ISSN : 0974 - 7486 Volume 8 Issue 4

Materials Science

Trade Science Inc.

An Indian Journal

Full Paper

MSAIJ, 8(4), 2012 [147-154]

Structure micro-segregation of rheocast gray cast iron

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Received: 19th October, 2011 ; Accepted: 19th November, 2011

ABSTRACT

The processing of metals in the semi-solid state is becoming an innovative technology for the production of globular structure with minimum micro-segregation and high quality cast parts. This research is aimed to study the microstructure characterization and micro-segregation of semi-solid processing gray cast iron. Increasing fraction of solid has significant effect on the primary particle morphology as well as micro-segregation of gray iron cast structure. Elements segregation decreases with increasing the fraction of solid up to 0.12. It is found that elements segregation starts to increase by increasing fraction of solid above 0.12. This change of behavior of elements segregation before and after 0.12 fraction of solid related to primary solid agglomeration. Processing window (f_s = 0.02 to f_s = 0.13) can be withdrawn for production of semi-solid gray cast iron casting combine higher strength, higher elongation and minimum micro-segregation compared with ordinary gray iron casting.

KEYWORDS

Semi-solid processing;
Micro-segregation;
Gray cast iron;
Cooling plate;
Microstructure.

INTRODUCTION

Semi-solid metal(SSM) processing has been successfully established as a unique technique for production of metallic components with high integrity and improved mechanical properties, which can be further divided into rheoforming and thixoforming[1]. There is no doubt that SSM processing will have a bright future and may give a facelift to the metallurgical processing industry. However, to achieve this goal, there is still a long way to go. Based on the current situation, it appears that future efforts should be directed to the following five areas: development of new processes, understanding the mechanisms for the formation of globular structure, development of new alloys for SSM processing, the rheological behavior of SSM slurries, and microstructure–property relationships in SSM formed materials.

The solidification of alloy systems with limited solubility proceeds with a number of phenomena taking place simultaneously once the temperature falls below the liquidus, the mushy zone. These include crystallization, solid movement, solute redistribution, constituents' segregation, and ripening. In such alloy systems, the concentration of minor elements is often in excess of their solubility limits in the principal phases. The outcome is multi-step solidification to form a multi-phase structure instead of single phase with complete solubility. For alloying systems having a principal partition coefficient less than 1 ($k < 1$), the solute atoms are rejected into the remaining liquid which may lead to micro- and/or macro-segregation during solidification[2].

The influences of micro-segregation, grain boundary segregation, melting point eutectics and brittle intermetallic compounds for conventional as-cast material on formability have been reported[3]. Moreover, Micro-segregation resulting from the solute redistribution causes non-equilibrium second phase, porosity and crack formation which could degrade the mechanical properties of metal products[4]. Semi-solid processing of gray cast iron using cooling plate method has been reported in the literature[5-7] where, structure improvement of fine globular primary particles, distribution of the graphite flakes and matrix structure, and their effect on tensile strength for wide range of primary fraction of solid were discussed. However, the previous literature[7] did not include any discussion on structure micro-segregation of rheocast gray cast iron during solidification.

The purpose of this report is to study the effect of the structure micro-segregation changes by the semi-solid processing using cooling plate technique for gray cast iron. The effect of different fraction of solid on the structure micro-segregation is investigated to achieve the goal. Under the optimized conditions a processing window for production of gray cast iron by semi-solid casting is achieved.

EXPERIMENTAL

Strips of the constant width 25mm and the length 155mm with the thickness 14mm were investigated in this study. Sand mold was made using silica sand of AFS 69 gfn, 6% sodium bentonite and 1% cereal. The charge material used for all trials is gray cast iron bar stock. The chemical composition of cast iron samples is shown in TABLE 1. Samples weighting approximately 1kg were melted using an electrical resistance furnace. The charge was heated in an argon atmosphere up to temperature of 1773 K, and then soaked for 30 min to allow the charge to attain the desired temperature. At 1773 K, the melt charge was removed from the furnace to the controlled pouring system, consisting of isolated box to regulate the melt temperature and speed-changeable motor to adjust the pouring rate as shown in details in somewhere else[7]. At the desired temperature, the melt charge is allowed to be poured over a

TABLE 1 : Chemical composition of cast iron samples (wt.%)

C	Si	Mn	P	S	C.E.[a]	T^L (K) (liquidus)	T^S (K) (solidus)
2.95	1.96	0.60	0.02	0.08	3.61	1541	1418

[a]C.E.: carbon equivalent (=%C + 1/3 (%Si + %P)).

cooling plate inclined at the known angle to the horizontal (10°) with constant motor speed 600 rpm (constant pouring rate), and to flow into a mold cavity at the end of cooling plate. Before pouring, 0.4 weight percent of Fe–75% Si inoculant was set on the surface of the cooling plate. The temperature of semi-solid slurry was measured by thermocouples inserted within the isolation box and the sand mold flask. The primary fraction of solid corresponding to this temperature is calculated using Scheil's equation and the austenite distribution coefficient *k* has been determined by the model of Goettsch and Dantzig[8].

Rectangular cast iron samples were cut from the strip casting. Microstructure, SEM observations and hardness measurement for cross section surface at 35mm distance from pouring base were studied. The microstructure was observed with optical microscope using ground and polished specimens. Mapping analysis for processed gray cast iron specimens were examined using a Hitachi S-800 scanning electron microscope equipped with an energy dispersive X-ray (EDS) analyzer.

RESULTS AND DISCUSSION

All metallic materials contain solute elements or impurities that are randomly distributed during solidification. The variable distribution of chemical composition on the microscopic level in a microstructure, such as dendrites and grains, is referred to as microsegregation. Variation on the macroscopic level is called macro-segregation. Because these segregations generally deteriorate the physical and chemical properties of materials, they should be kept to a minimum. Micro-segregation varies considerably with the history of the growth of the solid. For example, micro-segregation often increases with cooling rate in the case of equiaxed dendritic solidification, but it decreases in the case of unidirectional dendritic solidification[9].

Solidification of ordinary hypoeutectic gray cast iron begins with the precipitation of austenite dendrites from the melt as temperature falls under the liquidus. The

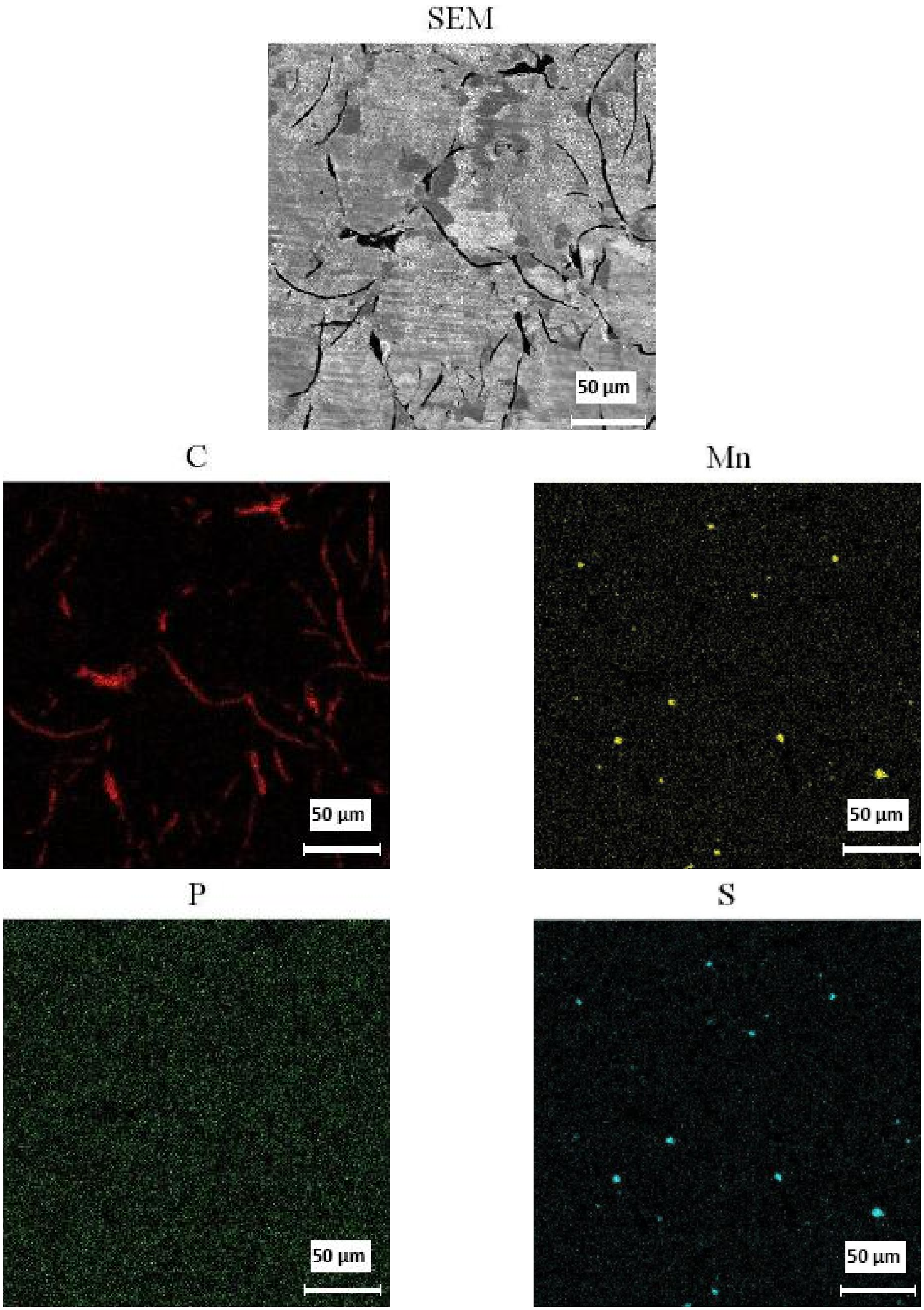

Figure 1 : SEM micrograph together with X-ray maps of ordinary casting.

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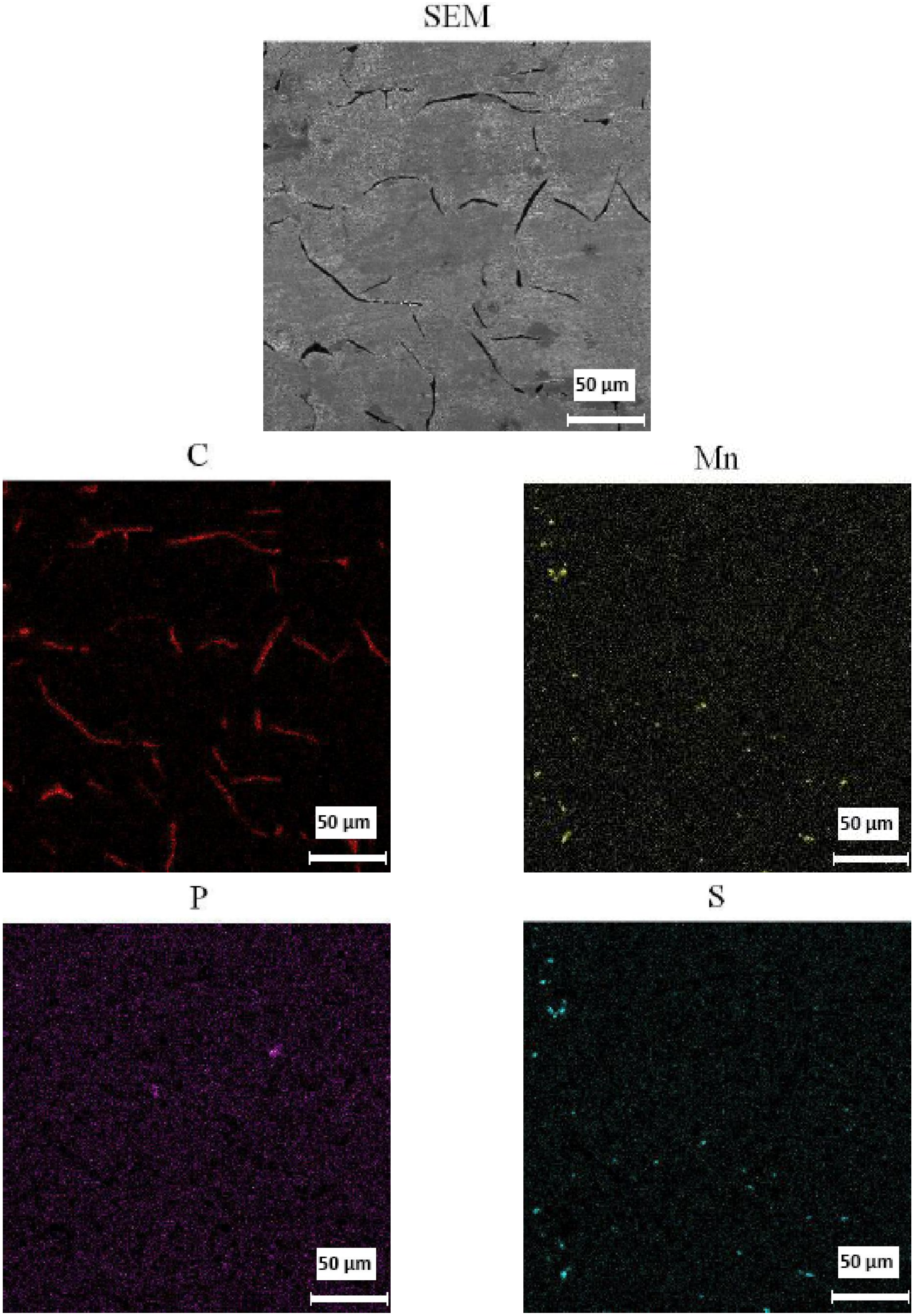

Figure 2 : SEM micrograph together with X-ray maps of semi-solid casting(f_s=0.05).

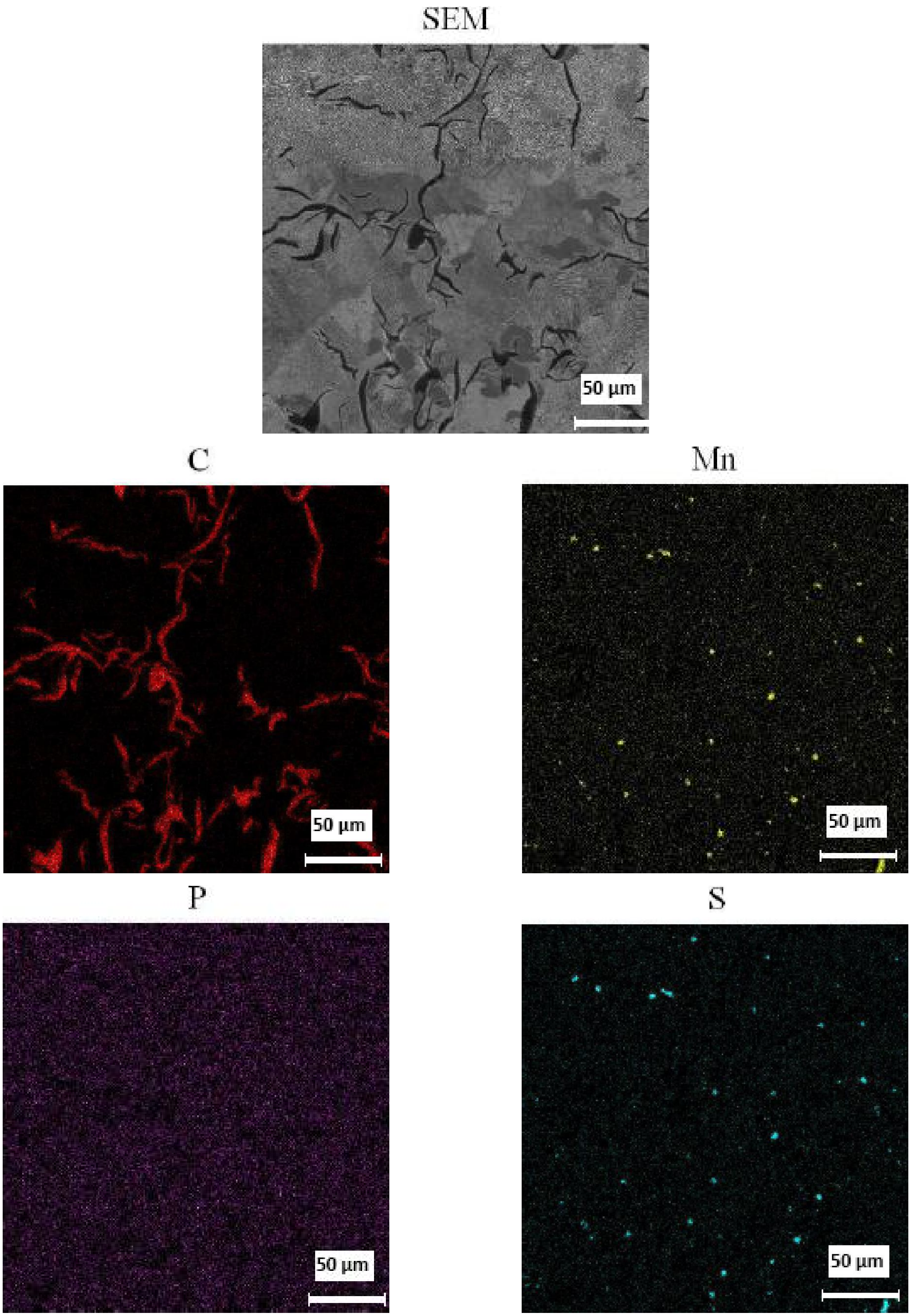

Figure 3 : SEM micrograph together with X-ray maps of semi-solid casting (f_s=0.12).

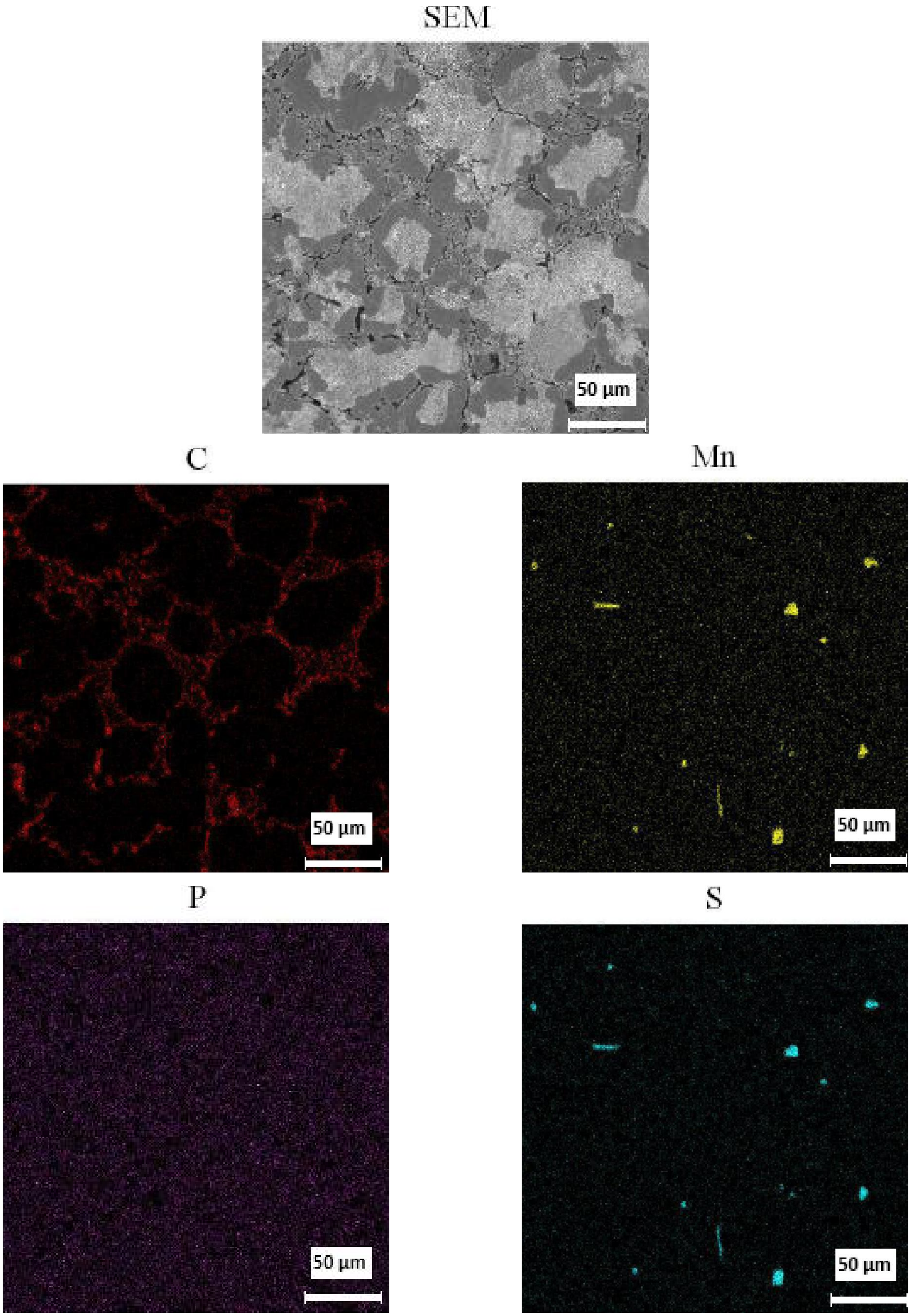

Figure 4 : SEM micrograph together with X-ray maps of semi-solid casting (f_s=0.18).

previous[5-7] investigations stated that shape and size of the primary austenite particles is highly affected with the use of cooling plate due to the resultant high cooling rate of the melt. High cooling rate of melt increases the number of the effective nuclei relative to the rate at which latent heat is dissipated. Increasing primary fraction of solid causes an increment of under cooling and changes graphite morphology. Tensile strength of semi-solid processed gray cast iron is relatively high compared with ordinary one. The values of both the tensile strength and the elongation depend on the fraction of solid. It is found that graphite morphology (size and type), primary solid agglomeration and cutting graphite network have a large influence on both the properties in semi-solid processing. The total fracture strength is observed to depend on the graphite morphology as well as the matrix contribution that mainly depends on fraction of solid.

Figures 1-4 show SEM micrograph and X-ray maps of ordinary semi-solid casting with different grades of fraction of solids. It is clear that morphology and distribution of C, Mn, S elements are highly affected by the semi-solid processing. In case of P element, it is clear that its morphology and distribution has no clear affect. The very low weight concentration of P (0.02%) in the original composition iron may be the reason behind that. Figure 5 shows the effect of fraction of solid on Mn and S zones size in the semi-solid processed gray cast iron. For low fraction of solid (fs =0.12), it is clear that increasing fraction of solid decreases Mn and S zones sizes and changes its distribution. Further increasing of fraction of solid (*f*s from = 0.12) results in increasing of Mn and S zones sizes. Previous study[7], which considered as primary part of this work, show that for low fraction of solid (*f*s =0.12), increasing fraction of solid results in an increment in the tensile strength as well as the elongation, comparing with the ordinary gray cast iron due to the fine graphite formation (fine graphite type A). Further increase of fraction of solid (*fs* = 0.14–0.18) leads the graphite morphology to become finer graphite (type D), consequently the tensile strength decreased. Finally, increment of fraction of solid (*f*s > 0.18) leads to increasing of tensile strength due to the agglomerations of primary solid particles. Those agglomerations of the primary solid particles cut the network of the eutectic graphite.

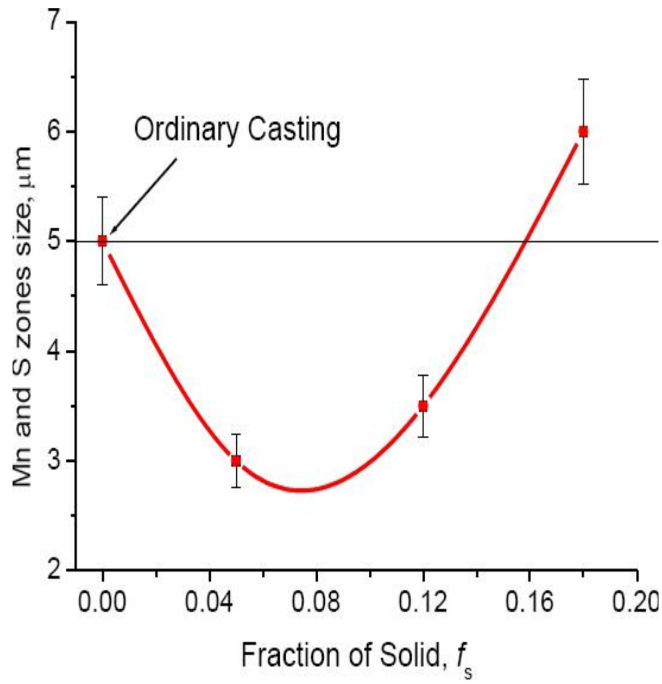

Figure 5 : Effect of fraction of Solid on Mn and S zones size.

Solidification is basically governed by nucleation and growth phenomena. Normally, for solidification systems having partition coefficient $k < 1$, growth does not take place with complete mixing of solute elements within the growing solid phase and rejected into the bulk liquid to form a highly enriched boundary layer ahead of solidification front[10]. For present semi-solid processes using cooling plate technique, it is important to understand the implication of forced convection and solute distribution in the context of semi-solid casting. In the present study the cooling plate is used for production the semi-solid slurry. Where, the rheocast microstructures are the result of a combination between the rapid solidification and the flow-related fragmentation of the dendrites in semi-solid state.

At low fraction of solid, the cooling rate due to cooling plate and velocity of slurry flow of solid have a considerable effect on the primary solid particles. At high fraction of solid, the amount of solid in the slurry increases, which nucleate in the cooling plate wall washed away from the wall into the slurry will have very small velocity relative to the flow of slurry. This result together with the convection effect may lead to the presence of coarse solid particles in the semisolid state, which was the result of the agglomeration and coalescence of the solid particles. These agglomeration and coalescence at high fraction of solid are considered to be the reason of formation of micro-segregated Mn and S coarse zones. That not the case for low fraction of solid, where the higher cooling rate compared with the ordinary casting and relatively higher velocity of slurry over the cooling plate surface lead to higher nucleation and good particles distribution.

Using the data shown in present study (see Figure 5) and the data shown in previous study[7], processing window(f_s = 0.02 to f_s= 0.13) can be withdrawn for production of semi-solid gray cast iron castings combine higher strength, higher elongation and minimum micro-segregation compared with ordinary gray iron casting.

CONCLUSION

Effects of semi-solid processing of gray iron using cooling plate technique were investigated. Increasing fraction of solid has significant effect on the primary particle morphology as well as micro-segregation of gray iron cast structure. Elements segregation decreases with increasing the fraction of solid up to 0.12. It is found that elements segregation start to increasing by increasing fraction of solid above 0.12. Further increasing of fraction of solid (fs = 0.12) results in increasing of Mn and S elements segregation. Processing window (fs = 0.02 to fs = 0.13) can be withdrawn for production of semi-solid gray cast iron castings combine higher strength, higher elongation and minimum micro-segregation compared with ordinary gray iron casting.

ACKNOWLEDGEMENTS

The authors would like to thank staff of Central Metallurgical R&D Institute, CMRDI for their kind help in measurements, Prof. Dr. A. A. Nofal, Prof. Dr. M.A. Waly of Foundry Technology Lab., CMRDI, Egypt, and Dr. N. Fathy of Physics dept., College of Science, University of Hail, KSA for their useful discussion and technical support.

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