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Effect of Sr addition on an Al–7Si–10 vol.% SiC_p cast composites

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Abstract

The effect of additions of Sr (in the range 0.05–0.5%) on the microstructural characteristics of Al–7 wt.% Si–10 vol.% SiC_p composites have been studied. Optical microscopy (OM), SEM, EDS, WDS microanalysis techniques and X-ray diffraction powder techniques have been used for the characterization of the composites. It was found that Sr concentrations between 0.05 and 0.20 facilitates incorporation of higher volume fraction of SiC particles and also does not contribute to the overall modification of the matrix. However, at higher wt.% of Sr, Sr-rich compounds were found. These Strontium rich compounds were located at the matrix–ceramic interface.

Keywords: MMCs; Interface; Microstructures; Particle-reinforcement

1. Introduction

Al–Si–SiC_p cast composites are one of the most important system studied. A variety of manufacturing processes including stir casting (vortex method) and PM routes have been employed to produce these composites on commercial scale [1]. This is because of its simplicity, flexibility and capability of manufacturing large size components/products (ingots or near shape casting). The success of the vortex method depends on the wetting characteristics between the reinforcement and liquid metal matrix. This phenomenon influences the incorporation and dispersion of reinforcement in the melt. Additions of some alloying elements in small quantities improve the distribution of SiC particles. Some alloying elements previously investigated are: Ca, Li, La, Ti, Cu [2]. Mg in particular [3] enhances the wetting characteristics better than the others. The presence of Mg improves wetting by reducing the surface tension of the liquid metal. Furthermore Mg has a tendency to segregate to the reinforcement–matrix interface thus reducing the Mg content in the matrix. In general the addition of about 1 wt.% Mg produces a beneficial effect on the wetting phenomenon. To modify the eutectic phase of monolithic hypoeutectic Al–Si cast alloys, elements such as Na, Sr or Sb are often added to these alloys. The presence of small amounts of Sr (0.02–0.04 wt.%) produces a globular-fibrous eutectic silicon morphology. This microstructural characteristics improves the mechanical properties of monolithic alloys [4]. In this work an Al–7 wt.% Si–10 vol.% SiC_p composites with different Sr concentration were studied with optical microscopy (OM)-image analysis, SEM-EDS-WDS microanalysis and X-ray diffraction techniques, in order to obtain information on the effect of the Sr on the cast composites. In particular SEM-EDS-WDS techniques were employed to reveal the matrix–SiC interface characteristics. For reference, unreinforced–unmodified, unreinforced–modified and reinforced–unmodified samples were also studied.

2. Methods and materials

The material characterized in this study was an Al–7 wt.% Si reinforced with 10 vol.% of SiC_p. The SiC particle had an average diameter of 38 μm. Cylindrical samples of 2.5 cm in diameter and of 15 cm in length, respectively, were manufactured by the vortex method and subsequently poured into a metallic mould. Composite samples were obtained with different concentration of Sr in order to evaluate the effect on

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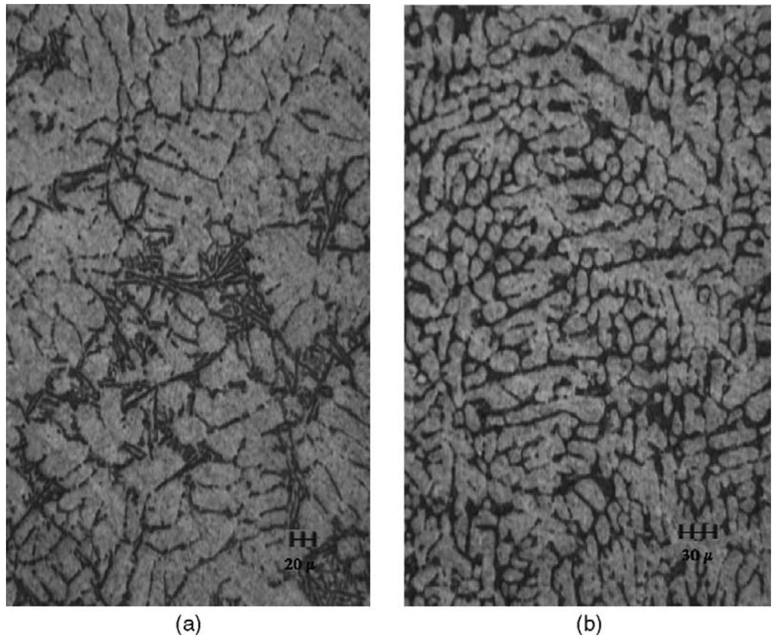

Fig. 1. (a) Structure of unreinforced–unmodified Al–7 wt.% Si alloy. (b) Structure of unreinforced–modified alloy with 0.02 wt.% Sr.

the Si morphology, incorporation of SiC_p in the matrix and presence of Sr compounds. Samples with the following concentrations were studied: 0.01, 0.05, 0.10, 0.20, 0.30, 0.40 and 0.50 wt.% Sr. The samples were prepared by conventional metallographic techniques. Using the immersion-swab technique samples were etched with freshly prepared 1 vol.% hydrofluoric acid. These conditions were very important because over etching dissolves the Sr compound and under etching does not reveal properly the microstructure, specially the Sr compounds. The etched samples were observed by OM coupled to image analysis system. In each sample ten fields of view were examined in order to obtain the SiC particle density (particles/mm^2) and dendritic arm spacing (DAS in μm). EDS and WDS studies by line scan and elemental maps were done on the samples with high Sr concentration.

3. Results and discussion

In the cast unreinforced–unmodified and unreinforced–modified (0.02 wt.% Sr) Al–7 wt.% Si alloys, the common phases detected were α(Al) solid solution and Al–Si eutec-

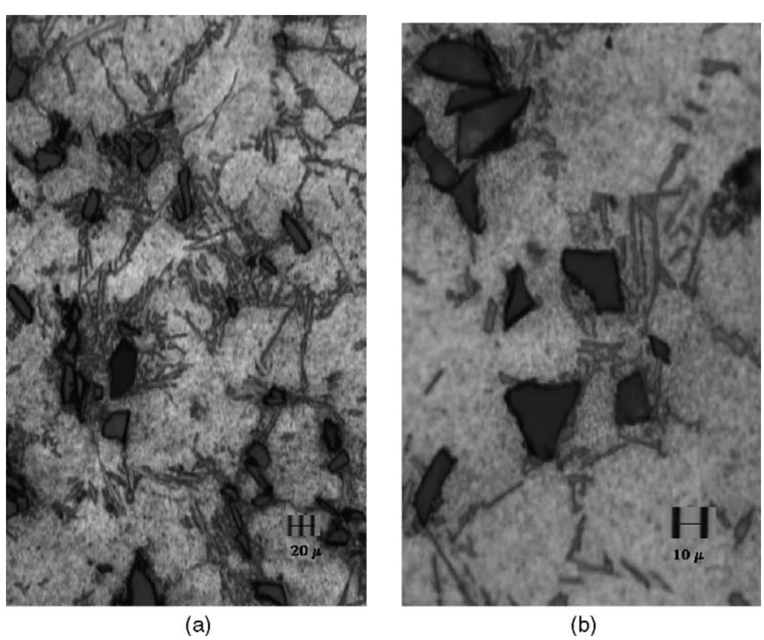

Fig. 2. (a) Structure of unmodified composite Al–7 wt.% Si–10 vol.% SiC_p. (b) Detail of the Al–Si eutectic phase.

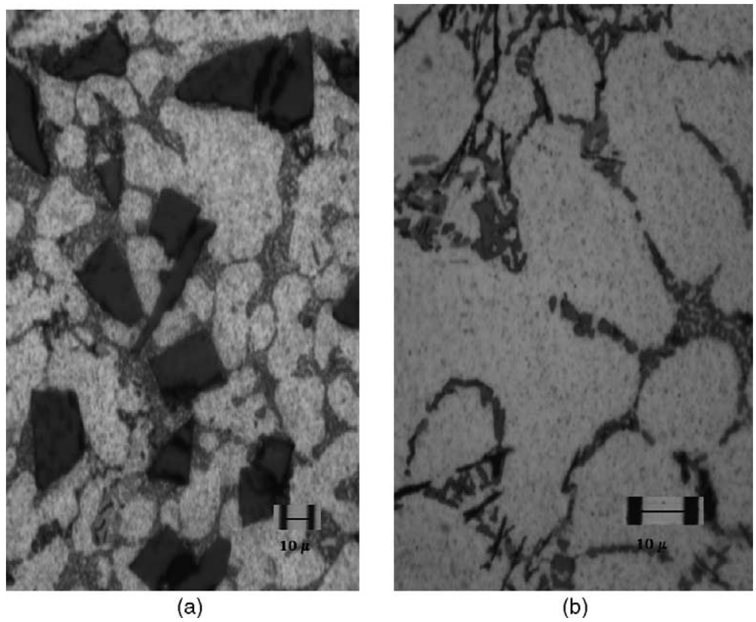

Fig. 3. (a) Cast composite with 0.05 wt.% Sr (high magnification). (b) Cast composite with 0.20 wt.% Sr (showing zones with slightly overmodification).

tic phase or eutectic network. The first sample shows acicular eutectic silicon morphology and the sample treated with Sr shows a globular-fibrous eutectic silicon morphology Fig. 1a and b). In order to compare the effect of the presence of SiC on the matrix and stirring during composite manufacturing, a sample of unmodified Al–7 wt.%–10 vol.% SiC_p was analyzed. The structural characteristics as well as the phases found in the unmodified–unreinforced matrix and unmodified cast composite are similar. In both cases eutectic silicon morphology was acicular. Stirring and additions of SiC_p on the matrix do not produce modifications of the eutectic silicon (Fig. 2a and b). However, eutectic silicon in the composites modified with 0.05 wt.% Sr shows a fine globular-fibrous morphology (indicating acceptable modification rating [5]). Also eutectic Si particles in this sample were slightly bigger than those in the unreinforced–modified Al–7 wt.% Si monolithic alloy, see Fig. 3a. Composites treated with 0.10 and 0.20 wt.% Sr are

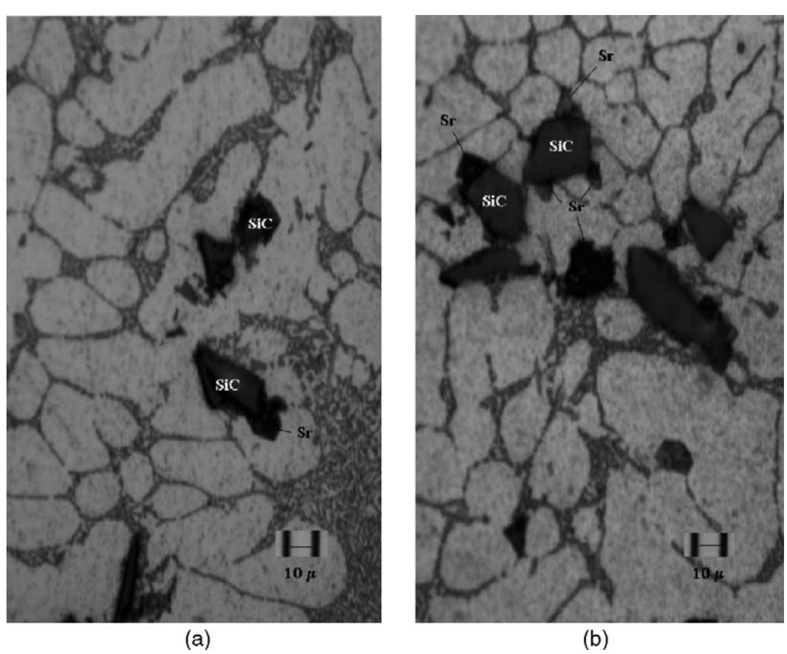

Fig. 4. (a) Composite with 0.3 wt.% Sr (showing the size and distribution of Sr-particles). (b) Composite with 0.4 wt.% Sr (showing the increased of size and quantity of Sr-particles).

Table 1
Average DAS values of monolithic alloy and composites with different Sr levels

Samples	Monolithic alloy			Cast composites (wt.% Sr)						
	Non-modified	Modified	Non-modified	0.01	0.05	0.10	0.20	0.30	0.40	0.50
DAS (μm)	18	19	15.5	17	18	18.5	17.5	16	15.5	17

Table 2
Effect of Sr concentration (wt.%) on SiC particle density (particles/mm^2)

	wt.% Sr							
	No Sr	0.01	0.05	0.10	0.20	0.30	0.40	0.50
Particle density	80	120	250	265	190	170	130	95

compared with 0.05 wt.% Sr cast composite. The Si eutectic phase was smaller in both cases. This indicates a good modification rating. Addition of larger amount of Sr (up to 0.20 wt.%) concentration does not lead to overmodification of the matrix. In other words, eutectic Si phase did not coarsen. Detailed analysis of 0.20 wt.% Sr composite revealed the presence of slightly over modified zones of the eutectic Si phase, Fig. 3b. In cast composites with Sr concentration between 0.05 to 0.20 wt.%, Sr rich particles were not found. In these samples, the SiC particle distribution was essentially homogeneous in the matrix, with the exception of a few clusters of SiC particles.

Microstructure of composites with 0.3 wt.% Sr showed small polyhedral particles of a Sr rich phase. These particles were located at the matrix–SiC interface, Fig. 4a. The size and amount of these particles were increased with the increase in Sr concentration. Composites with 0.3, 0.4 and 0.5 wt.% Sr showed over modification of eutectic silicon phase, Fig. 4b (coarsening of Si eutectic phase). Dendritic arm spacing (DAS) were measured in both monolithic samples (unmodified and modified) and reinforced composites and all the samples exhibit similar DAS values, Table 1 presents the results of the average DAS values.

In order to assess the effect of Sr adding on the efficiency of incorporation of SiC in the casting, SiC particle density (particles by mm^2) was measured using quantitative metallographic technique. The results are presented in Table 2.

According to Table 2 the efficiency of incorporation of SiC_p is the highest in samples with 0.05 and 0.10 wt.% Sr. Composites containing Sr were analyzed by X-ray diffraction powder technique. The results corroborated the presence of $SrAl_2Si_2$ in composites containing more than 0.3 wt.% Sr, see Fig. 5. Results obtained suggest that (a) a fraction of Sr is used to promote the modification of Al–Si eutectic network of the matrix and (b) another fraction could improve the wetting between Al and Si liquid metal matrix and SiC_p. This is linked to a high concentration of particles, absence of overmodification and non-precipitation of Sr rich compound in composites with Sr concentration between 0.05 and 0.20 wt.%.

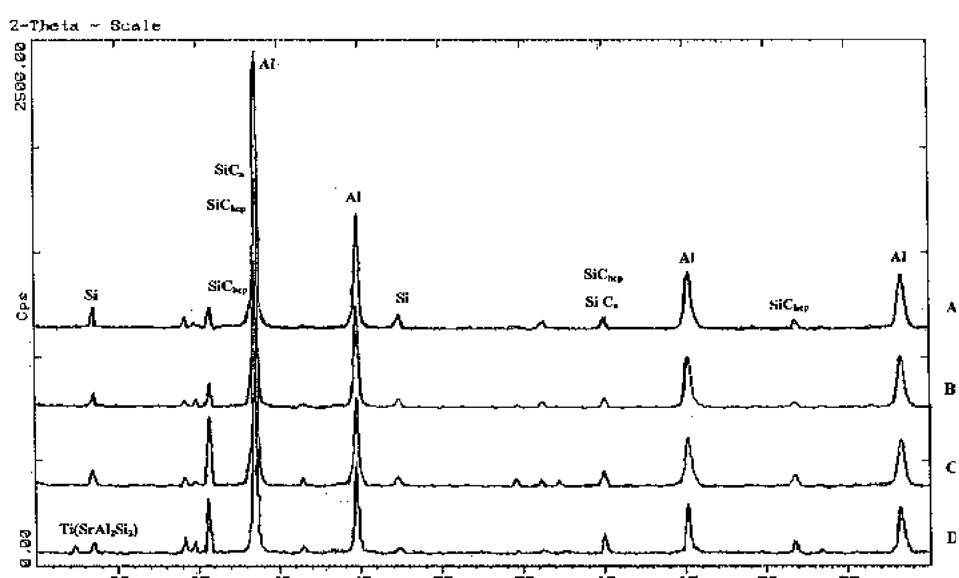

Fig. 5. X-ray diffraction patterns for different samples (A) with 0.01 wt.% Sr, (B) with 0.05 wt.% Sr, (C) with 0.20 wt.% Sr and (D) with 0.50 wt.% Sr.

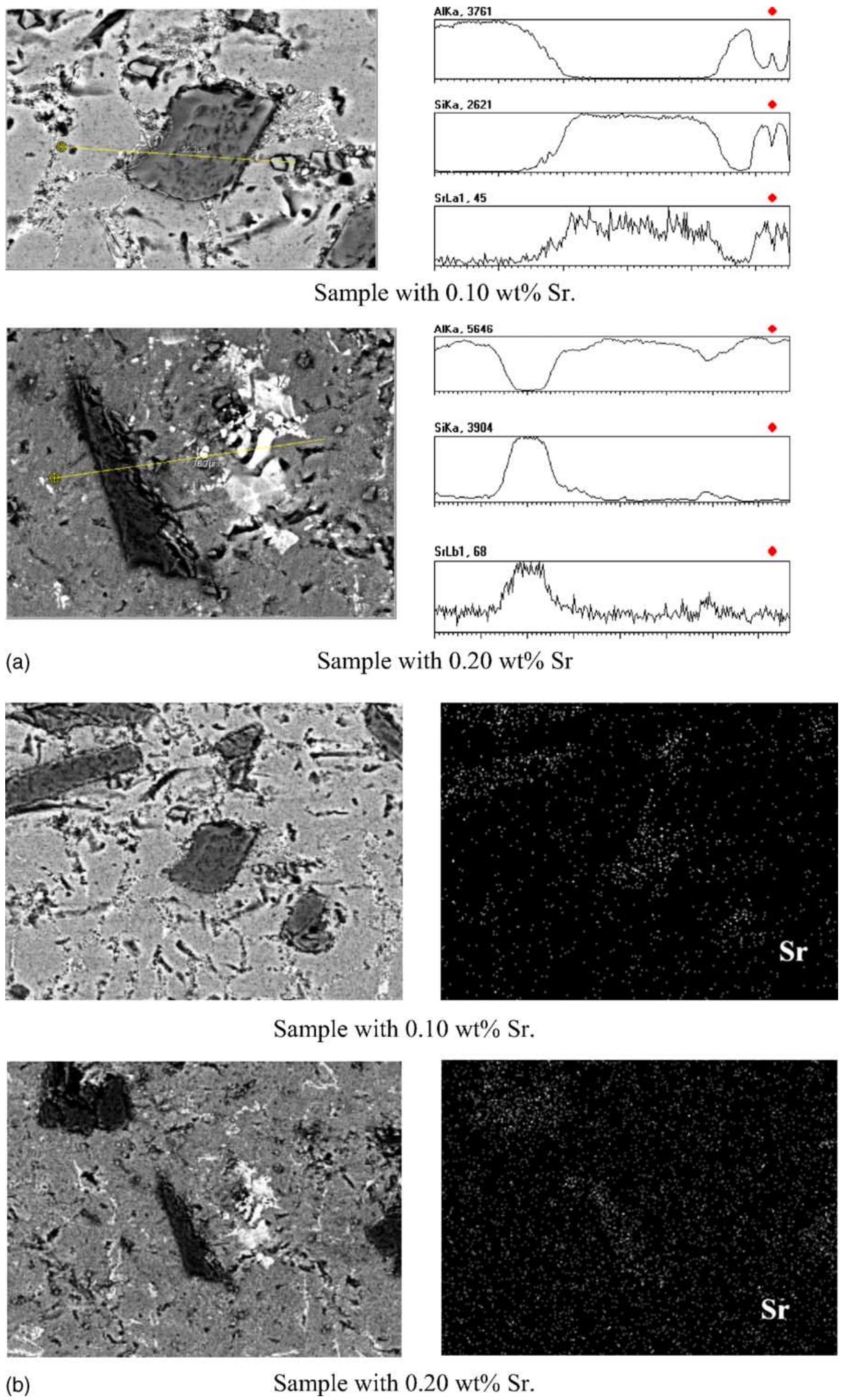

Fig. 6. (a) EDS line scan for sample with 0.10 and 0.20 wt.% Sr. (b) Elemental maps of Al, Si and Sr for before same sample.

Based on observations relating Al–Si eutectic morphology, efficiency of SiC incorporation and absence or presence of Sr rich phase following can be inferred that:

(a) Additions of Sr in the range 0.05–0.20% leads to excellent modification of Si in Al–Si–SiC_p composites.
(b) Addition of SiC_p and Sr do not affect DAS.
(c) Efficiency incorporation of SiC_p in Al–Si alloy is maximum with additions of Sr in the range of 0.05–0.10 wt.%.
(d) Addition of 0.20 wt.% Sr or higher lead to SiC clusters, porosity. In addition Sr rich particles were observed at matrix–SiC interface

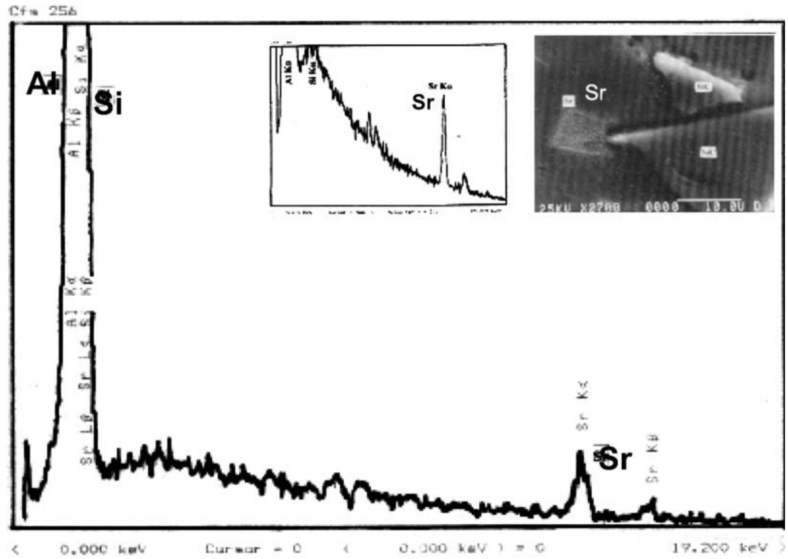

Fig. 7. WDS Sr elemental mapping and spectrum of Sr rich particle for the composite with 0.40 wt.% Sr.

EDS line scan analysis of 0.10 and 0.20 wt.% Sr composite across matrix–SiC–matrix are shown in Fig. 6a and b. The Sr concentration profile reveals a Sr peak over the white particle. It also shows a higher Sr concentration over the SiC particle compared to that in the matrix.

The set of EDS elemental maps on the same region shown in Fig. 6b, indicated the Sr rich particles were located exactly on the matrix–SiC interface. Small quantities of Sr apparently cover the SiC particle. Similar results were observed in samples containing 0.4 wt.% Sr. In an attempt to determinate the composition of Sr-rich particle, WDS analysis were carried out. The average composition of Sr particles was 41.5 wt.% Sr, 32 wt.% Al and 24.5 wt.% Si. After carrying out a large number of measurements, it seems that there is not exact ratio between Sr:Al:Si, but the formula could be $SrAl_2Si_2$, based on ternary phase diagram [6]. Fig. 7 shows the WDS Sr elemental mapping and spectrum from Sr rich particle located on the interface SiC_p–matrix.

4. Conclusions

Addition of Sr has a profound effect on the microstructure of Al–7 wt.% Si–10 vol.% SiC_p composites.

In cast composites, the addition of Sr in the range 0.05–0.20 wt.%:

- promotes a higher incorporation of SiC_p in the matrix;
- results in a good modification rating of Al–Si eutectic phase;
- the coarsening of Al–Si eutectic phase was not promoted;
- a fraction of Sr apparently improves the wettability.

Addition of more than 0.20 wt.% Sr results in:

- overmodification of Al–Si eutectic phase;
- Sr rich compounds precipitated at the ceramic–matrix interface;
- according to results of EDX and X-ray diffraction the Sr rich compound is $SrAl_2Si_2$, based on ternary Al–Si–Sr phase diagram.

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