# Breakup of eutectic carbide network of white cast irons at high temperatures

MA QIAN*, LIU BAICHENG
*Department of Mechanical Engineering, Tsinghua University, Beijing 100084, People's Republic of China*
WANG ZHAOCHANG
*Department of Metallurgy, University of Science and Technology, Beijing, 100083, People's Republic of China*

The fracture toughness of white cast irons is related to the morphology of eutectic carbides,being better when isolated than when network-like. In this paper observations on the breakup of eutectic cementite network during annealing treatment of white cast irons are reported using a high temperature microscope and scanning electron microscopy (SEM). Dissolution-induced breakup and capillarity-induced breakup are identified. The former occurs through growth of holes and pre-existing fissures as well as through fragmentation at narrow necks and narrow roots of branches. The latter is observed through growth of perturbations. Dissolution-induced breakup is closely associated with the morphology of the as-cast eutectic cementite. A combination of solidification processing and heat treatment thus produces a more positive breakup effect.

## 1. Introduction

The normal continuous network of the as-cast eutectic carbide structure, which heavily contributes to the brittleness of white cast irons, can be modified into much more favourable isolated globules using high temperature treatment [1]. The key point of this modification lies in the breakup of the network. Many theories concerning the breakup of rod-like and plate-like second phases during annealing treatment have been developed [2–6]. In general, these theories can always be applied to explain or infer certain aspects of the breakup of the eutectic cementite network in white cast irons. However, to capitalize on the full potential of high temperature treatment to modify the eutectic cementite network, a thorough understanding of the breakup details is required. In this work, the breakup modes of the eutectic cementite network are identified and documented using a high temperature microscope and SEM. In addition, a strategy of controlling the breakup of the eutectic cementite network through a combination of solidification processing and heat treatment is also developed on the basis of the observations.

## 2. Experimental procedures

The white cast iron, having the compositions (wt %) of 2.54 C, 1.35 Si, 1.72 Cr, 0.019 S, and 0.068 P, was prepared by induction melting charges of pig iron, steel scrap, and Fe–Cr alloy. The melt was tapped into two ladles with a superheating temperature of 1773 ± 20 K. One ladle of the melt was left unmodified, and the other was treated with additions of 1.0% Fe–29RE–41Si (wt %) alloy. Both of them were poured into green sand moulds of 20 mm diam. × 120 mm rods at 1673 K. Small pieces of specimens were cut from the middle of the ingot, polished and etched in Nital. Annealing of the specimens was performed at 1253 ± 2 K in a high temperature microscope under an argon atmosphere (99.999% purity). The heating rate was around 673 K $min^{-1}$. Since a high temperature microscope carries lower resolution, SEM observations were then made on the cementites in a fixed viewing field of the specimen that underwent different annealing treatments. Besides, a long time holding treatment readily obscures the image in high temperature microscope, a group of specimens were therefore annealed in a muffle furnace for additional observations using optical microscopy. The volume fraction of the eutectic cementite in these specimens was measured as a function of the holding time using a Cambridge Quantimet-image analysis 900. For each specimen, 20 viewing fields were analysed under a magnification of × 100.

## 3. Results

Fig. 1 depicts the situation of an individual eutectic cementite network before and after annealing. It can be clearly seen that dissolution of the eutectic cementite initiated and developed everywhere at the interface. At narrow necks breakup took place, while the heavy sectional parts thinned and narrowed, resulting in more

* *Present address*: Department of Mechanical Engineering, Kyushu Institute of Technology, Tobata, Kitakyushu 804, Japan.

0022–2461 

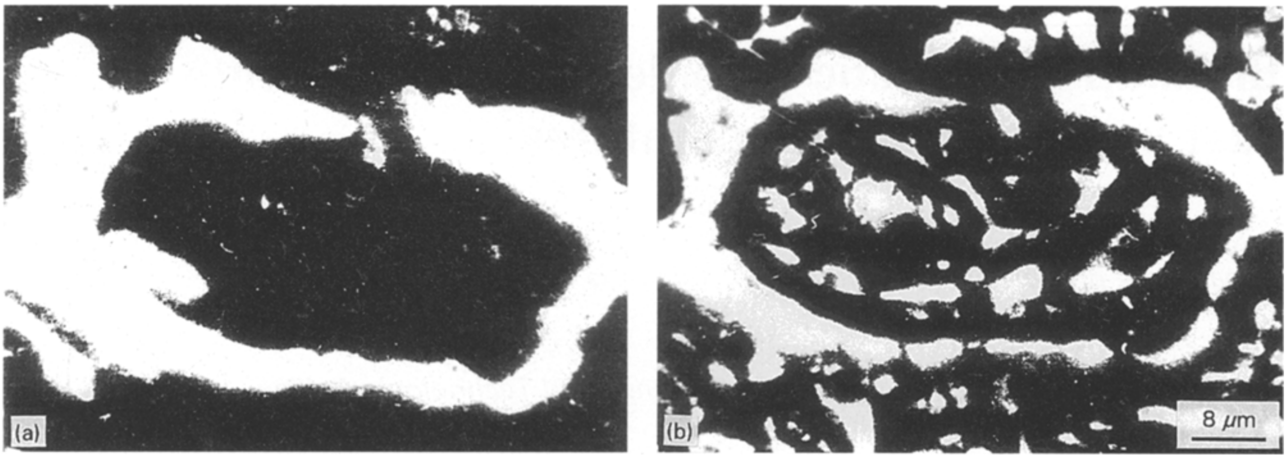


*Figure 1* Change in morphology of an individual eutectic cementite network annealed at 1253 K. (a) As-cast and (b) held for 2 h.

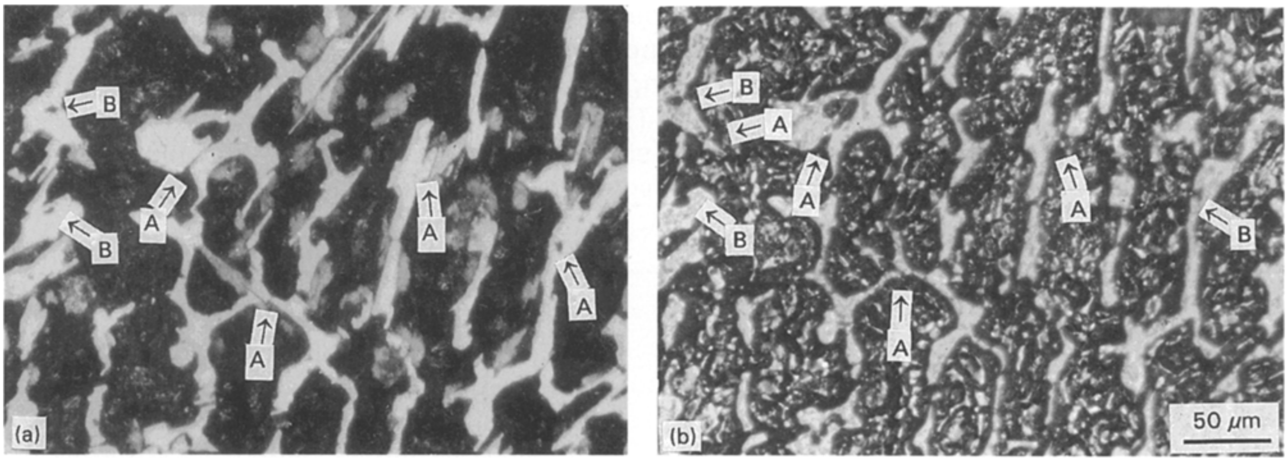


*Figure 2* Change in morphology of the network structure after annealing at 1253 K. (a) As-cast and (b) held for 2 h.

necks. The reduction in section size of the network can be estimated by making a comparison between Fig. 1(a) and (b). It seems that the network underwent a more or less homogeneous dissolution in most regions.

A real network structure consisting of a number of single networks is usually imperfect. Fig. 2 indicates that, apart from breaking up at narrow necks and narrow roots of branches, fragmentation also occurs directly through growth of pre-existing fissures (A) and holes (B) (Fig. 2(b)).

Fig. 3 exhibits the SEM observations on the same eutectic cementite plate that underwent different annealing treatments. It is observed that new holes are generated in the eutectic cementite plate during annealing (Fig. 3(b)), and expansion of them also leads to breakup at length (Fig. 3(c, d)). The interior of the holes consists of austenite at the holding temperature (Fig. 3(d)).

The photomicrograph of Fig. 4 was taken from the specimen treated in a muffle furnace after 12 h at 1253 K. Evidence of perturbation-induced breakup is clearly demonstrated.

Fig. 5 shows the changes in volume fraction of the eutectic cementite in the course of annealing. A dissolution process with an apparent reduction in volume fraction of the eutectic cementite and a coarsening process with little change in volume fraction of the eutectic cementite can be identified in accordance with Fig. 5.

## 4. Discussion

### 4.1. Dissolution-induced breakup

Dissolution-induced breakup is caused by the reduction in volume fraction of the eutectic cementite, which arises from the demand for increasing the carbon content of austenite to the cementite–austenite equilibrium value. This reduction is practically independent of interface curvatures of the as-cast microstructure in driving force. Moreover, the curvature effects upon the rate of reduction everywhere at the interface are generally negligible for coarse eutectic cementites that underwent an apparent dissolution [7]. Hence, it was observed that dissolution of the eutectic cementite initiated and developed everywhere at the interface (Fig. 1). As a result, expansion of pre-existing holes and fissures occurs; breakup at narrow necks and narrow roots of branches takes place. Formation of new holes can also be interpreted by dissolution of the thinnest part in the eutectic cementite plate. However, the reduction in volume fraction of the eutectic carbide is limited at certain annealing

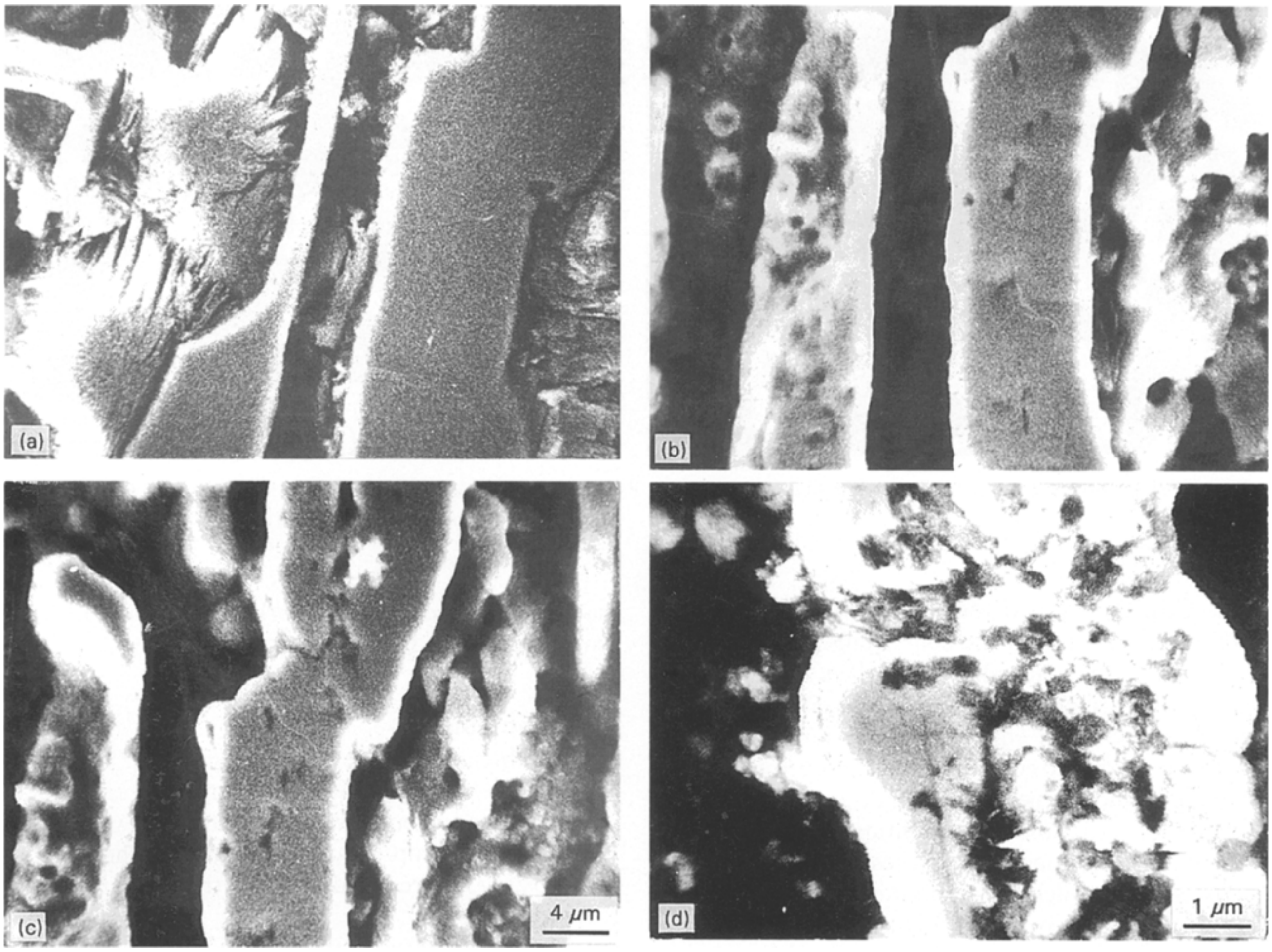


*Figure 3* SEM observations on the morphological changes of the same eutectic cementite plate during annealing at 1253 K. (a) As-cast, (b) held for 1.5 h, (c) held for 4.5 h and (d) magnified observation of a local area in (c) after 8 h.

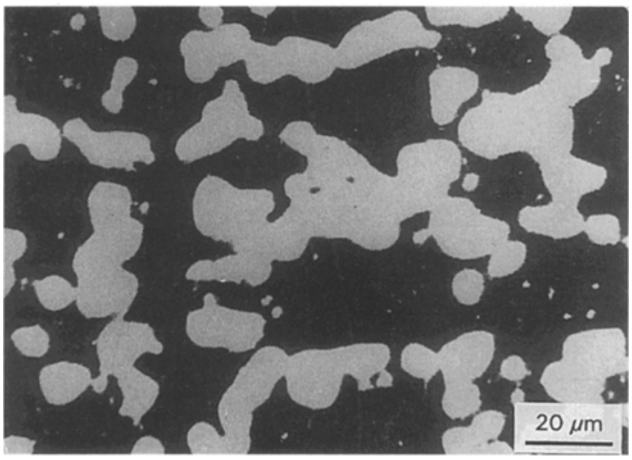


*Figure 4* Evidence of perturbation-induced breakup; held for 12 h at 1253 K.

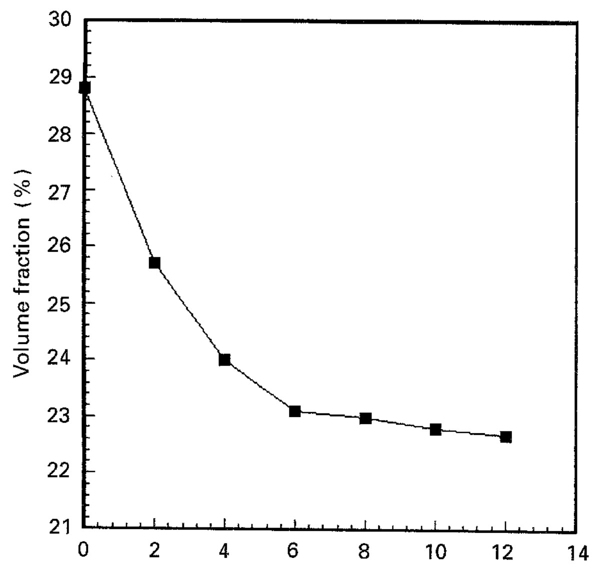


*Figure 5* Change in volume fraction of the eutectic cementite during annealing at 1253 K.

temperatures, which dictates that a solid network with uniform section size will probably not break up. Hence, the first step toward a desired breakup effect is to create an inhomogeneous as-cast microstructure with more geometric defects such as fissures, holes, narrow necks, notches and the like.

On the formation and development of holes observed in Fig. 2 and Fig. 3, it is possible that cementite oxidized at the specimen surface during microscopy, to yield Fe and $CO_2$, so that surface oxidation could have contributed at least in part to hole production. In this respect the surface observations in the high temperature microscope might not be fully representative of behaviour in the bulk. This would not invalidate the general nature of the results and conclusions.

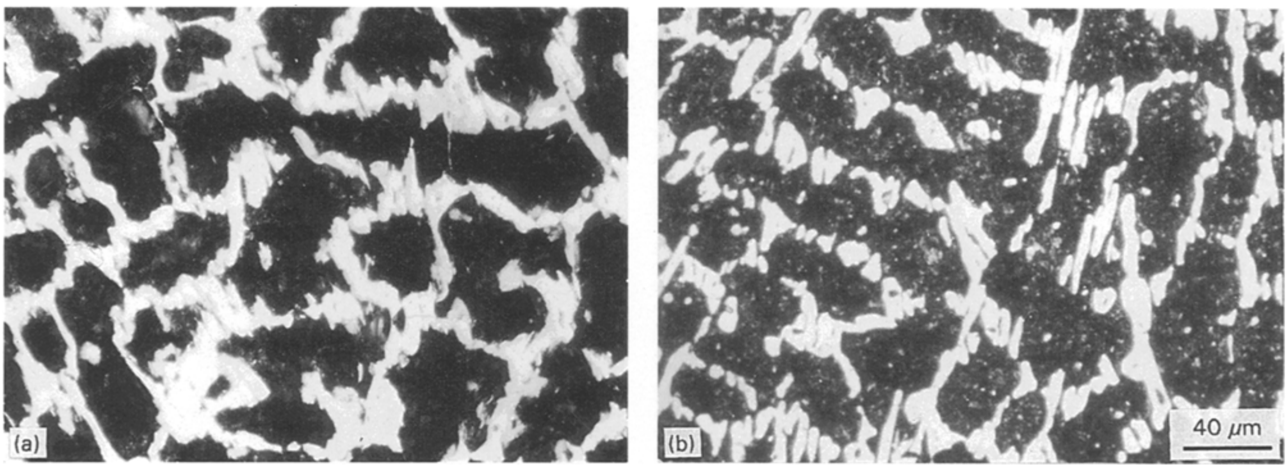


*Figure 6* The network structure modified with addition of 1.0 wt% RE–Si–Fe, (a) As-cast and (b) annealed for 4 h at 1253 K.

### 4.2. Capillarity-induced breakup

Following dissolution the coarsening process occurs which will be virtually controlled by interface curvatures, provided that the interface free energy is isotropic and local equilibrium is established at all interfaces. Tips and edges of the eutectic cementite will become rounded due to their high curvatures as the process goes on, and cylindrization of the plate-like cementite occurs via the edge recession [6]. Rayleigh's perturbation model [3, 8] and the chemical potential model developed by the present authors [9, 10] can then be applied to interpret the consequent breakup of the rod-like cementite as shown in Fig. 4. Besides, expansion of holes that remain in the cementite plate at the end of dissolution may also occur in this process, because the curved edges of these holes all have high curvatures. However, it should be pointed out that capillarity-induced breakup is limited to the later stages of annealing treatment. It is a time-consuming process. Hence, dissolution-induced breakup will generally dominate unless the annealing time is prolonged sufficiently.

### 4.3. Combined control of breakup

The observations revealed that the breakup effect is closely associated with the as-cast microstructure. Breakup can therefore be controlled first by means of appropriate solidification processing. This strategy was performed by using RE modification during the solidification of white cast irons [11, 12]. Fig. 6(a) shows the typical as-cast structure of the eutectic cementite of the pilot alloy after RE modification. The normal smooth and solid eutectic cementite network was largely reduced and replaced by a more inhomogeneous network which contains a lot of tightly connected plate-like cementites. The fissures between these plate-like cementites and the notches and the necking parts in the cementites are all potential breakup areas. After annealing at 1253 K for 4 h, it can be seen that the network became almost discontinuous (Fig. 6(b)).

## 5. Conclusions

1. The breakup modes of the network structure of eutectic cementite at high temperatures include fragmentation at narrow necks and narrow roots of branches; breakup through growth of holes and pre-existing fissures; and breakup through growth of perturbations.
2. The breakup effect of the eutectic cementite network at high temperatures is closely associated with the morphology of the as-cast eutectic cementite. Combined control of the breakup through solidification processing and heat treatment is thus more effective.

## Acknowledgement

The authors are very grateful to the referee for his valuable comments on the manuscript.

## References

1. S. B. BINER, *Can. Metall. Quart.* **24** (1985) 155.
2. F. A. NICHOLS and W. W. MULLINS, *Trans. TMS-AIME* **233** (1965) 1840.
3. F. A. NICHOLS, *J. Mater. Sci.* **11** (1976) 1077.
4. P. Y. ZHU and Q. Y. LIU, *Mater. Sci. Tech.* **2** (1986) 500.
5. YONG LAI TIAN and R. W. KRAFT, *Metall. Trans.* **18A** (1987) 1403.
6. J. C. MALZAHN, T. H. COURTNEY and Y. LENG, *Acta Metall.* **37** (1989) 1735.
7. H. B. AARON and G. R. KOLTER, *Metall. Trans.* **2** (1971) 393.
8. LORD RAYLEIGH, *Lond. Math. Soc. Proc. Ser.* 1 **10** (1879) 4.
9. MA QIAN, LIU BAICHENG and LI RUNQI, *Acta Metall. Mater.* **42** (1994) 4083.
10. *Idem, ibid.* **42** (1994) 4087.
11. WANG CHAO CHANG, HSU HENG TSUN and MA QIAN, *Mater. Sci. Tech.* **6** (1989) 905.
12. B. ZHAO and E. W. LANGER, *Scand. J. Metall.* **11** (1982) 287.

*Received 19 May*
*and accepted 31 October 1994*