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STUDY ON EFFECT OF INCLINED PLATE ANGLE AND MATERIAL ON MORPHOLOGY OF GRAPHITE FLAKES IN GRAY IRON

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STUDY ON EFFECT OF INCLINED PLATE ANGLE AND MATERIAL ON MORPHOLOGY OF GRAPHITE FLAKES IN GRAY IRON

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Abstract

Among the various methods that use to produce semisolid feedstock materials, casting by inclined plate is one of the most effective and low cost that requires little equipments. Length, angle and material are main parameters that affect final microstructure of pieces casted by inclined plate. In this study, in specific length and at different angles (10°, 20°, 30° and 40°) the effect of changes in slope material on characteristic of flake graphite was investigated. A large number samples were prepared under different conditions and microstructure analysis by SEM microscope were perfomed on samples and for closer study images were evaluated by Clemex and MIP image analysis software. Results shown the angle at which can achieve optimize microstructure changes with variation in slope material, that this angle for graphite and steel plate is 30° and 20°, respectively. Use of inclined plate in casting reduces length and thickness of flake graphite. Also for specimens casted at 30° on graphite plate, radius of tip curvature for flake graphites is larger than specimens casted at 20° on steel plate and without inclined plate that reduces stress concentration on tip of flakes.

Keywords: grey iron, inclined plate, flake graphite, optimum angle, radius of tip curvature.

Introduction

Compared to conventional casting processes, semi-solid casting process has many advantages such as reduction of solidificatio shrinkage, lower processing temperature, improved mechanical properties and et cetera [1]. A number of slurry preparation methods have been developed, among which the controlled nucleation method has received a lot of attention [2]. According to this theory, several practical techniques have been developed, including the inclined cooling plate [3-5], rotating duct [6] and cooling chute process [7]. Inclined cooling plate method is simple for preparing the semisolid alloy, and can be easily applied in industry. The basic principle involves pouring of molten alloy upon inclined plate or channel where crystals are nucleated and subsequent casting into a mold placed at the end of the slope [8]. Grey cast iron is one of the most widely used metallic materials for engineering construction. The reason for this is that grey iron possesses a very attractive combination of properties. It is a low cost material. It has outstanding casting characteristics and it possesses a unique combination of damping capacity and wear resistance [9]. These beneficial features are counteracted by one major disadvantage. Grey iron is extremely brittle. For this reason engineers often restrict its usage to situations of low operating stress where advantage can be taken of its dimensional stability [9]. Physical and mechanical properties of gray cast iron largely influence by the shape, size, amount and distribution of graphite flakes, and for a fixed amount of graphite, mechanical properties of grey iron are a function of the shape and distribution of flakes. Not only the shape of graphite, but graphite flake size is also important because it is directly associated with strength [10].

In this study effect of inclined cooling plate on shape, distribution and radius of tip curvature graphite flakes in grey cast iron was investigated.

Experimental procedure

In this experiment hypereutectic gray cast iron ingots with 4.53 wt.% carbon equivalent used as charge material, that chemical composition is expressed in table 1. In this study, wedge shaped pieces with a 4.08 cm^2 cross section and 10 cm height, that its schematic picture is shown in figure 1, had been embedded in the mold made of silica sand of 65 AFS gfn and sodium silicate adhesive that strengthened by CO_2 injection. About 10 Kg gray cast iron ingots with specific composition was melted inside induction furnace until 1450 °C. After withdrawal the melt from the furnace about 0.2 wt.% Fe-75%Si was added to melt as inoculants. At 1300 °C, melt charge was poured on cooling plate that inclined at the known angle to the horizon, and at the end of cooling plate flowed into the mold cavity. This experiment was done at 10°, 20°, 30° and 40° angles and tow different materials of inclined plate that including plain carbon steel and graphite material.

Table 1. Chemical composition of gray cast iron samples (wt.%)

Chemical composition	Fe	C	Si	Mn	P	S	Cr	Ni	Mo	Al
Weight percent	92.3	3.55	2.93	0.459	0.024	0.096	0.139	0.030	0.021	0.006

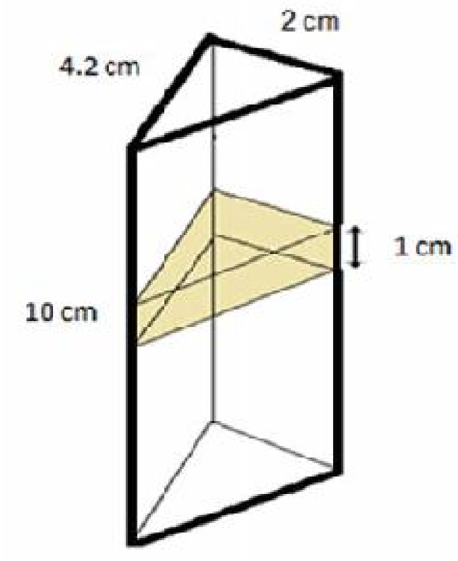

Figure 1. Schematic picture of wedge piece.

Samples were coded with the G10, G20, G30, G40 and S10, S20, S30, S40 that G and S represent graphite and steel inclined plate, respectively. Schematic picture of the casting process is shown in figure 1. Graphite plate that used has 45 cm, 5 cm and 1 cm length, width and thickness, respectively. Also in order to compare changes in the microstructure casted by cooling slope with conventional casting, samples were casted without cooling slope that these represent with W.

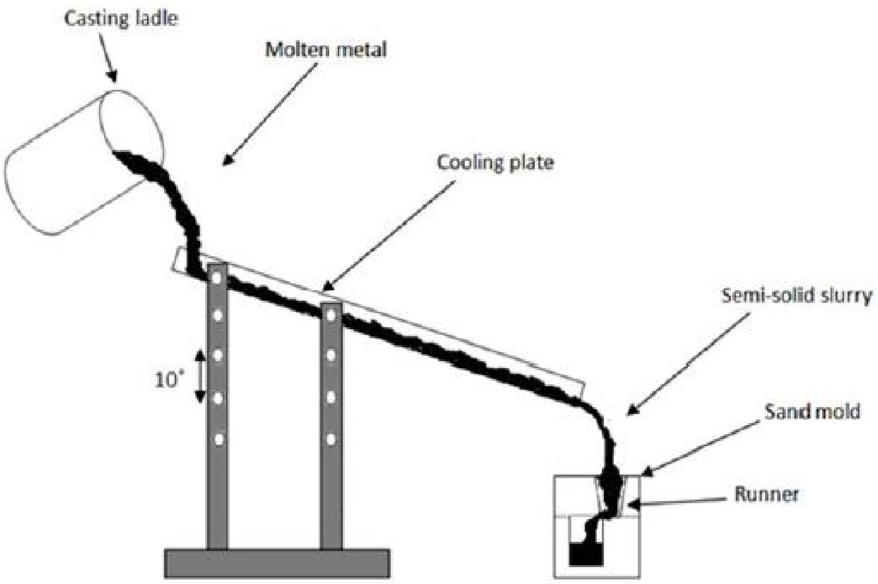

Figure 2. Schematic picture of casting process by inclined plate.

Triangle grey iron samples with 1 cm thickness were cut from surface cross section of wedge pieces at 4.5 Cm distance of pouring base, and then roughly and finely ground, polished and etched with 2% Nital. The specimens were investigated by scanning electron microscope (SEM). To measuring length and thickness of graphite flakes, the SEM images were analyzed by Clemex software.

At 10000x magnification SEM images of samples were prepared in order to provide a criterion for measuring the curvature radius of graphite flakes tip. By MIP image analysis software the coordinates of separate three points on tip of graphite flakes specified and a circle was drawn. In every sample the circle radius was measured for 50 flakes and their average was introduced as a criterion for the radius of graphite tip curvature.

Results and discussion

1. Study on length of graphite flakes

Microscopic image of the sample cast without using inclined plate is shown in figure 3. Two types of graphite flakes, C and D can be seen in the picture. Kish graphite (type C) shown in the image in form of thick flake while type D was in form of fine graphite flakes with random orientation which grown among a dendritic network. These two distributions of graphite in the microstructure lead to heterogeneity and attenuation the mechanical properties of cast iron.

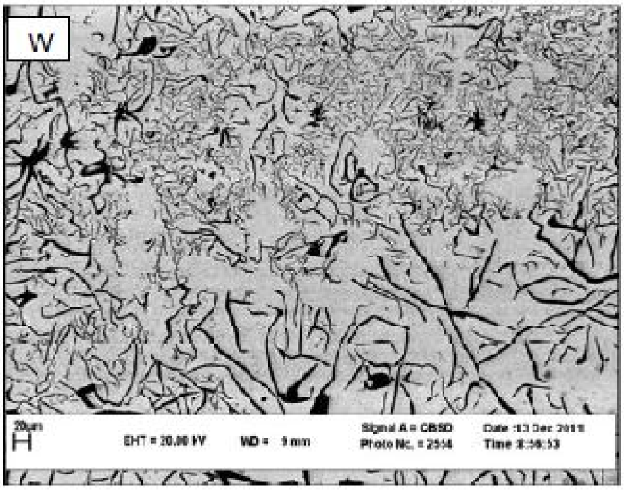

Figure 3. SEM image of sample that casted without using inclined plate (W sample).

SEM image of samples that casted by graphitic and steel inclined plate at different angle is shown in figure 4 and figure 5, respectively. In figure 4: G10, G20 and G40 samples have flake graphite with C distribution while G30 sample has A distribution. In figure 5: flakes in S10, S30 and S40 samples have C distribution and S20 has A distribution. In samples with A type distribution and random orientation average length and width (figure 6) of graphite flakes compared to kish graphite flake(graphite type C) is less and gray iron with such distribution of graphite flakes has a higher tensile strength. According to the results obtained by researchers [10] whatever the length of graphite flakes is less the tensile strength is more. Thus the best conditions in terms of type, distribution and size of graphite flake in the structure of gray cast iron obtained at 30° and 20° angle by graphitic and steel inclined plate, respectively.

Due to carbon equivalent of gray cast iron that used, the primary graphite was kish type that continued to grow as long as they were surrounded by molten alloy. But due to the severe temperature drop of molten in contact with the ramp and the applied shear stress, the molten alloy around the initial graphite flake was rapidly dispersed and eutectic composition replaced, that this eutectic composition decomposed to eutectic graphite and pearlite. Shear stress that was applied during the melt flow on the inclined plate had great influence on nucleation and form of graphite flakes. Considering that length was fixed in this experiment, shear stress and duration of contact with the surface of the melt were two determinant parameters [11]. With increasing angle to the horizon, the amount of shear stress increased gradually which was reduced the size of graphite flake and the melt around it, as a result it prevented from further growth which ultimately led to the formation of normal graphite flake at the optimum angle. In other hand, increasing inclined plate angle more than optimum angle led to reduction in effective duration of shear. Since the duration of shearing parameter due to increasing melt velocity was overcame on effective shear stress, reduction of melt temperature was lower and more melt remained around graphite flakes that this increased possibility of graphite flakes growth. Due to difference in surface heat transfer coefficient the optimum angle of slope was different for the two types. Assuming that heat transfer was occured only through conduction from the surface of inclined plate and considering the equation of heat transfer through conduction (equation 1) that provided by Fourier, the coefficient of thermal conductivity (K) for graphite(119-165 w/(m·k)) is about 2 times in compared with mild steel (45-65 w/(m·k)) [12]. So more time was need for conduction the same heat by steel plate. That it was possible by reducing the inclined angle to the horizon.

$$q = -KA\frac{\partial T}{\partial x} \quad (1)$$

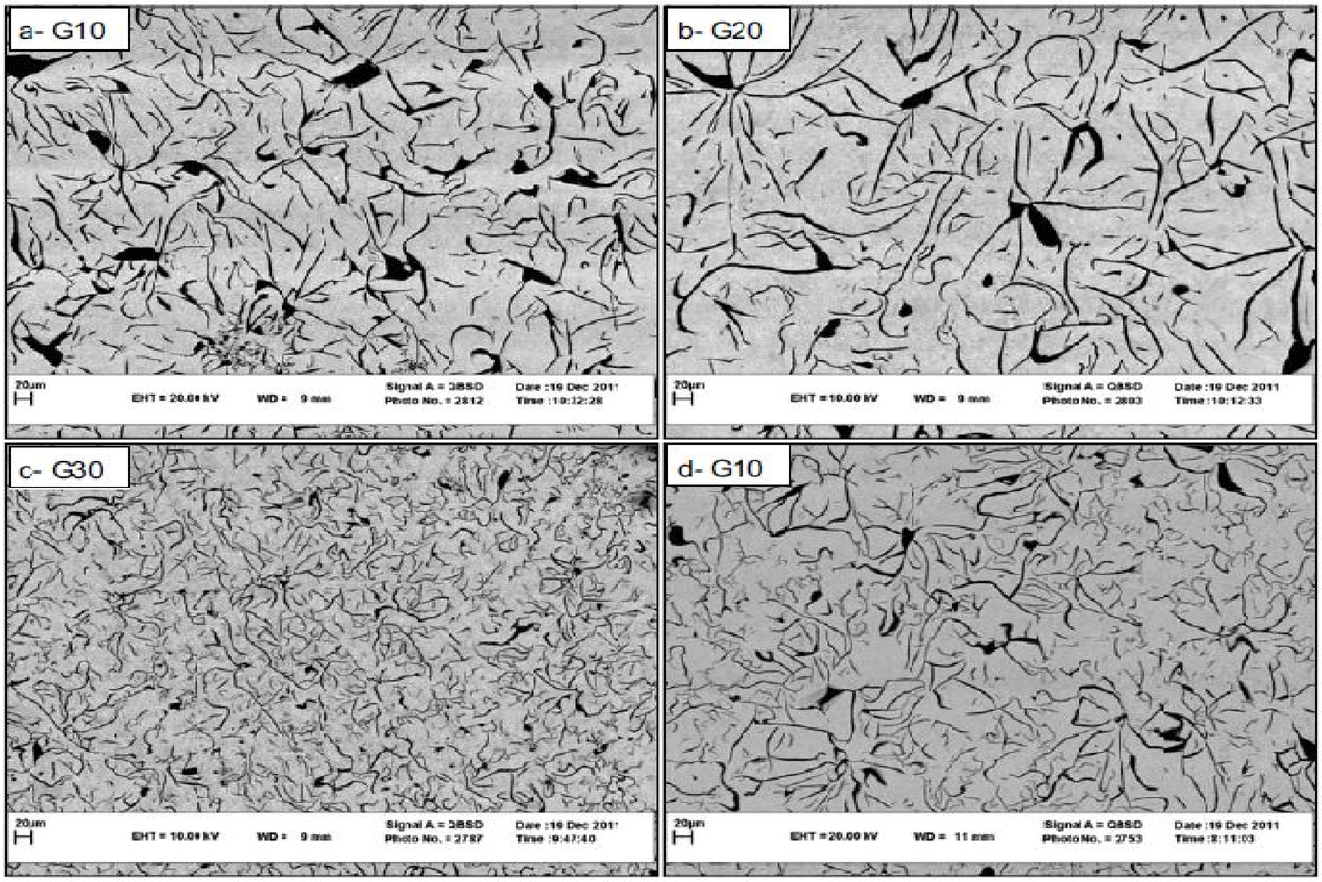

Figure 4. SEM image of samples that cast by graphitic inclined plate at: a- 10° (G10), b- 20° (G20), c- 30° (G30) and d- 40° (G40) angle.

2. Study on tip curvature of graphite flakes

With change of slope plate material the optimum angle with the best distribution was varied that the optimum angle for the inclined plate of graphite and steel was 30 and 20 degrees, respectively. According to these results, SEM images of the microstructure of samples that were casted under optimal conditions prepared and the effect of casting conditions on the shape and radius of graphite flake tip curvature was studied.

As can be seen in figure 7, maximum radius of graphite flake tip curvature is relating to samples that casted at angle 30° on graphitic inclined plate. In sample that casted at 20° on steel inclined plate graphite flake was sharper and tip curvature radius was slightly less. But in sample casted without inclined plate graphite flakes quite had a sharp tip. The average radius of graphite flake tip curvature was calculated for each sample that results have reported in figure 8.

Because of shear stress that applied to the graphite flakes and increasing in cooling rate, the radius of graphite tip curvature increased that the greatest effect was observed in G30 sample. In collision with the surface, tip of primary graphite that formed in the melt like dendrites was broke and caused to decreasing in sharpness of graphite flakes tip; that use of gray cast iron with this graphite form is desirable in tensile

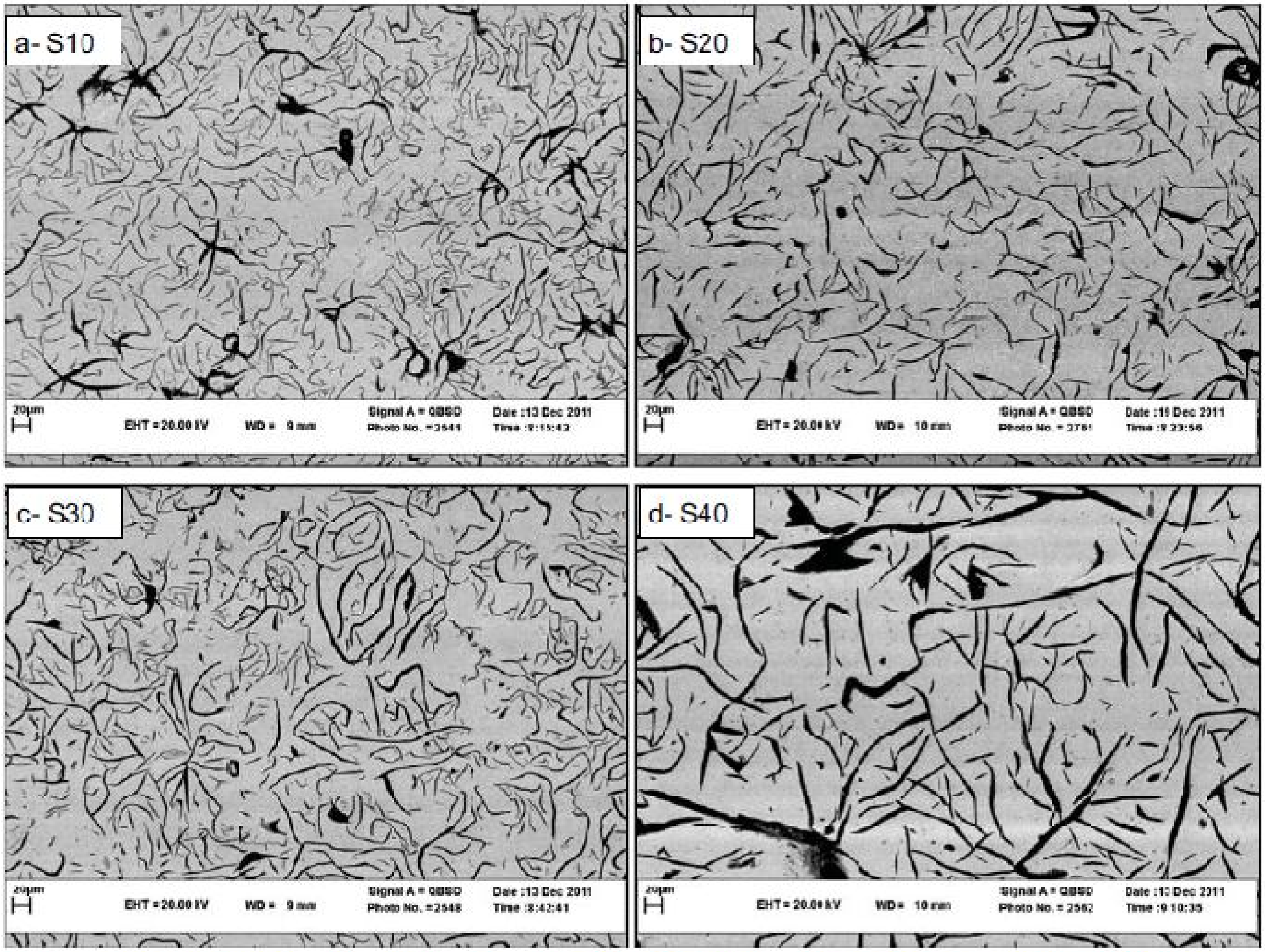

Figure 5. SEM image of samples that cast by steel inclined plate at: a- 10° (S10), b- 20° (S20), c- 30° (S30) and d- 40° (S40) angle.

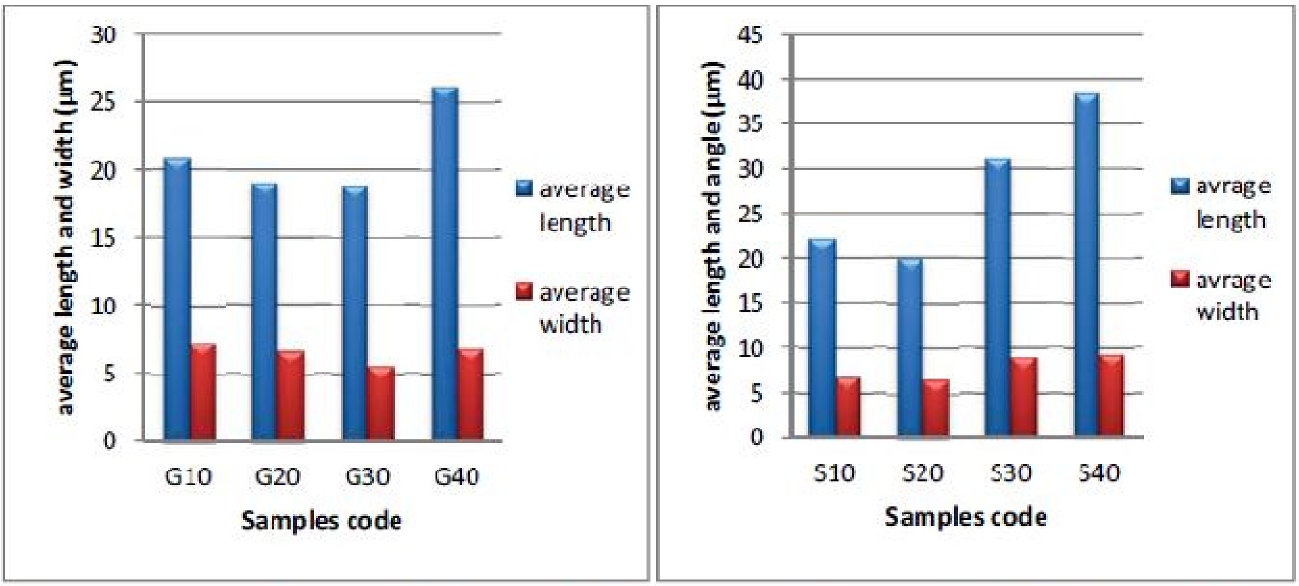

Figure 6. average length and width of graphite flake in sample casted by graphitic and steel inclined plate at different angle.

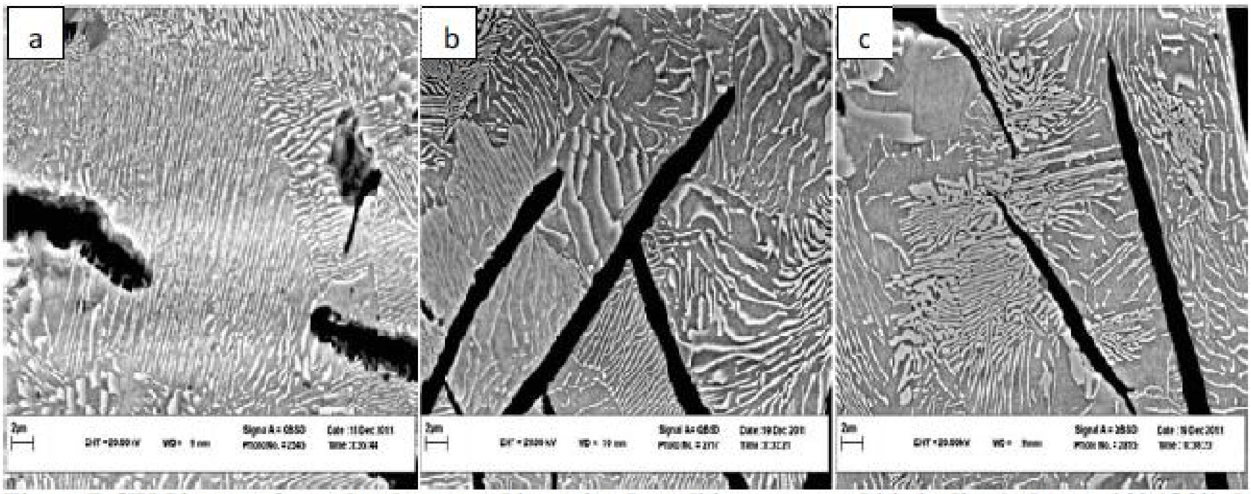

Figure 7. SEM image of samples that casted in optimal conditions: a- graphitic inclined plate at 30° (G30), b- steel inclined plate at 20° (S20) and c- without inclined plate (W).

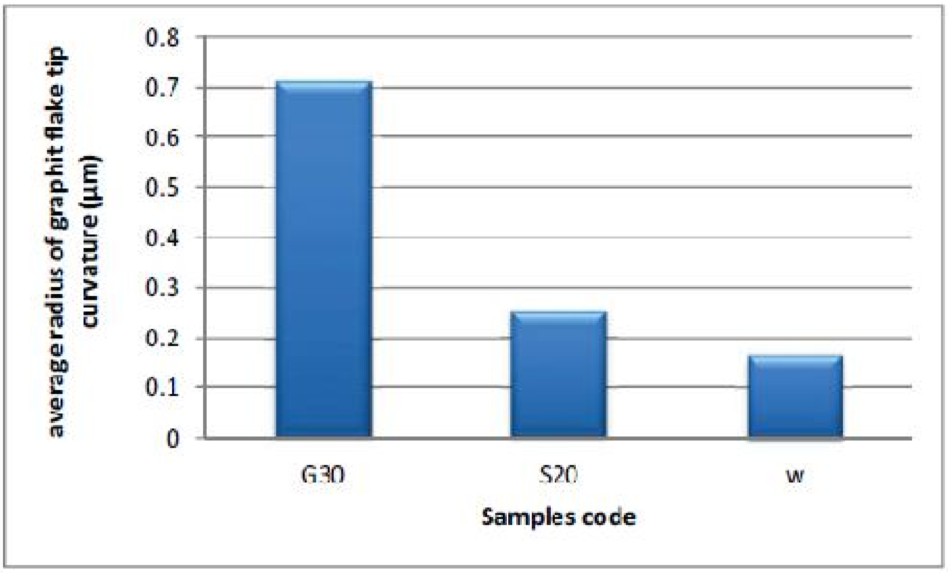

Figure 8. Average radius of graphite flake tip curvature.

loading. When a grey iron is subject to a tensile stress, damage commences very early in graphite flakes which are oriented normal to the direction of tensile stress. Once the micro-cracks initiate, their tips become sites of intense stress concentration and as a result local regions of plastic deformation develop in the adjacent matrix. Until finally the local plastic zones become enlarge and adjacent flakes link by a zone of plastically deformed matrix. With further loading the plastic strain in the ligaments increases until eventually the matrix separates [9]. Whit observation of failure mode it is clear that the fracture toughness will increase as decreasing stress concentration on graphite flakes or in other words reducing the size of graphites.

Conclusion

1. The optimum angle of inclined plate varies with changes in slope plate material.

2. Minimum average of length and thickness with A distribution of flake graphite flakes is relating to the G30 and S20 samples.
3. Graphite flakes in microstructure of G30 (with a curvature radius 0.71 μm) compared with S20 (with a curvature radius 0.25 μm) and W sample (with a curvature radius 0.16 μm) possess a large curvature radius or more rounded tip.

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