Effect of Ce, Co, B on formation of LaCo$_{13}$-structure phase in La(Fe,Si)$_{13}$ alloys

Xiang CHEN$^{1,2}$, Yun-gui CHEN$^1$, Yong-bai TANG$^1$, Ding-quan XIAO$^1$

1. School of Materials Science and Engineering, Sichuan University, Chengdu 610065, China; 2. College of Engineering and Technology, Neijiang Normal University, Neijiang 641002, China

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Abstract: The effect of Ce, Co, and B on the formation of 1:13 phase in La(Fe, Si)$_{13}$ alloys was investigated by XRD, SEM and EDS. The results show that Co can improve the formation of 1:13 phase in as-cast LaFe$_{11.6-x}$Co$_x$Si$_{1.4}$ alloys, but in as-cast and annealed LaFe$_{11.6-x}$Si$_{1.4}$-Co$_x$ alloys, it will hamper the formation of 1:13 phase and help the formation of $\alpha$-Fe(Co, Si) solid solution. Ce$_{2}$Fe$_{17}$ phases will form when $x$ reaches a certain value in as-cast and annealed La$_{1-x}$Ce$_x$Fe$_{11.5}$Si$_{1.5}$ alloys. B can improve the formation of 1:13 phase accompanied with Fe$_2$B phase in as-cast LaFe$_{11.6}$B$_y$Si$_{1.4}$ alloys. B improves the formation of $\alpha$-Fe solid solution in LaFe$_{11.6-x}$Si$_{1.4}$B$_y$ alloys, and there is almost only $\alpha$-Fe in as-cast and annealed LaFe$_{11.6-x}$Si$_{1.4}$B$_y$Si$_{1.5}$ alloy. In all, the introduction of Co, B, and Ce cannot eliminate the $\alpha$-Fe phases in corresponding alloys prepared by the high-temperature and short-time annealing process.

Key words: LaFe$_{11.6-x}$Si$_x$ alloys; high-temperature and short-time annealing; 1:13 phase

1 Introduction

The LaFe$_{11.6-x}$Si$_x$ alloys with 1.1$\leq x \leq$1.6 have several advantages in comparison with the other magnetic refrigeration materials with giant magnetocaloric, such as the low price of starting materials and excluding deleterious elements, which have been investigated extensively [1–4]. In LaFe$_{11.6-x}$Si$_x$ alloys, Si element is very important to form and stabilize LaCo$_{13}$-type phase, lower the content of Si, and prolong the annealing time. In fact, the binary LaFe$_{11.6}$ alloy does not exist due to a positive formation heat between La and Fe. In hypothetical LaFe$_{11.6}$ alloy, the Fe atoms would be located at two different crystals sites: Fe I at the Wyckoff position 8b (0, 0, 0) and Fe II at 96i (0, y, z) in a ratio of 1:12. The La atoms are located at 8a (1/4, 1/4, 1/4) surrounded by 24 Fe II atoms, and one central Fe I atom and its nearest neighbors of 12 Fe II atoms form a cluster. In the LaCo$_{13}$-type LaFe$_{11.6-x}$Si$_x$ alloys, Si atoms in LaFe$_{11.6-x}$Si$_x$ randomly occupy both 8b and 96i sites [5]. The substitution of elements with similar chemical properties is the common way of improving comprehensive properties of materials. Ce substituting La in La$_{1-x}$Ce$_x$Fe$_{11.6-x}$Si$_x$ alloys has been investigated extensively [6–9]. The reason is that the single LaCo$_{13}$-type structure can be obtained when the CeFe$_{13-x}$Si$_x$ (2.4$\leq x \leq$2.6) alloys are annealed only for 12 h [10]. For Fe element, most researches are on the Co substitution [11–14]. The reason may be that LaCo$_{13}$ with $T_c$=1297 K is the only stable alloy among the RT$_{13}$ alloys (R=rare earth elements, T=transition elements) [15]. The result shows that the preferential substitution of Co atoms at Fe II 96i site effectively lowers the La–Fe positive formation heat to stabilize the cubic LaCo$_{13}$-type structure in La(Fe,Co)$_{13}$-Si$_x$ alloys [16]. Besides the LaFe$_{11.6-x}$Si$_{1.4}$B$_y$ alloys, the investigations on the nominal substitution for Si were rarely reported. As grain refining agents in steel, boron atoms are also introduced in the form of interstitial atoms in LaFe$_{11.6-x}$Si$_x$B$_y$ alloys. Addition of boron improves formation of the LaCo$_{13}$-type phase in as-cast LaFe$_{11.6-x}$Si$_x$ alloys [18]. In addition, the result of the introduction of B as the substitution element for Fe or Si in LaFe$_{11.6-x}$Si$_x$ alloys shows that all the annealed samples exhibited a cubic LaCo$_{13}$-type structure with a few percent of $\alpha$-Fe and La-rich phases in LaFe$_{11.6-x}$Si$_x$, LaFe$_{11.6-x}$B$_y$Si$_x$, and LaFe$_{11.6-x}$B$_y$Si$_{1.5}$ samples [19]. Up to now, the studies about the introduction of Ce, Co, B in LaFe$_{11.6-x}$Si$_x$ alloys have been focused on the influence of magnetocaloric

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Corresponding author: Xiang CHEN; Tel: +86-28-85405670; E-mail: gxucx@163.com

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properties. However, there are few elaborate studies on the effects of the substitution of Ce and Co for La and Fe, respectively, also the introduction of B as interstitial or substitutional atoms on the formation of LaCo$_{13}$-structure phase in as-cast and annealed LaFe$_{11.6}$Si$_{1.4}$ alloys have not been studied yet.

In this work, the phase and microstructure of the as-cast and annealed LaFe$_{11.6}$Co$_x$Si$_{1.4}$, La$_{1-x}$Ce$_x$Fe$_{11.5}$Si$_{1.5}$, LaFe$_{11.6}$B$_x$Si$_{1.4}$, LaFe$_{11.6}$Si$_{1.4}$B$_x$, and LaFe$_{11.6}$Si$_{1.4}$B$_x$ alloys are investigated. In addition, based on the random distribution of Si atoms on both of Fe sites in LaCo$_{13}$-type LaFe$_{13-x}$Si$_x$ alloys, the effects of Co and B on the formation of LaCo$_{13}$-structure phase in LaFe$_{11.6}$Si$_{1.4}$-Co$_x$, LaFe$_{11.6}$Si$_{1.4}$B$_x$, and LaFe$_{11.6}$Si$_{1.4}$B$_x$ alloys are investigated.

2 Experimental

Approximately 10 g polycrystalline LaFe$_{11.6}$Co$_x$Si$_{1.4}$, LaFe$_{11.6}$Co$_x$Si$_{1.4}$-Co$_x$, La$_{1-x}$Ce$_x$Fe$_{11.5}$Si$_{1.5}$, LaFe$_{11.6}$B$_x$-Si$_{1.4}$, LaFe$_{11.6}$Si$_{1.4}$B$_x$, LaFe$_{11.6}$Si$_{1.4}$B$_x$, and LaFe$_{11.6}$Si$_{1.4}$B$_x$ buttons were fabricated, respectively by conventional arc melting in a high purity argon atmosphere using high purity (La 99.9%, Ce 99.9%, Fe 99.9%, Si 99.9999%, Co 99.9%, B 99.9%) elements after the alloys were re-melted five times to achieve a homogeneous composition. The as-cast alloys were divided into two parts. One part was annealed by different high-temperature and short-time processes in a molybdenum wire furnace of 3×10$^3$ Pa, followed by furnace cooling down to room temperature. The phase purity and crystal structure were determined by powder X-ray diffraction (XRD) using Cu (K$_{α}$) radiation (Dandong DX—2600). Scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) observation were carried out with Hitachi S—3400N.

3 Results and discussion

Figure 1 shows the XRD patterns of as-cast LaFe$_{11.6}$Co$_x$Si$_{1.4}$ and LaFe$_{11.6}$Co$_x$Si$_{1.4}$-Co$_x$ alloys. By analyzing and indexing the X-ray diffraction patterns, it can be found that the as-cast LaFe$_{11.6}$Co$_x$Si$_{1.4}$ alloys mainly consist of $α$-Fe and LaFeSi phases. As non-equilibrium solidification phase, a certain amount of 1:13 phase is also observed, but the amount of 1:13 phase is different in the as-cast alloys. The diffraction intensity ratio of 1:13 phase has no obvious change with $x=0.0$, 0.3 and 0.5, but there is a sharp increase when $x=0.7$ in as-cast LaFe$_{11.6}$Co$_x$Si$_{1.4}$ alloys. This indicates that Co can improve 1:13 phase in as-cast LaFe$_{11.6}$Co$_x$Si$_{1.4}$ alloys only when Co reaches a certain amount.

![Figure 1 XRD patterns of as-cast LaFe$_{11.6}$Co$_x$Si$_{1.4}$ and LaFe$_{11.6}$Co$_x$Si$_{1.4}$-Co$_x$ alloys](image1)

Figure 2 shows the backscattered SEM micrograph of as-cast LaFe$_{10.9}$Co$_0.7$Si$_{1.4}$ alloy. The mixed matrix consists of the main black (position I) and white (position II) microstructures. According to the result of the EDS analysis of as-cast LaFe$_{10.9}$Co$_0.7$Si$_{1.4}$, shown in Table1, the black and white microstructures are $α$-Fe and LaFeSi phases, respectively. There is a certain of grey microstructure around the black grain, and grey microstructure changes gradually from light grey to dark grey with the increase of Fe and the decrease of La and Si, which is corresponding to the diffusion process between $α$-Fe atom and La and Si atoms of LaFeSi phase. In the grey microstructure, there is a small amount of 1:13 phase around the $α$-Fe grain, which accords with the character of peritectic reaction: Fe+LaFeSi$\rightarrow$LaFeSi$_{13}$ [20]. In addition, Co can substitute Fe to form substitution solid solution in each phase of as-cast LaFe$_{10.9}$Co$_0.7$Si$_{1.4}$ alloy. Because of the random distribution of Si atoms on both Fe sites in LaCo$_{13}$-type LaFe$_{13-x}$Si$_x$ alloys, Si can be regarded as the substitution element for Fe in LaCo$_{13}$-type LaFe$_{13-x}$Si$_x$ alloys like the substitution of Co for Fe.

For further studying the effect of Co on the 1:13 phase formation in LaFe$_{13-x}$Si$_x$ alloys, Co is introduced...
Table 1 EDS analysis of different positions in Fig. 1

<table>
<thead>
<tr>
<th>Position</th>
<th>x(La)/%</th>
<th>x(Fe)/%</th>
<th>x(Co)/%</th>
<th>x(Si)/%</th>
<th>Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>01.18</td>
<td>86.20</td>
<td>05.26</td>
<td>07.36</td>
<td>α-Fe</td>
</tr>
<tr>
<td>II</td>
<td>30.59</td>
<td>26.24</td>
<td>08.02</td>
<td>35.14</td>
<td>LaFeSi</td>
</tr>
<tr>
<td>III</td>
<td>27.21</td>
<td>37.17</td>
<td>07.64</td>
<td>27.99</td>
<td>Unknown</td>
</tr>
<tr>
<td>IV</td>
<td>11.99</td>
<td>69.69</td>
<td>05.80</td>
<td>12.53</td>
<td>1:13 phase</td>
</tr>
</tbody>
</table>

as the substitution element for Si in LaFe_{11.6}Si_{1.4-x}Co_x alloys. The XRD patterns of as-cast LaFe_{11.6}Si_{1.4-x}Co_x alloys show that the amounts of 1:13 and LaFeSi phases gradually decrease and the amount of α-Fe(Co, Si) solid solution increases with the increase of Co content, as shown in Fig. 1. When x reaches 0.7, there is almost only α-Fe(Co, Si) solid solution. This indicates that Co will hamper the formation of 1:13 and LaFeSi phases and improve the formation of α-Fe(Co, Si) solid solution in as-cast LaFe_{11.6}Si_{1.4-x}Co_x alloys.

Figure 3 shows the XRD patterns of LaFe_{11.6-x}Co_xSi_{1.4} and LaFe_{11.6}Si_{1.4-x}Co_x alloys annealed at 1523 K for 5 h. One can find that the annealed LaFe_{11.6-x}Co_xSi_{1.4} alloys consist of the cubic 1:13 phase and a small amount of impurity phase of α-Fe. From the backscattered SEM micrographs of the annealed LaFe_{11.6-x}Co_xSi_{1.4} alloys, as shown in Fig. 4, the amount of impurities including α-Fe and LaFeSi phases has no obvious change with the increase of Co content, which indicates that the introduction of Co as the substitution for Fe in LaFe_{13-x}Si_x alloys cannot reduce the amount of impurities with the same annealing time or increase the diffuse reaction speed of Fe + LaFeSi→La(Fe,Si)_{13}. In the annealed LaFe_{11.6-x}Si_{1.4-x}Co_x alloys, there is a certain amount of 1:13 phase when x≤0.5, but α-Fe is also a main phase. The annealed LaFe_{11.6}Si_{1.4-x}Co_y alloys mainly consist of α-Fe(Co, Si) solid solution, while the amount of 1:13 phase is quite small.

Because the single LaCo_{13}-type structure can be obtained when the CeFe_{13-x}Si_x (2.4≤x≤2.6) alloys are annealed for only 12 h [10], the substitution of Ce for La in LaFe_{13-x}Si_x alloys may improve the formation or reduce the annealing time [21]. Figure 5 shows the XRD patterns of the as-cast La_{1-x}Ce_xFe_{1.5}Si_{1.5} alloys (0≤x≤0.5), from which one can find that the main phases are α-Fe and LaFeSi phases, and the minor phase of 1:13 phase is observed in those alloys. When x=0.33, the amount of 1:13 phase is the largest, the diffraction peaks ratio of 1:13 phase is almost the same as that in other as-cast La_{1-x}Ce_xFe_{1.5}Si_{1.5} alloys. In addition, there is a certain amount of Ce_{2}Fe_{17} phase when x reaches 0.5, which indicates that the substitution of Ce for La in as-cast La_{1-x}Ce_{2}Fe_{1.5}Si_{1.5} alloys has some limits.

Our previous work showed that the Ce_{2}Fe_{17} phase cannot be eliminated by annealing at 1373 K for 2 h + 1523 K for 5 h and then furnace cooling to room temperature [22]. In this work, the as-cast La_{1-x}Ce_{2}Fe_{1.5}Si_{1.5} alloys were annealed at 1523 K for 5 h and then furnace cooled to room temperature. Figure 6 shows XRD patterns of the annealed La_{1-x}Ce_{2}Fe_{1.5}Si_{1.5} alloys.
alloys with \( x = 0, 0.1, 0.2, 0.33, 0.35, \) and 0.5, respectively. The main phase is 1:13 phase, and impurity phase is a small amount of \( \alpha\text{-Fe} \) in La\(_{1-x}\)Ce\(_x\)Fe\(_{11.5}\)Si\(_{1.5}\) alloys for \( 0 \leq x \leq 0.33 \). Ce\(_{2}\)Fe\(_{17}\) phase begins to appear in La\(_{0.65}\)Ce\(_{0.35}\)Fe\(_{11.5}\)Si\(_{1.5}\) alloy. There is a large amount of Ce\(_{2}\)Fe\(_{17}\) phase when \( x \) reaches 0.5. All of those indicate that the substitution of Ce for La in annealed La\(_{1-x}\)Ce\(_x\)Fe\(_{11.5}\)Si\(_{1.5}\) alloys also has some limits. The maximal Ce substitution for La to form continuous solid solution in annealed La\(_{1-x}\)Ce\(_x\)Fe\(_{11.5}\)Si\(_{1.5}\) alloys is \( x = 0.33 - 0.35 \). In addition, the diffraction peaks of the cubic 1:13 phase have obvious shift to high angle with the increase of Ce content, as shown in Fig. 6. This is a signature of lattice contraction, which attributes to the radius of Ce (0.27 nm) which is smaller than that of La (0.278 nm). This also shows that Ce can substitute La in La\(_{1-x}\)Ce\(_x\)Fe\(_{11.5}\)Si\(_{1.5}\) alloys with LaCo\(_{13}\)-structure to form solid solution.

The backscattered SEM micrographs of La\(_{1-x}\)Ce\(_x\)Fe\(_{11.5}\)Si\(_{1.5}\) annealed at 1523 K for 5 h are shown in Fig. 7. One can find that there is small amount of Ce\(_{2}\)Fe\(_{17}\) in La\(_{0.67}\)Ce\(_{0.33}\)Fe\(_{11.5}\)Si\(_{1.5}\), which cannot almost be observed in the La\(_{0.6}\)Ce\(_{0.3}\)Fe\(_{11.5}\)Si\(_{1.5}\). When \( x \) reaches 0.5, and the Ce\(_{2}\)Fe\(_{17}\) occupies about 30% in volume proportion. Those also show that the maximal Ce substitution for La to form continuous solid solution in La\(_{1-x}\)Ce\(_x\)Fe\(_{11.5}\)Si\(_{1.5}\) alloys is \( x = 0.33 - 0.35 \). In addition, the EDS result of the annealed La\(_{0.5}\)Ce\(_{0.5}\)Fe\(_{11.5}\)Si\(_{1.5}\) shows that the ratios of La and Ce in \( \alpha\text{-Fe(Si)} \) solid solution are 1.2% and 0.7%, respectively, which indicates that the solid solution range of La and Ce in \( \alpha\text{-Fe(Si)} \) solid solution is very small. In Ce\(_{2}\)Fe\(_{17}\) alloy, there is certain amount of La and Si, thus Ce\(_{2}\)Fe\(_{17}\) alloy should be the (La, Ce)\(_{2}(\text{Fe,Si})_{17}\) solid solution.

As grain refining agents in steel, B atoms are also introduced in the form of interstitial atoms in LaFe\(_{11.6}\)Si\(_{1.4}\)B\(_{y}\) alloys. According to the XRD patterns of as-cast LaFe\(_{11.6}\)Si\(_{1.4}\)B\(_{y}\) alloys, as shown in Fig. 8, the addition of B improves formation of the LaCo\(_{13}\)-type
phases in as-cast LaFe$_{11.6}$Si$_{1.4}$ alloys, and the amount of 1:13 phase increases with the increase of B content. But the introduction of B will result in the formation of Fe$_2$B phase and the amount also increases with the increase of B content. The effects of B as the substitution element for Fe or Si in LaFe$_{11.5}$B$_{0.5}$Si$_{1.1}$ and LaFe$_{11.6}$B$_{0.5}$Si$_{1.5}$ alloys on the magnetocaloric properties were studied in detail in Ref. [19], but the influence on the formation of 1:13 phase and microstructure has few reports. In Fig. 8, the XRD patterns of as-cast LaFe$_{11.6-x}$B$_x$Si$_{1.4}$ alloys show that B as the substitution element for Fe can improve the formation of 1:13 phase. The amount of 1:13 phase increases with the increase of B content, and there is a large amount of 1:13 phase when x reaches 0.5. However, there is also Fe$_2$B phase, and the amount increases with the increase of B content like as-cast LaFe$_{11.6}$Si$_{1.4}$ alloys. For the substitution of B for Si, the amount of 1:13 phase in as-cast LaFe$_{11.6}$Si$_{1.4}$B$_{0.3}$ or LaFe$_{11.6}$Si$_{1.4}$B$_{0.5}$ alloys is larger than that in LaFe$_{11.6}$Si$_{1.4}$, but is less than that in LaFe$_{11.6}$B$_{0.5}$Si$_{1.4}$ or LaFe$_{11.6}$Si$_{1.4}$B$_{0.5}$ with the same B content. In the as-cast LaFe$_{11.6}$Si$_{1.4}$Co$_{0.7}$ alloy, there is almost only $\alpha$-Fe solid solution [23].

![XRD patterns of as-cast LaFe$_{11.6-x}$B$_x$Si$_{1.4}$ alloys](image)

**Fig. 8** XRD patterns of as-cast LaFe$_{11.6-x}$B$_x$Si$_{1.4}$ and LaFe$_{11.6}$Si$_{1.4}$B$_x$ alloys

Our previous work showed that the Fe$_2$B phase cannot be eliminated by annealing at (1373 K, 1.5 h) + (1523 K, 5 h) and then furnace cooling to room temperature [23]. In this work, the as-cast LaFe$_{11.6}$Si$_{1.4}$B$_x$, LaFe$_{11.6}$B$_{0.5}$Si$_{1.4}$ and LaFe$_{11.6}$Si$_{1.4}$B$_x$ alloys were annealed at 1523 K for 5 h and then furnace cooled to room temperature. In Fig. 9, the XRD patterns of the annealed LaFe$_{11.6}$Si$_{1.4}$B$_x$, and LaFe$_{11.6}$B$_{0.5}$Si$_{1.4}$ alloys show that the main phase is 1:13 phase and the impurity includes $\alpha$-Fe and Fe$_2$B phases, and the amount of Fe$_2$B phase increases with the increase of B content, which indicates that the annealing process in this work cannot eliminate Fe$_2$B phase. In the annealed LaFe$_{11.6}$Si$_{1.4}$B$_x$ alloys with x=0.3 and 0.5, there is a large amount of 1:13 phase besides $\alpha$-Fe, which is different from the annealed LaFe$_{11.6}$Si$_{0.7}$Co$_{0.7}$ alloy. In addition, there is a certain amount of Fe$_2$B phase. In all, the introduction of B as interstitial atoms or the substitution for Fe in as-cast LaFe$_{11.6-x}$Si$_{1.4}$B$_x$ alloys can obviously improve the formation of 1:13 phase, but the Fe$_2$B as accompanying phase of B introduction cannot be eliminated by high-temperature and short-time annealing. Thus there is a certain amount of Fe$_2$B phase in annealed LaFe$_{11.6}$Si$_{1.4}$B$_x$, LaFe$_{11.6}$B$_{0.5}$Si$_{1.4}$ and LaFe$_{11.6}$Si$_{1.4}$B$_x$ alloys, and the amount increases with the increase of B content, which is harmful for the magnetocaloric effect [23]. Thus, how to hamper or eliminate Fe$_2$B phase needs further study.

![XRD patterns of LaFe$_{11.6}$Si$_{1.4}$B$_x$, LaFe$_{11.6}$B$_{0.5}$Si$_{1.4}$ and LaFe$_{11.6}$Si$_{1.4}$B$_x$ alloys](image)

**Fig. 9** XRD patterns of LaFe$_{11.6}$Si$_{1.4}$B$_x$, LaFe$_{11.6}$B$_{0.5}$Si$_{1.4}$ and LaFe$_{11.6}$Si$_{1.4}$B$_x$ alloys annealed at 1523 K for 5 h

Figure 10 shows the backscattered SEM image of the annealed LaFe$_{11.6}$B$_{0.5}$Si$_{1.4}$B$_x$, and LaFe$_{11.6}$B$_{0.5}$Si$_{1.4}$B$_x$ alloys with x=0.1 and 0.3, respectively. Compared with the microstructure of LaFe$_{11.6}$Si$_{1.4}$ annealed at 1523 K for 5 h, one can find that the grain of 1:13 phase is small and that of $\alpha$-Fe is much larger. The Fe$_2$B and $\alpha$-Fe mix, and locate the boundary of 1:13 phase grain. In addition, there is small white microstructure (LaFeSi phase) at the boundary of 1:13 phase grain. On a whole, whether the substitution of Co for Si in LaFe$_{11.6}$Si$_{1.4}$B$_x$Co$_{0.7}$ alloys or the substitution of B for Si in LaFe$_{11.6}$B$_{0.5}$Si$_{1.4}$B$_x$ alloys both will make the formation of 1:13 phase difficult or the amount of 1:13 phase small compared with the same substituted amount of Co or B for Fe. Si element can be adjusted to the formation heat, and there is a critical value of Si content in LaFe$_{11.6}$Si$_{1.4}$B$_x$ alloys. The formation heat is positive when the amount of Si is smaller than the critical value, which results in no 1:13 phase and only $\alpha$-Fe solid solution when Co and B reach a certain amount in as-cast or annealed LaFe$_{11.6}$Si$_{1.4}$Co$_{0.7}$, LaFe$_{11.6}$Si$_{1.4}$B$_x$, alloys. Thus, how to decrease the formation heat in substitution of Si deserves further study.
and annealed LaFe$_{11.6}$Si$_{1.4}$ solution when Co and B reach a certain amount in as-cast LaFe$_{11.6}$ alloys. The substitution of Ce for La has some limits in the formation of 1:13 phase accompanied with Fe$_2$B phase in as-cast and annealed La$_{1-x}$Ce$_x$Fe$_{11.4}$Si$_{1.6}$ compounds [J]. Journal of Magnetism and Magnetic Materials, 2003, 264(2): 209–213.


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4 Conclusions

Co can substitute Fe in different phases of as-cast LaFe$_{11.6}$Co$_x$Si$_{1.4}$ alloys and the amount of 1:13 phase increases when x reaches 0.7. But the introduction of Co cannot reduce the annealing time or increase the diffuse reaction speed, which results in the fact that the amounts of impurities including α-Fe and LaFeSi phases have no obvious change with the increase of Co content in annealed LaFe$_{11.6}$-α-Fe solid solution when Ce reaches 0.35, and the amount increases with the increase of Ce in annealed La$_{1-x}$Ce$_x$Fe$_{11.5}$Si$_{1.5}$ alloys. Ce$_2$Fe$_{17}$ phase begins to be observed when x reaches 0.35, and the amount increases with the increase of Ce in annealed La$_{1-x}$Ce$_x$Fe$_{11.5}$Si$_{1.5}$ alloys.

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Ce, Co, B 对 La(Fe,Si)_{13} 合金中 LaCo_{13} 结构 1:13 相形成的影响

陈 湘 1,2, 陈云贵 1, 唐永柏 1, 肖定全 1

1. 四川大学 材料科学与工程学院，成都 610065；
2. 内江师范学院 工程技术学院，内江 641002

摘 要：通过 XRD、SEM、EDS 等方法，研究Ce、Co、B 对 La(Fe,Si)_{13} 合金中 LaCo_{13} 结构 1:13 相形成的影响。结果表明，在铸态 LaFe_{11.6}Si_{1.4} 合金中，Co 能够促进铸态 1:13 相的形成，但同时会有 Fe_{2}B 相产生，在铸态以及热处理后的 LaFe_{11.6}Si_{1.4} 合金中，Co 能够促进 α-Fe(Co,Si) 固溶体相的形成。在铸态 La_{1-x}Ce_{x}Fe_{11.5}Si_{1.5} 合金中，当 Ce 的含量达到一定值后，合金中将有 Ce_{2}Fe_{17} 相形成，且随着 Ce 含量的增加而增加。在铸态 LaFe_{11.6}B_{x}Si_{1.4} 合金中，B 能够促进 1:13 相的形成，但同时会有 Fe_{2}B 相产生，在铸态以及热处理后的 LaFe_{11.6}Si_{1.4}Co_{x} 和 LaFe_{11.6}Si_{1.4}B_{x} 合金中，Co 能够促进 α-Fe(Co,Si)固溶体相的形成。在 La_{1-x}Ce_{x}Fe_{11.5}Si_{1.5} 合金中，基本上只有 α-Fe(Co,Si) 固溶体相存在，这点与 LaFe_{11.6}Si_{1.4}Co_{x} 相似。在高温短时热处理的 La(Fe,Si)_{13} 合金中，引入 Ce、Co、B 并不能消除杂相 α-Fe，且同时会伴随新的杂相的形成，如 Ce_{2}Fe_{17} 和 Fe_{2}B 相。

关键词：LaFe_{13-x}Si_{x} 合金；高温短时热处理；1:13 相

(Edited by Hua YANG)