Morphology and Phase Transformation in Rapidly Cooled Hypoeutectic Commercial Grey Iron

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Abstract – **The role of cast iron in metallurgical industry worldwide is highly significant and despite decades of intensive research, the evolving solidification microstructure of this very important engineering material is ever revealing. Hence, this study shows how rapidly solidified Fe–C hypoeutectic commercial alloy can produce different morphologies and even phases at constant elemental composition. The research showcases powder droplets of different sizes ranging between 53 µm to 850 µm corresponding to cooling rate of 500 Ks^{-1} to 75,000 Ks^{-1} produced using state-of-the-art drop-tube technique. The microstructural analysis of the as-cast and the various rapidly cooled droplets was carried out using optical metallography, x-ray diffraction analysis and scanning electron microscopy; which reveals how cooling rate eventually influences the phase formation and emerging microstructures of the alloy from initial Graphite–Ferrite to Cementite–Martensitic phases in the as-cast and droplets respectively. Hence, the summary of the result shows that at constant elemental composition, cooling rate has significant effect on the structure and the eventual mechanical property (microhardness) of these versatile engineering materials as hardness increase with cooling due to increasing martensitic formation.**

Index Terms – **Microstructure, Rapid Solidification, Grey iron, Phase formation and Microhardness**

I. INTRODUCTION

Traditionally, grey cast iron was chosen for its flexibility, good castability, low-cost (20–40 % less than steel) and wide range of achievable mechanical properties through its readily adjustable microstructure from several industrial applications [1]-[2]. The blue print of any metallic alloy at any stage is its evolved morphology after undergoing a process which definitely affects its microstructure and mechanical property. Basically, the as-cast structure of grey cast iron rely on its chemical composition prior to the casting process, the type and quantity of inoculants used and the cooling conditions employed [3]. So normally, the microstructure of common low alloy grey cast iron such as BS1425 grade 250 provided by British Steel is usually characterized by network of graphite lamellas dispersed into the ferrite matrix which makes the material brittle. However, foundry practice or metallurgical processes often affect nucleation and development of graphite with discrete flakes resulting in evolving phases and modified microstructure of the same material for better performance. So more often, the size and kind of graphite flakes, usually enhances the intended properties. Indeed, the size, morphology and graphite lamellas distribution in cast iron are significant in obtaining its mechanical behaviour [4]–[7]. Generally for grey iron, the initial or as-cast microstructure is governed by the solidification process that produces it and the solid state transformation (eutectoid reaction) it has experienced. Hence, conditions under which the eutectoid reaction occurs is been depended upon by normal matrix microstructure. Chemical composition and the cooling rate are among the variables that influence the mechanism of the eutectoid reaction through its temperature range. The outcome of eutectoid is vital in determining the mechanical properties of grey iron for any further metallurgical process of this alloy hence a need for further investigation. Thus, the impact of alloying elements on mechanical properties of Fe-C may probably be similar to the influence on eutectoid changes [8]. Basically, microstructural characteristics provides insight to certain property of grey cast iron generally, however the impact of rapid cooling on its phase transformation, evolved morphology and microhardness have not been put on the research spot light. Therefore, due to the mixture of its microstructure , formation of multiple micro-cracks at the graphite-ferrite lamellas tips such that even at low tensile stresses; the complex behaviour of grey iron with respect to notch sensitivity and in both tensile and fatigue testing not well understood makes grey cast iron exhibits a random mechanical performance [9]-[11]. So, the primary objective of the study is to evaluate the variability of the various samples morphology including the as-cast and relating the microstructure and mechanical property interdependence [12].

II. METHODOLOGY

Commercial grey cast iron which was the material used for this study is the most popular casting materials worldwide having millions of the world's production tonnage. The starting material was a low grade alloyed commercial grey cast iron that has been solidified with detailed description of BS 1452 Grade 250, been delivered to be recurring 25 mm x 60 mm round solid bar by British Steel, West Yorkshire, United Kingdom. Elemental composition of the alloy comprises of 2.7% C; 2.83% Si; 0.58% Mn; 0.15% P;

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0.05% S; and 93.34% Fe. In the Institute for Materials Research at university of Leeds United Kingdom, a 6.5m high drop-tube facility was used to obtain droplet samples sieved into 9 dissimilar groups from ≥ 850 μm to ≤ 53 μm sizes with as-cast sample for practical study of its physical structure and component under microscopic test and analysis. Light optical microscope and scanning electron microscopy were utilized for the morphological analysis of the samples. While microhardness test and analysis was carried out in other laboratory of the contributing authors. The experimental sample were in droplets form obtained from fragments of the sample been received weighing ~20 g which was feed into the State-of-the-art drop tube apparatus. The chopped pieces were placed into crucible made of alumina with 3 concentric laser drilled ejection openings at the bottom level (approximately 300 μm diameter). This sample container holder is immediately safeguarded by hollow graphite having ability to absorb electromagnetic energy for efficient induction heating and heat retention. Hence, the whole sample carrier is then subjected to vacuum and under this tight pressure; it is then heated up at the topmost of the equipment. An R-type thermocouple placed in the crucible but not allow to touch the content is used to monitor the alloy temperature within the crucible. Once the alloy melts, it via the thermocouple reading; it is then forced-out by applying 300 kPa of Helium gas to the crucible. The melts travels downward under free fall and the applied pressure melt cool quickly into droplets as it moves towards tube base [13]-[14]. Thereafter, the droplets close to sphere-shaped formed are gathered, sieved and separated into 8 dissimilar size ranges of sample starting from the maximum (850 μm) to the minimum (53 μm) sizes. To characterise the droplets, each group size was mounted on transcoptic powder resin using hot press metallurgical sample preparation machine. The mounted samples were then prepared for morphological observation by grounding, polishing, etching, drying and subject to microscopy to reveal the droplets microstructure. While grounding, enough pressure must be applied to revealed the interior hemisphere of the droplets by using appropriate grade of grinding (Silicon carbide) paper and polishing(diamond) paste and after thorough sample preparation, the various sample sizes were subjected to other non-destructive test such as XRD analysis (Panalytical Machine), SEM characterization (Evo 60) and microhardness indentation measurement using a TUKONTM 1202 Wilson Hardness (Vickers) analyser at room temperature with an average of 10 reading per sample using HV0.05 as indentation load. Meanwhile, Figure 3 shows the illustration between the estimated rate of cooling and the droplet diameters been produced for each particle sizes.

III. RESULTS AND DISCUSSION

The optical and SEM micrographs of the as-cast and the particles sizes been solidified are as presented in this section after thorough morphological examination. The elemental composition analysis of the alloy is as outlined in the table below showing the grey iron to be hypoeutectic with carbon equivalent (CE) of 3.40. Figure 1 reveals the optical morphology difference between the start materials (as-received) [9] as compared to those of the rapidly cooled droplets of this commercial grey iron alloy [15]-[16]. The droplets micrographs reveals absence of graphite in any of the rapidly cooled samples morphologies, meaning better microhardness (Fig. 3) in the containerless cooled droplets Fig. 1 (a) & (b) and (c) & (d).

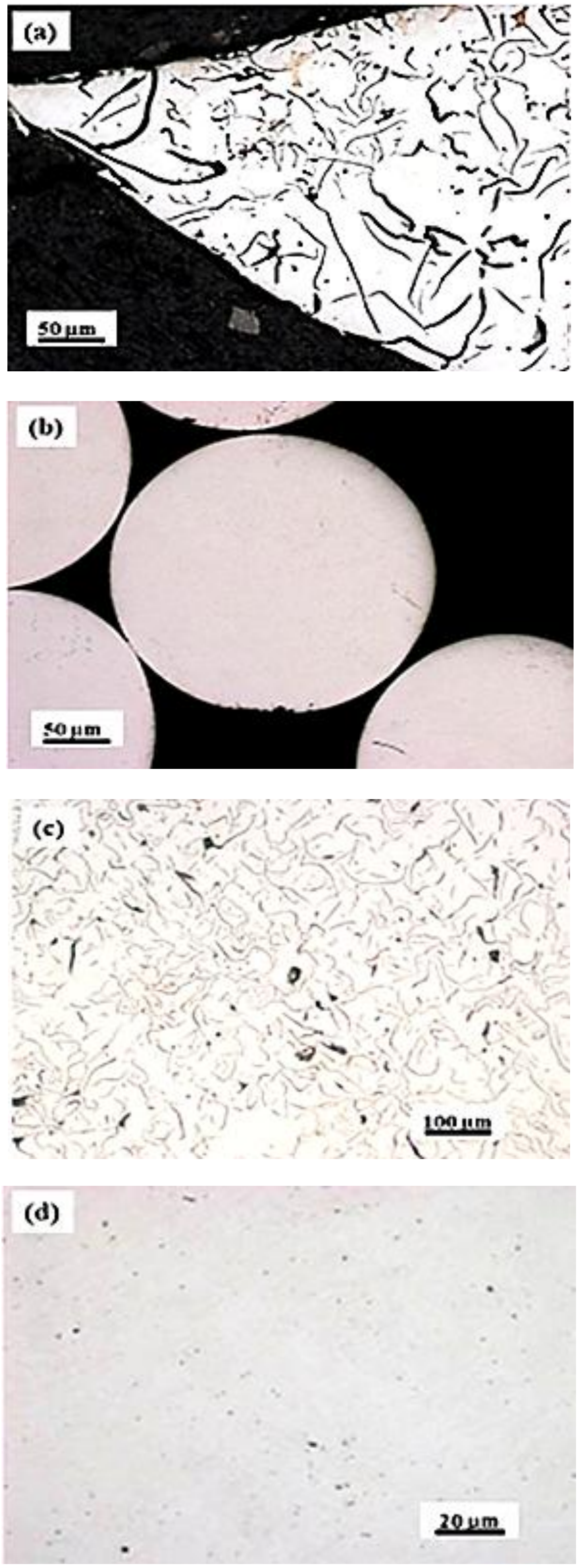
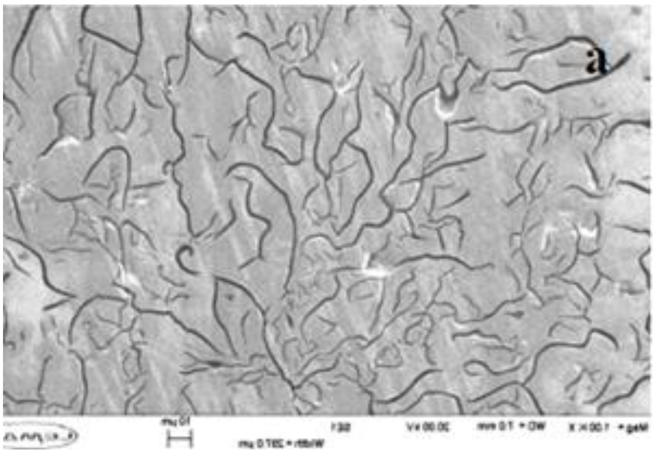
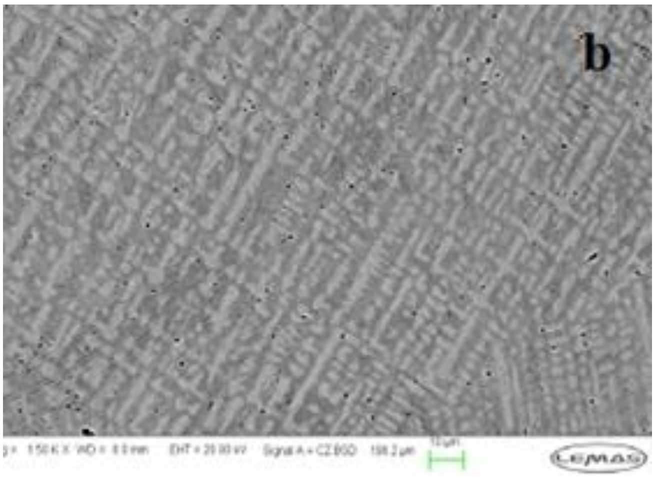
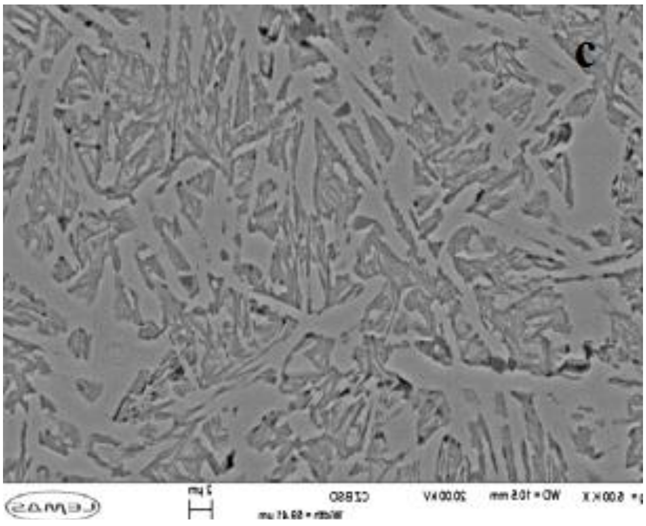


Fig 1. Light optical unetched photograph taken by means of a microscope of: (a) the as-cast specimen (tip-edge) showing graphite in ferritic matrix been distributed randomly, (b) the middle segment of the as-cast sample with feature of Type C graphite structure. (c) A swift solidified droplets from its tube with an absence of graphite as shown in the enlarged photograph taken by means of a microscope in (d).







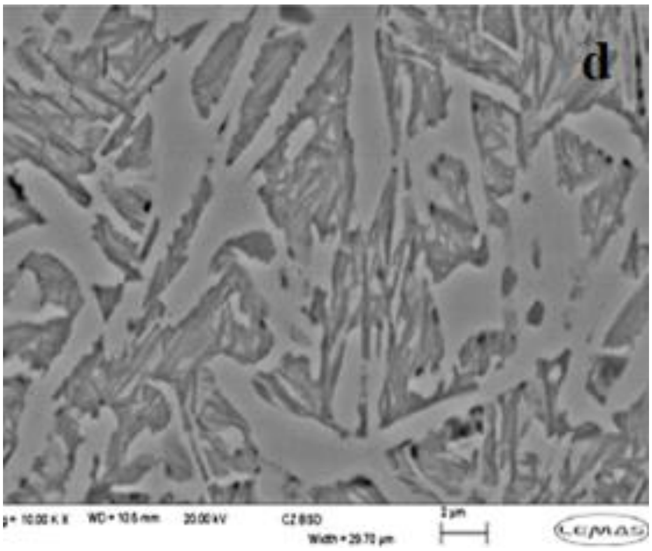


Fig 2. Photograph of samples at different cooling rate been taken by Scanning Electron Microscope ,in which its increase is inversely proportional to particle sizes with smaller droplets: (a) as-cast sample revealing the graphite having discrete flakes , (b) 800-500 µm, (c) 106-75 µm and (d) 75-53 µm. The light segment is Ferrite in the as-cast with presence of austenite in powder sample. The interdendritic section consist of Fe3C and α-Fe. Reducing the size of droplets size makes dendrites become less fragmented. Considerable differences were observed in the structure of 106-75 and 75-53 µm sizes which shows martensitic microstructure [17].

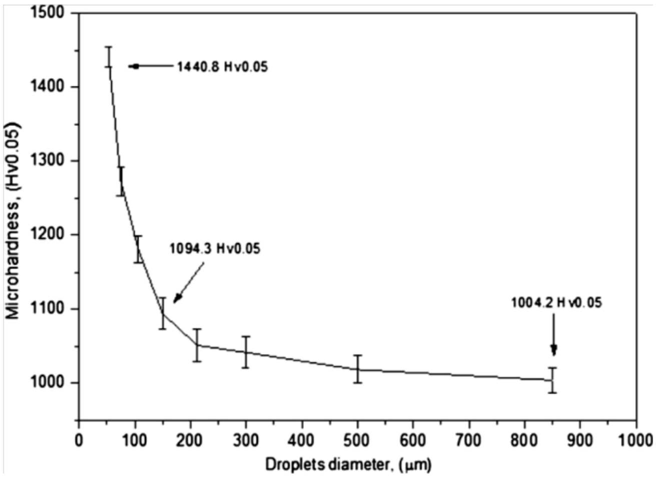


Fig 3. Microhardness values (Hv0.05) of droplet against the as-cast sample diameters. The smaller the droplet, the higher the cooling rate.

IV. CONCLUSIONS

From the explanations in the figures above on the structural and continuous phase changes noticed at a steady composition of droplets been quickly cooled , it was observed that adequate undercooling in Helium gas which resulted to constant increase in microhardness was due to an increased in cooling rates as illustrated in Figure 3. The observed Phase transformation of ferritic matrix to austenite and stronger martensitic in undercooled droplets shown in Figure 2(d) confirms this. therefore, the evidence highlighted in this study has proven that with fast structural processing to solid form which includes the one produced by drop-tube and other previously utilized methods such as ;laser welding, austenitising/austempering heat treatment, levitation approaches by research fellows on this metallic alloy, it is possible to change the mechanical property of many significant commercial alloy such as the one been examined in this study base on its processing interdependence with microstructure.

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