Key Engineering Materials Vol. 457 (2011) pp 67-72
© (2011) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/KEM.457.67

Growth of Eutectic Austenite in Free Graphite Cast Irons

Rivera, Graciela Leonor[1,a], Boeri, Roberto Enrique [1,b] and Sikora, Jorge Antonio[1,c]

[1] Metallurgy Division INTEMA- Faculty of Engineering
National University of Mar del Plata – CONICET
Av. Juan B. Justo 4302 (B7608FDQ) Mar del Plata - ARGENTINA
[a] glrivera@fi.mdp.edu.ar, [b] boeri@fi.mdp.edu.ar, [c] jsikora@fi.mdp.edu.ar

Keywords: free graphite cast iron, austenite growth, macrostructure.

Abstract. The present work investigates the growth of the eutectic austenite of hypereutectic free graphite cast irons of different graphite morphology.

The study was based on the analysis of several samples obtained from a highly hypereutectic cast iron melt. A hypereutectic melt was used in order to ensure the absence of proeutectic austenite. With the aim of obtaining samples of different graphite morphology but nearly identical chemical composition, the melt was nodularized by using a standard procedure, and different samples were cast after various fading periods. Through this procedure, spheroidal, vermicular and flake graphite samples were obtained

The results show that the eutectic austenite grows dendritically in all samples investigated. Nevertheless, significant differences were found in the size of the solidification units (grains) and in the microsegregation patterns as the graphite morphology changes from spheroidal to flake.

Introduction

Free graphite cast irons are alloys of great metallurgical complexity. As a result, there is no universally accepted description of its solidification process. Most research efforts have focused on the understanding of the changes in the graphite morphology. Nevertheless, little attention has been paid to the nucleation and growth of austenite. Although there is a general agreement on the dendritic nature of the proeutectic austenite, noticeable discrepancies appear regarding the growth of the eutectic austenite, for both eutectic and hypereutectic alloys. A proper understanding of the solidification process, particularly about the size and morphology of the solid phases, is needed to carry out precise predictions of the reological properties of the melt, leading to more accurate calculations of the mould filling. Furthermore, the understanding of the interaction of the solidifying phases and the location of the last portions of the melt to freeze, will explain the formation and distribution of inclusions, microshrinkage and microsegregation.

Most studies of the solidification of cast irons that apply interrupted solidification techniques and the examination of the microstructure show that of the graphite morphology affects noticeably the growth of the austenite-graphite eutectic [1-5]

Other studies focused on the examination of the macroscopic features of cast iron solidification show that solidification grains are observed in cross sections of castings of different sizes [6-8].

The authors of the present study have examined the solidification of cast iron over the last decade. Different articles focused on the macro and microstructures of irons of different graphite morphology and carbon equivalent content. In all cases the austenite was found to grow dendritically, resembling the usual behaviour observed in most metallic alloys [9-16]. Nevertheless, when those earlier results of the authors are compared to other investigations and bibliography specialized in cast irons, it becomes clear that there is no universally accepted knowledge on this subject, as very particular features are commonly attributed to the solidification of the different types of cast irons [17-19]. These discrepancies encouraged the authors to continue studies in the subject.

The literature shows general agreement on the morphology of primary or proeutectic austenite, which is invariably shown with dendritic morphology. Nevertheless, large discrepancies are found regarding the growth of eutectic austenite, present in both eutectic and hypereutectic irons. Diószegi et al [8], Angus [17], Morrogh et al. [18], Frás et al [19] and Stefanescu [20], propose the existence of two different types of austenite, primary austenite of dendritic shape, and eutectic austenite, that does not show dendritic morphology, as interacts with graphite as it grows.
The present investigation focuses on the study of the morphology of the eutectic austenite in hypereutectic gray irons of different graphite morphology and nearly identical chemical composition. The study comprises the analysis and comparison of the macrostructure and the microstructure of the samples.

Experimental Procedure

The studies were carried out on samples obtained from a hypereutectic cast iron melt of 4.75% carbon equivalent, of the following chemical composition: C: 3.75%, Si: 2.99%, Mn: 0.25%, S: 0.013%, P: 0.032%, Cu: 0.94% , Ni: 0.63%. The melt was nodularized and inoculated in separate ladles by using 1.5 wt % of FeSiMg (9%Mg) and 0.65 wt% FeSi (75%Si) respectively. After this treatment, the melt was returned to the induction furnace, where it was held at 1530ºC. Different graphite morphology samples were obtained from the same melt by allowing the nodularizing effect to fade with time. Based on prior experiments, samples consisting of 30 mm diameter cylindrical rods of 90 mm length were cast after 0, 4 and 8 minutes in resin bonded sand molds. The graphite structure of the first extraction was spheroidal, and the melt was called *S*. The following melts showed vermicular, called *V*, and flake graphite, called *F*.

The macrostructure was revealed by using a procedure developed earlier by the authors, called DAAS (Direct Austempering After Solidification), that is described in detail and validated in the literature [9,15]. This procedure requires that the samples are hot shaken out and austempered. Samples prepared in that manner retain the primary austenite grains, and therefore show the macrostructure directly after regular etching with Picral (5%).

The microsegregation patterns were revealed by using color metallography techniques that were reported and validated in the literature [10,21]. The color etching is sensitive to the concentration of Si, and therefore it reveals the location of the last portions of melt to freeze, which are poor in Si.

Results and Discussion

Fig. 1 shows the unetched microstructure of samples of melts *S*, *V* and *F*. The structure of sample *S* is fully spheroidal, while sample *V*, extracted after 4 minutes of fading, is mostly vermicular. Sample *F*, after 8 minutes of fading, shows flake graphite. The distinctive features of the proeutectic graphite can also be noticed. Sample *S* shows large proeutectic nodules, while sample *F* shows coarse flakes graphite. A greater dispersion of the proeutectic graphite is found on sample *S*.

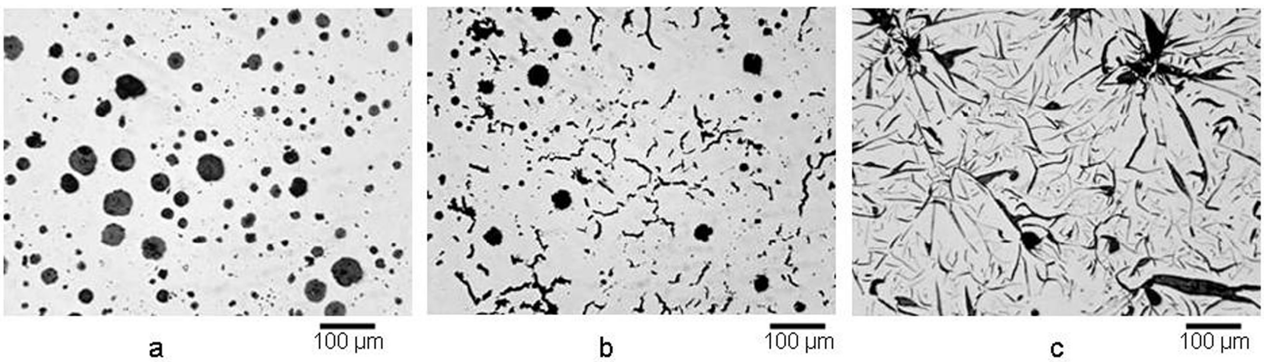

Fig. 1. Unetched microstructure of samples studied (a)*S*, (b)*V*, (c)*F*

Fig. 2 shows, at the left side, the solidification macrostructure of samples *S*, *V* and *F*, and, at the right side, the corresponding microstructures as revealed by color etching. Significant differences are seen at both, the macrostructure and the microstructure as the graphite morphology changes. The macrostructure shows that samples with spheroidal and vermicular graphite show much smaller grain size than the flake graphite sample *F*. This shows that, for a similar cooling rate, a larger number of austenite nucleus have developed over the same period of time per unit volume, suggesting that a greater nucleation rate of austenite characterizes the solidification of hypereutectic spheroidal and vermicular cast irons. In order to rationalize this observation it becomes necessary to identify the factors that could control austenite nucleation in hypereutectic cast irons. There is a general agreement in that graphite is the first solid phase forming upon cooling of hypereutectic melts. Therefore, a first analysis should establish whether those solid precipitates present in the melt can effectively act as nucleation sites for austenite. Mizoguchi et al [22] and Pedersen et al [7] research into this subject and conclude that primary graphite inoculates austenite. Furthermore, Fredrikson et al [1] showed results that are in agreement with those found in this study, stating that the first stages of the solidification of spheroidal graphite cast irons are characterized by a larger nucleation rate of austenite than that found on flake graphite irons. All these findings could lead to the conclusion that the smaller grain size that characterizes the solidification macrostructure of hypereutectic spheroidal graphite cast iron, as opposed to the large grains found in flake iron, is the result of the larger nucleation rate of the austenite caused by the larger dispersion of proeutectic spheroids present in the liquid. The graphite precipitates would act as nucleation sites for eutectic austenite as the remaining liquid cools below the eutectic temperature. Nevertheless, it must be pointed out that this explanation is specific for hypereutectic melts, as earlier studies of the authors have shown that an increase in the dispersion of graphite in hypoeutectic spheroidal graphite irons does not cause a refinement in the solidification grain size [13]. Such a different behavior between hypo and hypereutectic spheroidal graphite irons (SGI) could take place because austenite is the proeutectic phase in hypoeutectic SGI, and it must nucleate from a melt free from graphite precipitates. In hypoeutectic irons, graphite would precipitate below the eutectic temperature.

At this stage of the discussion of results it is important to address some limitations of the experimental methodology. Although the method guarantees that, with the exception of Mg and dissolved gasses, the chemical composition of all samples is similar; this is not the case for the inoculation efficiency. In fact, only the first casting, of spheroidal graphite, has fresh inoculation. The following castings will show not only smaller Mg content, but also a fading in the inoculation effect of FeSi and FeSiMgCe. This smaller nucleation rate could have magnified the differences observed in this study between SGI and flake graphite irons (FGI). Nevertheless, the macrostructures obtained in this investigation for FGI are entirely similar to those found in earlier investigations that used properly inoculated samples [12].

The macrostructure of the vermicular graphite sample, *V*, deserves a particular comment, as it shows unusual features. Two families of grains of different size are observed, as shown in Figure 2. Some large grains having a size similar to that of gray iron sample *F*, and other much smaller grains. This feature of the macrostructure suggests that the solidification of vermicular iron involves a transition between the solidification mechanism of spheroidal and flake graphite irons. Vermicular irons usually show different amounts of spheroidal graphite. In the case of melt *V*, the presence of spheroids is noticeable. It is therefore possible that in this case, the solidification involves the simultaneous precipitation of some small austenite crystals in contact with spheroidal graphite, that will originate the smaller grains, and other larger austenite dendrites that grow cooperatively with vermicular graphite precipitates, leading to the larger size grains.

The microstructure of samples *S* and *V* show that the microsegregation associated to the last to freeze liquid are dispersed throughout the matrix. On the other hand, sample *F* shows continuous microsegregation patterns, which seem to mark the borders of the eutectic cells (or colonies).

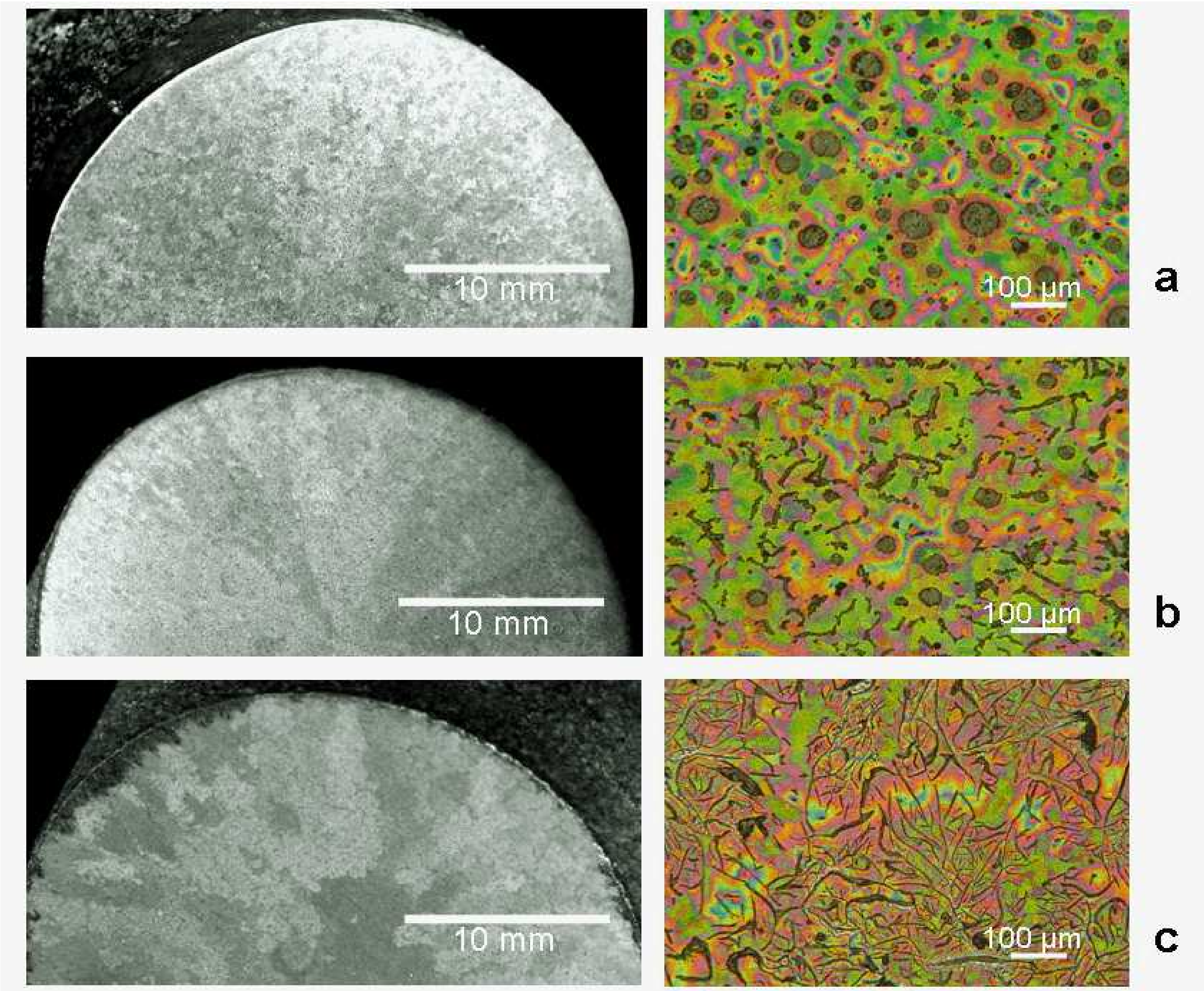

Fig. 2. Macro and microstructures of samples studied (a) *S* (b) *V*, (c) *F*

The top row photographs of Fig. 3 show the color microstructures of samples *S*, *V* and *F*, while the bottom figures show the same areas where the microsegregated portions of the matrix have been manually contoured using black lines that join neighboring segregated regions. It is important to point out that the areas marked through this procedure do not represent solidification units or grains, but they are what can be called "colonies". A large number of colonies exist within a grain of the macrostructure, assuming that a grain is a portion of the volume having similar austenite crystal orientation. This understanding differs from that of other authors [2,19]. The size of the colonies of sample *F* is about five times larger than that found on samples *V* and about ten times of than seen on sample *S*. Such large change is probably caused by differences in the growth of the eutectic. In flake graphite irons, the contact of the growing austenite dendrites leads to the formation of nearly spherical colonies of eutectic, where graphite and austenite grow cooperatively with both phases in contact with the melt, originating nearly spherical colonies that grow at a relatively high rate [1]. On the other hand, the interaction of the growing austenite dendrites with graphite spheroids leads to the encapsulation of the graphite particles by austenite [1]. As a result, further growth is controlled by the diffusion of carbon through the austenite envelopes, leading to irregularly shaped colonies that are smaller than those found on flake graphite iron. The behavior of vermicular iron appears to be a transition between spheroidal and flake iron mechanisms. Graphite precipitates are initially spheroidal, but soon after solidification advances they degenerate to vermicular shapes, that grow coupled with austenite and can generate large grains as in the case of flake iron [5].

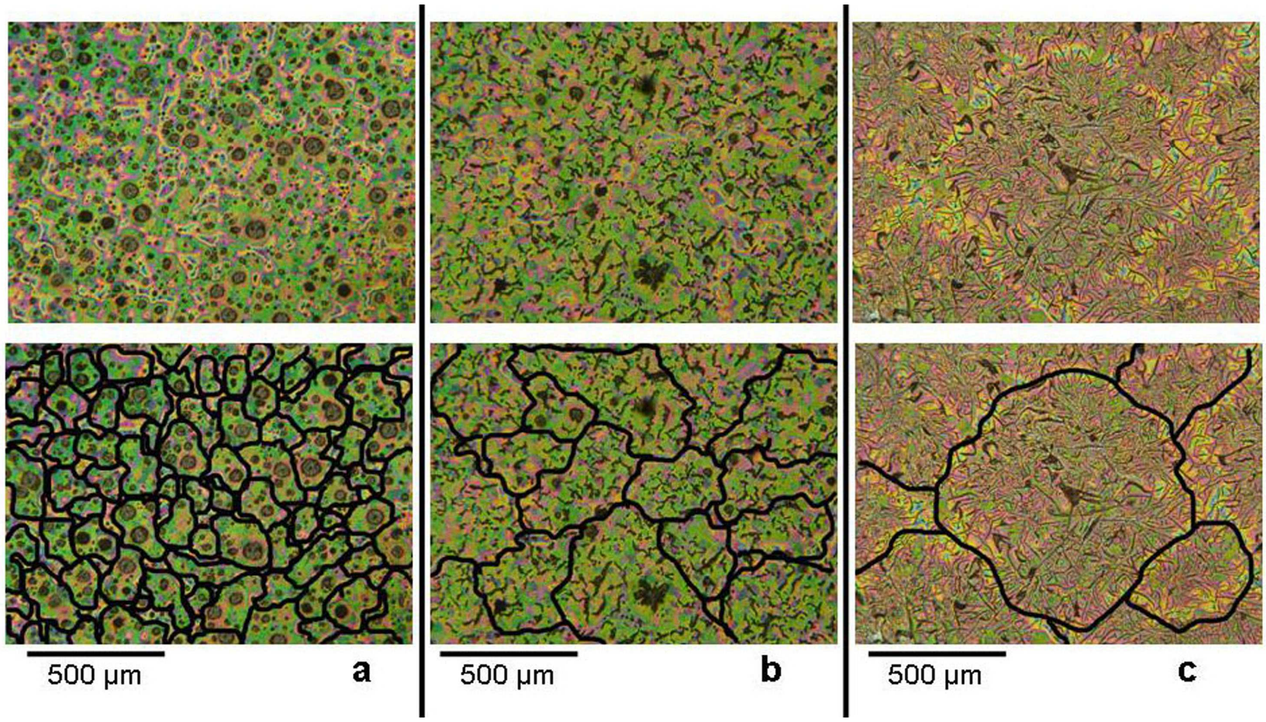

Fig. 3. Microstructures of samples studied (a) *S* (b) *V*, (c) *F*

Conclusions

- The morphology of graphite influences the solidification of free graphite cast irons, leading to marked differences in both the solidification macrostructure and microstructure.
- The macrostructure of hypereutectic spheroidal cast iron shows smaller grains than flake graphite iron of the same chemical composition. This suggests that the nucleation rate of austenite is considerably larger in spheroidal graphite irons.
- The larger nucleation rate characterizing spheroidal cast iron solidification may result from the nucleating effect of proeutectic spheroidal graphite present in the melt at the time the eutectic temperature is reached. The dispersion of proeutectic graphite is larger in spheroidal cast iron than in flake graphite iron.
- The macrostructure of hypereutectic vermicular cast iron shares features of spheroidal and flake graphite irons, showing larger and smaller grains.
- Flake graphite cast irons show larger solidification colonies than spheroidal and vermicular graphite irons. As a result, a more continuous distribution of microsegregation is also observed in flake graphite iron.
- Under the experimental conditions of the present investigation, the size of the eutectic colonies of flake graphite irons is, in average, ten times larger than that of spheroidal graphite iron, and five times larger than that of vermicular graphite irons.

References

[1] H. Fredriksson, J. Stejerndahl and J. Tinoco: Mater. Sci. Eng. A Vol. 413-414 (2005), p. 363

[2] D. Stefanescu, H. Qiu and C. Chen: AFS Trans., Vol. 103, (1995), p. 189

[3] Y. Li, B. Liu and C. Loper: AFS Trans., Vol. 98, (1990), p. 483

[4] F. Mampaey: AFS Transactions, Vol. 108, (2000), p. 11

[5] E. Pan, K. Ogi and C. Loper: AFS Trans., Vol. 90, (1982), p. 509

[6] C. van de Velde: Proc. of the Ductile Iron Society's (1998), p. 143

[7] K. Pedersen and N. Tiedje: Mat. Sci. Eng. A, Vol. 413-414 (2005), p. 358

[8] A. Diószegi, K. Liuand I. Svensson: Int. J of Cast Met. Res., Vol. 20 (2007), p. 68

[9] R. Boeri and J. Sikora: Int. J of Cast Met. Res., Vol. 13 (2001), p. 307

[10] G. Rivera, R. Boeri and J. Sikora: Mat. Sci. and Tech., Vol. 18 (2002), p. 691

[11] G. Rivera, R. Boeri and J. Sikora: AFS Trans., Vol. 111 (2003), p. 1

[12] G. Rivera, R. Boeri and J. Sikora: Scrip. Mater., Vol. 50 (2004), p. 331

[13] G. Rivera, R. Boeri and J. Sikora: Int. J of Cast Met. Res., Vol. 16 (2003), p. 23

[14] G. Rivera, R. Boeri and J. Sikora: Proc. of Eighth Int. Symposium on Sci. and Proc. of Cast Iron Beijing, China, (2006), p. 45

[15] G. Rivera, P. Calvillo, R. Boeri, Y. Houbaert and J. Sikora: Mat. Charact., Vol. 59 (2008), p. 1342

[16] R. Boeri, J. Sikora and G. Rivera: Proc. of 2008 Keith Millis Symposium on Ductile Cast Iron, Las Vegas, USA, (2008), p. 111

[17] H. Angus *"Cast Iron - Physical and Engineering Properties".* 1976, Butterworth & Co. Ltd.

[18] H. Morrogh and W. Olfield: Iron Steel (1959), p. 431

[19] E. Frás, M. Górny, W. Kapturkiewicz and H. Lopez: Int. J of Cast Met. Res. Vol. 20 (2007), p. 233

[20] D. Stefanescu *"Cast Iron"*; 1988, Metals Handbook, ASM, 9º Edición, Vol.15.

[21] G. Rivera, R. Boeri and J. Sikora: Cast Metals, Vol.8 (1995), p. 1

[22] T. Mizoguchi, J. Perepezko and C. Loper: AFS Trans., Vol. 105 (1997), p. 89