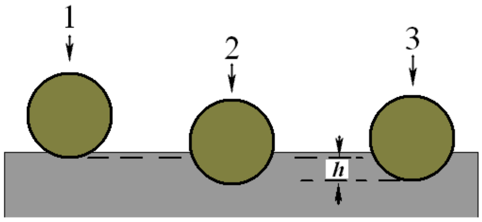

Fig 2 The steps in measurement of hardness with a sphere of steel.

$$\text{Rockwell B number} = \frac{130 \text{ depth of indentation}}{0.002}.$$

Heat transfer

Conduction heat transfer is the normal transfer of energy within solids. Conduction heat transfer also occurs through gases and liquids, but it then only predominates if the gases or liquids are stagnant or move slowly.The mathematical model forconduction heat transfer is Fourier's Law of conduction,

$$\dot{Q}_x = -\kappa A \frac{\partial T}{\partial x}$$

Where Q_x is the heat transfer in the x direction of area A due to the temperature gradient $\partial T/\partial x$. The thermal conductivity κ is an index of ability of a material to conduct heat due to a temperaturegradient in that material (Rolle, 2000).

Metallographic examination

The specimens of metallographic were prepared to examine the flake morphology and matrix microstructure of the composites. The surfaces of the metallographic specimens are prepared by methods of polishing and etching. After preparation, the distribution of graphite flakes was examined under an optical microscope at a magnification of 100×.

Results andDiscussion

Tensile test results

Tensile tests were performed on the gray cast iron specimens. Table 1 shows the tensile test results of three specimens made of of 0.7, 1.5, and 2.8 inch mold wall thickness. As shown in Table 1, the results revealed that the tensile properties of the gray cast iron improved due to low cooling rates. The maximum of tensile strength, hardness and percentage elongation are 255.06 MPa, 210 Brinell and 0.82% with 1.5 inches mold wall thickness. The heat transfer of specimens casted with 0.7 inches mold wall thickness is 501.66 watts greater than that of 1.5 and 2.8 inch mold wall thickness.

The plots of the cooling rate curves as a function of time are shown in Fig.3. The constant oftemperature ranges are 668 °C, 680 °C, and 719 °Cfor 1.5, 0.7 and 2.8inch mold wall thickness, respectively.

Table 1 mechanical testing.

Size (inch)	Tensile strength(MPa)	Elongation At break (%)	HB (Brinell)	$\dot{Q}_x$ (W)
0.7	243.92	0.71	210	501.66
1.5	255.06	0.82	210	476.57
2.8	253.31	0.80	205	453.65

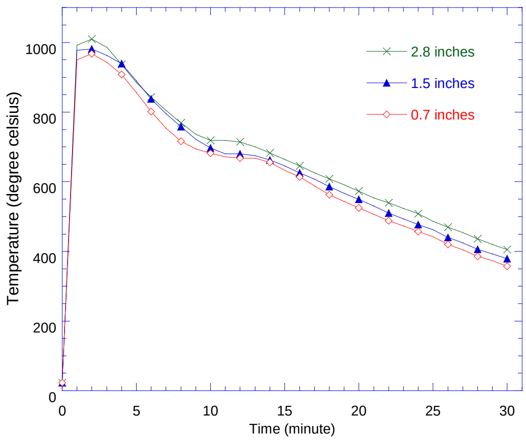

Fig 3 The plots of the cooling rate curves of the different mold wall thickness obtained from thermocouples.

Microstructure

The graphite flakes of the specimens were observed using an optical microscope after polishing and etching as shown in Fig.4 (A, B, C). The large graphite flakes seriously interrupt the continuity of the pearlitic matrix, thus reducing the strength and ductility of the gray iron. The small graphite flakes are less damaging and therefore generally preferred. Flake graphite is subdivided into five types (patterns), which are designated by the letters A through E. Type A graphite is shown Fig.4 (A, B, C). The orientation distribution of Type A graphite is random. It is the commonly preferred type of graphite giving optimum strength properties.

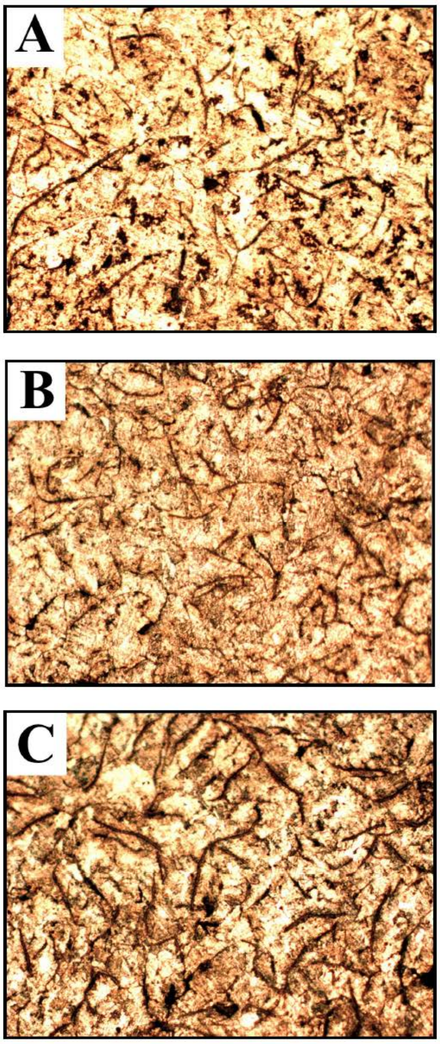

Fig 4 Microstructure of solidified gray cast iron from the different mold wall thickness (A) 0.7 inch (B) 1.5 inch and (C) 2.8 inch.

SEM observation

Figs. 5, 6 and 7 show the tensile fracture surfaces of the gray cast iron specimens. Fig. 5 (b) shows the fracture surface of the gray cast iron similar to flowers. The dendrite in metallurgy is a characteristic tree-like structure of crystals growing as molten metal freezes, as shown in Fig. 5 (A) produced by fast growth along energetically favorable crystallographic directions. This dendrite growth has large consequences in regards to material properties.

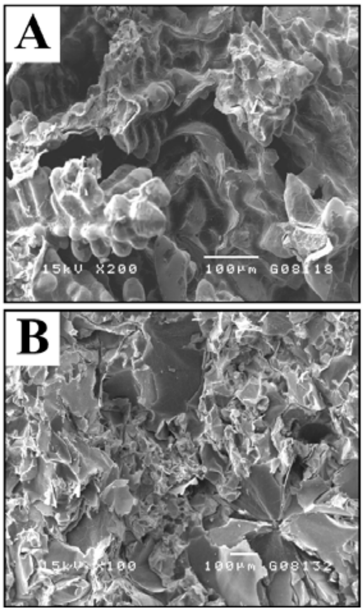

Fig 5 Tensile fracture surfaces of the mold wall thickness of 0.7 inche.

The main part of the fracture surface is the boundary between the graphite and metal matrix. Fig 6 and 7 show the fracture surface of graphite. The total elongation of the gray cast iron is about 0.71-0.80 %. The low value of total elongation yields a result in low tensile strength that causes low ductility and brittle.

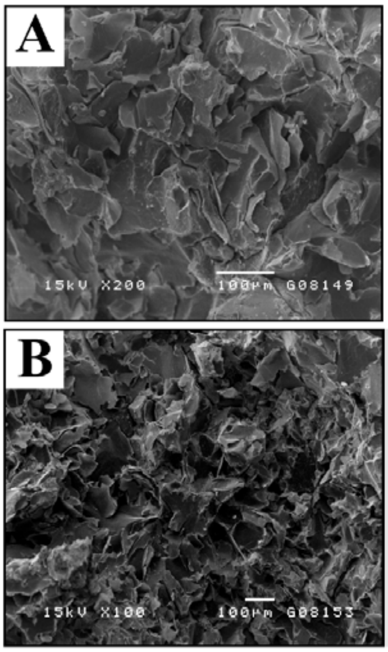

Fig 6 Tensile fracture surfaces of the mold wall thickness of 1.5 inche.

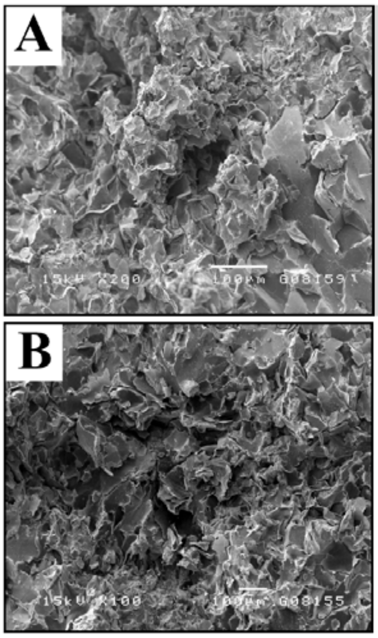

Fig 7 Tensile fracture surfaces of the mold wall thickness of 2.8 inche.

Conclusions

The evaluation of the gray cast iron with different cooling conditions (the mold wall thickness of 0.7, 1.5, and 2.8 inch) shows that the cooling rate has an effect on the tensile properties, microstructure and hardness brinell (HB). The results of this work indicate that the tensile properties and hardness of the gray cast iron to increase when use the mold wall thickness of 1.5 inches were casted. The tensile fracture of the specimens made of the mold wall thickness of 0.7 inches has dendrite structure produced by fast cooling rate. Thedendrite structure that will result in the tensile strength decreased.

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