Vol. 51, No. 7

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2023-03-19

ChinaRxiv

Abstract

Fe-based oxide dispersion strengthened (ODS) alloys co-reinforced with Al2O3 and NiAl were fabricated via aluminothermic synthesis, and the size, distribution, and kinetic behavior of Al2O3 nanoparticles were investigated. The research indicates that the addition of TiO2 gel can form Al2O3 nanoparticles approximately 10 nm in size, which, due to interfacial energy effects, all become associated with NiAl. When the mass fraction of added TiO2 gel reaches 1.24%, the alloy achieves a maximum tensile strength of 849 MPa while retaining an elongation of 13%.

Full Text

Vol. 51, No. 7
July 2015, pp. 791–798

Study on Thermite Synthesis of an Fe-Based ODS Alloy Co-Strengthened by Nano-Al_2O_3 and NiAl*

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Abstract An Fe-based oxide dispersion strengthened (ODS) alloy co-strengthened by Al_2O_3 and NiAl was prepared by the thermite synthesis method. The size, distribution, and motion behavior of Al_2O_3 nanoparticles were investigated. The results show that the addition of TiO_2 xerogel can form Al_2O_3 nanoparticles with a size of about 10 nm. Owing to the effect of interfacial energy, all of these Al_2O_3 nanoparticles combine with NiAl. When the mass fraction of added TiO_2 xerogel reaches 1.24%, the tensile strength of the alloy reaches a maximum value of 849 MPa while maintaining an elongation of 13%.

Keywords nano-Al_2O_3; interfacial energy; tensile properties; oxide dispersion strengthened alloy

CLC number TG148 **Document code** A **Article number** 0412-1961(2015)07-0791-08

Al_2O_3 NANOPARTICLE AND NiAl REINFORCED Fe-BASED ODS ALLOYS SYNTHESIZED BY THERMITE REACTION

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Supported by National Natural Science Foundation of China (No. 51472015)

Manuscript received 2014-08-29, in revised form 2014-11-21

ABSTRACT Fe-based oxide dispersion strengthened (ODS) alloys are widely used in advanced aircrafts and gas turbine engines due to their good high temperature strength, creep properties and hot-corrosion resistance. Traditionally, ODS alloys are prepared by internal oxidation and mechanical alloying. However, internal oxidation cannot be applied to multi-component alloys. It is difficult to guarantee other elements from being oxidized. On the other hand, the use of mechanical alloying will bring in impurities in the process of ball milling which will compromise the purification of alloy particles surface. In this work, TiO_2 xerogel prepared by using sol-gel method was added to the thermite powder mixture and the mixture was then ignited by using a tungsten filament. It solidified rapidly after the molten metal flowed into the bottom of the graphite mold because of the gravity field. It was found that Al_2O_3 and NiAl were formed in situ in the molten metal. Therefore, Al_2O_3 nanoparticles and NiAl reinforced Fe-based ODS alloy could be prepared by using this method. The phase composition and morphology of the Fe-based ODS alloy were investigated by using the combination of OM, SEM, TEM, XRD. The size of Al_2O_3 nanoparticles and the influence of Brownian motion and interface energy on the distribution and movement of the Al_2O_3 nanoparticles were investigated. The mechanical properties of the Fe-based ODS alloy with different contents of TiO_2 xerogel was investigated by using mechanical properties testing machine. The experimental results show that the Fe-based ODS alloy consists of ferrite α-FeNiCrAl, NiAl, and Al_2O_3 nanoparticles. The diameter of Al_2O_3 nanoparticles is approximately 10 nm. Both Brownian motion and interface energy affect the motion of Al_2O_3 nanoparticles

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* Supported by National Natural Science Foundation of China, No. 51472015
Received: 2014-08-29; revised: 2014-11-21
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DOI: 10.11900/0412.1961.2014.00479

during the solidification, however, interface energy is dominant. The interface energy between Al_2O_3 nanoparticles and NiAl is lower than that of Al_2O_3 and ferrite α-FeNiCrAl. Therefore, nearly all the Al_2O_3 nanoparticles are connected with the NiAl phase. Higher TiO_2 xerogel additions increase the tensile strengthen and elongation of the Fe-based ODS alloy. When the content of TiO_2 xerogel is 1.24%, the tensile strength of the Fe-based ODS alloy attains 849 MPa and the elongation is 13%. Continuing adding the TiO_2 xerogel results in the release of large quantities of gas which produces holes in the Fe-based

ODS alloy and these holes decrease the mechanical properties of the alloy.

KEY WORDS Al_2O_3 nanoparticle, interfacial energy, tensile property, oxide dispersion strengthened alloy

Fe-Cr-Al alloys have excellent oxidation resistance and, as heat-resistant materials, can be used for long periods above 900 °C. However, their high-temperature mechanical properties are poor, and at present they still cannot be applied as high-temperature structural materials. If a high-temperature-stable coherent strengthening phase can be introduced into heat-resistant Fe-Cr-Al alloys, it may greatly improve the high-temperature mechanical properties of iron-based alloys. In the 1970s, Pickering[^1] added Ni and Al alloying elements to ferritic stainless steel and successfully developed 17-7PH ferritic stainless steel strengthened by a coherent NiAl phase using an aging process. Subsequently, researchers carried out relatively detailed studies on the growth kinetics of the NiAl phase and the corresponding mechanical properties of the materials. Taillard and Pineau[^2] studied the growth kinetics of the NiAl phase in ferrite and the mechanical properties of ferritic alloys. Zhu et al.[^3] studied the high-temperature creep properties of FeNiCrAl alloys. However, stainless steels strengthened by the NiAl phase obtained through aging have certain shortcomings. First, the volume fraction of the NiAl phase obtained by aging is low, generally below 10%, making its strengthening effect difficult to compare with that of the γ' phase in high-temperature nickel-based alloys. Second, during high-temperature service the NiAl phase readily coarsens, its volume fraction decreases, and the coherent strengthening effect is lost[^3]. Therefore, increasing the volume fraction of the NiAl phase, preventing its growth, or reducing its growth rate is the key to improving the high-temperature mechanical properties of NiAl-phase-strengthened iron-based alloys.

Oxide dispersion strengthening is one of the most effective methods currently available for improving the high-temperature performance of materials. Traditional oxide dispersion strengthening processes usually employ internal oxidation[^4] and mechanical alloying[^5-^7]. The internal oxidation method uses alloying elements that are present in small amounts in the alloy and have a strong affinity for oxygen to react with oxygen, forming oxide particles as a dispersion-strengthening phase. This method is feasible for certain special metals or alloys with simple compositions, but it presents problems for most alloys, because it is difficult to ensure that other alloying elements are not oxidized. In addition, the size of the dispersed phase is relatively large, and the degree of oxidation is difficult to control. Mechanical alloying (MA) is the most widely used method at present; prealloyed powder and fine oxide particles are subjected to high-energy ball milling in a protective gas atmosphere. However, during high-energy ball milling by the MA method, the oxygen content is not easily controlled, and impurities are readily introduced.

Preliminary work by our research group[^8] found that replacing the traditional mechanical alloying process with an aluminothermic reaction has unique advantages in preparing nano-oxide-strengthened iron-based alloys. Adding TiO_2 sol

to a multicomponent aluminothermic agent composed of Fe_2O_3 + NiO + Cr_2O_3 + CrO_3 + Al can, in the Fe alloy melt formed by the reaction, in situ generate nano-Al_2O_3 particles with a high volume fraction. The nano-Al_2O_3 particles often coexist with intermetallic compounds such as NiAl. Studies[^9-^11] have also found that, by designing the composition of a multicomponent aluminothermic agent, a NiAl intermetallic compound with a high volume fraction (greater than 50%) can be generated in the reaction product. Moreover, the morphology of the NiAl phase changes with the Al content in the aluminothermic agent; when the Al content is appropriate, the NiAl phase can appear as an interpenetrating network with the ferrite matrix. Therefore, an Al_2O_3/FeNiCrAl-NiAl iron-based oxide-dispersion-strengthened alloy with a network structure and jointly strengthened by NiAl and nano-Al_2O_3 particles can be synthesized in situ by an aluminothermic reaction. More importantly, the nano-sized Al_2O_3 particles formed in situ by the reaction will effectively inhibit the growth and coarsening of the NiAl phase, enabling the coherent strengthening effect of the NiAl phase to be retained to higher temperatures, thereby further improving the high-temperature strength and high-temperature creep resistance of iron-based oxide dispersion strengthened (ODS) alloys.

In this work, an aluminothermic reaction is used to synthesize in situ an iron-based ODS alloy with a network structure, co-strengthened by NiAl and nano-Al_2O_3 particles. Al_2O_3, NiAl, and the metal matrix are all generated in situ by chemical reactions. By calculating the Brownian motion of nanoparticles during solidification and the interfacial energy, the movement of Al_2O_3 nanoparticles in the liquid phase and their preferential distribution in the NiAl phase during amplitude-modulated decomposition are comprehensively analyzed. The relationship between the addition of different amounts of TiO_2 sol and the generation of Al_2O_3 nanoparticles, as well as the mechanical properties of the samples, is investigated, in order to determine the optimal addition amount and lay a foundation for preparing composite materials with excellent properties.

1 Experimental Methods

An iron-based ODS alloy co-strengthened by Al_2O_3 and NiAl was prepared by rapid solidification via an aluminothermic reaction. The aluminothermic raw materials mainly included Fe_2O_3, NiO, CrO_3, Cr_2O_3, Al powder, and TiO_2 xerogel powders with different contents prepared by a sol–gel method. The compositions of the aluminothermic agents are shown in Table 1.

After the aluminothermic agents were ground and mixed uniformly, they were loaded into a graphite crucible with a hole in the bottom; the hole at the bottom was sealed with Al foil. The graphite crucible was placed in an oven and dried at 120 °C for 2 h. The graphite crucible was then removed and placed on a Cu mold, and the aluminothermic agent was ignited by passing an electric current through a W wire. The experimental apparatus is shown schematically in Fig. 1.

Schematic of the thermite reaction setup

Figure 1: Schematic of the thermite reaction setup

Sketch of tensile sample

Figure 2: Sketch of tensile sample

Table 1 Chemical composition of experimental thermite

(mass fraction / %)

Content of TiO_2 / %	Al	NiO	Fe_2O_3	CrO_3	Cr_2O_3
0	29.03	12.77	34.38	14.62	9.19
0.87	28.78	12.66	34.08	14.50	9.11
1.24	28.69	12.63	33.96	14.44	9.08
1.98	28.45	12.51	33.70	14.33	9.03

The phase composition of the prepared iron-based ODS alloy was analyzed using a D/max-2200PC X-ray diffractometer (XRD), with a Cu target, an accelerating voltage of 40 kV, a current of 40 mA, and a scanning rate of 6°/min. The microstructure was observed using a BX51M metallographic microscope (OM) and a JSM-6010LA scanning electron microscope (SEM). The microstructure of the composite material was observed using a JEM-2100F transmission electron microscope (TEM), with an accelerating voltage of 200 kV and a resolution of 0.2 nm. TEM samples were prepared by ion milling using a GL-696F ion thinner. The tensile properties of the composite material were tested using a SANS5100 universal testing machine; the tensile specimen is shown in Fig. 2. Strain gauges of model BX120-2AA (resistance 119.9 Ω, gauge factor 2.08% ± 1%) were attached to the tensile section of the sample, and a JC-4A intelligent static strain indicator was connected to record the deformation in the elastic strain region. The curve measured by the strain indicator was fitted with the curve measured by the tensile testing machine to obtain a relatively accurate stress–strain curve. For each type of specimen, three samples were taken to measure tensile strength, and the average value was used as the measurement result.

Fig.1 Schematic of the thermite reaction setup

Fig.2 Sketch of tensile sample (unit: mm)

Fig. 3

Figure 3: Fig. 3

2 Experimental Results and Discussion

2.1 Microstructure

Figure 3 shows OM images of ODS alloys synthesized by thermite reaction using thermites with different TiO_2 sol contents. As can be seen from Fig. 3a, when no sol is added, the alloy microstructure consists of equiaxed grains, and the equiaxed grain diameter varies from several tens of micrometers to 100 μm. When 0.87% TiO_2 sol is added, the alloy microstructure still consists of equiaxed grains (Fig. 3b); compared with the sample without added sol, the equiaxed grains become smaller, with sizes mostly between 30-40 μm. When 1.24% TiO_2 sol is added, the alloy consists of fine dendrites, with dendrite sizes less than 10 μm (Fig. 3c). When 1.98% TiO_2 sol is added, the dendrite size becomes larger, defects in the sample increase, and micrometer-scale black particles appear (Fig. 3d).

Figure 4 shows the XRD pattern of the ODS alloy prepared with the addition of 0.87% TiO_2 sol. It can be seen that the alloy is mainly composed of two phases: the bcc-structured iron matrix α-FeNiCrAl and NiAl. The lattice constant of the NiAl intermetallic compound is 0.286 nm, which is extremely close to that of α-FeNiCrAl (0.287 nm). Therefore, the diffraction peaks of the two phases basically overlap. However, at the diffraction angle $2\theta = 30.78^{\circ}$, a weak (100) superlattice diffraction peak of the NiAl phase appears, indicating the presence of the NiAl intermetallic compound in the alloy.

Figure 5 shows SEM images of the iron-based ODS alloy samples. In the microstructure of the sample prepared without added sol, the grains are surrounded by relatively complete gray grain boundaries (Fig. 5a); gray and black phases exist inside the grains, and the particle-like black phase has a size of about 10 nm (Fig. 5b). Combined with the XRD spectrum, the black phase is judged to be the NiAl intermetallic compound. After adding 0.87% TiO_2 sol, the intergranular and intragranular regions exhibit different morphologies (Fig. 5c and d): black granular strengthening phases exist between grains, while the intragranular structure is lamellar. The intragranular region is composed of strip-like NiAl strengthening phase and α-FeNiCrAl matrix, forming a woven structure. This woven structure is very similar to the typical spinodal decomposition structure of $Fe_{30}Ni_{20}Mn_{25}Al_{25}$, and is preliminarily judged to be formed by liquid-phase spinodal decomposition during solidification[1]. Adding

Fig. 3 OM images of Fe-based oxide dispersion strengthened (ODS) alloy synthesized by thermite reaction process with TiO_2 xerogel contents of 0 (a), 0.87% (b), 1.24% (c) and 1.98% (d)

[1]12

Fig. 4

Figure 4: Fig. 4

Figure 5

Figure 5: Figure 5

Fig. 4 XRD spectrum of Fe-based ODS alloys synthesized by thermite reaction process with addition of 0.87% TiO_2 xerogel

When 1.24% TiO_2 xerogel was added, the microstructure of the alloy changed greatly, from equiaxed grains to fine dendrites (Fig. 5e and f). Granular phases were present between the dendrites; the structure within the dendrites was very fine, and the woven-like structure was no longer obvious. When 1.98% TiO_2 xerogel was added (Fig. 5g and h), the dendrites became finer, and the inter-dendritic regions became smaller and narrower.

Figure 6 shows the TEM images and diffraction patterns of the Fe-based ODS alloy sample prepared with the addition of 0.87% TiO_2 xerogel. As can be seen from Fig. 6a, the α-FeNiCrAl and NiAl two phases are distributed alternately, forming a lath-like structure. Laths with relatively small widths are distributed continuously and in parallel within a single phase; laths in different directions are perpendicular to one another and are interconnected. From the selected-area electron diffraction pattern shown in Fig. 6b (region 1 in Fig. 6a), it can be seen that this lath phase is composed of the NiAl intermetallic compound and α-Al_2O_3 two phases. The lath-like strengthening phase has a width of about 50 nm and a length of 200–500 nm. Black α-Al_2O_3 with a diameter of about 10 nm is uniformly distributed on the strengthening phase, and its formation is related to the addition of TiO_2 xerogel. Figure 6c is the selected-area electron diffraction pattern of the matrix (region 2 in Fig. 6a). It can be seen that the matrix is ferritic α-FeNiCrAl with a bcc structure. The TiO_2 xerogel exists spatially as a three-dimensional network structure composed of -O-Ti-O-. The xerogel surface adsorbs atomic groups such as -OH, -O-$COCH_3$, and -O-C_4-O_9 [13,14]. When the reaction temperature reaches about 300 ℃, atomic groups such as -OH detach from the xerogel surface, chemical bonds break, and carbonization ultimately occurs. At the same time, the -O-Ti-O- three-dimensional network structure breaks; O combines with C atoms to form a -C-O-Ti-O-C- nanostructure. As the temperature continues to rise, the C atoms in the intermediate oxide products burn and volatilize, and Al replaces Ti, ultimately forming -O-Al-O- (Al_2O_3) nanoparticles. Because nano-Al_2O_3 particles have lower interfacial energy with the NiAl phase [15–20], they preferentially combine with the NiAl phase. Figure 6d is a bright-field image of the interdendritic region. A blocky particulate phase with a size of about 50 nm exists between the dendrites. Figure 6e is the selected-area electron diffraction pattern of the blocky phase and surrounding matrix; the blocky phase is still the NiAl phase with a bcc structure, and the matrix is still the ferritic phase with a bcc structure.

Fig. 5 SEM images of Fe-based ODS alloys synthesized by the thermite reaction process with addition of 0 (a, b), 0.87% (c, d), 1.24% (e, f) and 1.98% (g, h) TiO_2 xerogel at low (a, c, e, g) and high (b, d, f, h) magnification

matrix α-FeNiCrAl.

2.2 Formation and Migration Behavior of Al_2O_3 Nanoparticles

The melting point of Al_2O_3 is 2045 ℃. It forms first in the high-temperature melt, and Al_2O_3 nanoparticles can migrate only in the liquid-phase melt. This also indirectly proves that the NiAl intermetallic compound is not a precipitated phase; rather, in the high-temperature melt there are regions enriched in Ni and Al elements, adjacent to which is Fe,

Fig. 6 TEM images and selected-area electron diffraction patterns of the Fe-based ODS alloy synthesized by thermite reaction when the TiO_2 xerogel addition is 0.87%.

Fig. 6 TEM images (a, d) and SAED patterns (b, c, e) of Fe-based ODS alloy synthesized by thermite reaction process with addition of 0.87% TiO_2 xerogel in dendrite (a, b), base (c) and interdendritic (d, e) regions (Figs. 6b, c and e correspond to the SAED patterns of rectangle areas 1, 2 in Fig. 6a and rectangle area in Fig. 6d, respectively)

Cr-element-enriched regions, that is, liquid-phase spinodal decomposition, also occurred. Because the interfacial energy between nano-Al_2O_3 particles and the melt enriched in Ni and Al elements is relatively low, the bonding of nano-Al_2O_3 particles with the Ni- and Al-rich melt reduces the overall free energy of the system. TEM image analysis has already shown that the Al_2O_3 nanoparticles are almost entirely distributed on the lath-like NiAl phase. The motion of Al_2O_3 nanoparticles in the high-temperature melt is mainly affected by two factors: interfacial energy and Brownian motion. Under the influence of interfacial energy, the particle migration velocity V is given by [21–24]:

$$V = \frac{\Delta\sigma d}{3\eta R}\left(\frac{a_0}{d}\right)^n \tag{1}$$

where a_0 is the interatomic spacing in the liquid metal, η is the viscosity, d is the distance between the particle and the interface, $\Delta\sigma$ is the interfacial energy, R is the particle radius, and n is the exponent. Among them, $\Delta\sigma_{Al_2O_3} = 1.38$ J/m^2 [18], $\Delta\sigma_{Fe} = 1.80$ J/m^2 [19], and $\Delta\sigma_{NiAl} = 1.40$ J/m^2 [20]. Since $a_0 = 0.344$ nm, $\eta = 6 \times 10^{-3}$ Pa · s [25], $R = 5$ nm, and $n = 4$ [23], at a position 50 nm from the NiAl-phase melt, the migration velocity of the Al_2O_3 nanoparticles is $V_{Al_2O_3-NiAl} = 250$ nm/s, and the migration velocities at distances of 5 and 10 nm are 24.9 and 3.12 mm/s, respectively. Thus, when only the influence of interfacial energy is considered, the Al_2O_3 nanoparticles migrate toward the NiAl phase, and the closer they are to the NiAl phase, the faster the migration velocity.

Brownian motion also has a significant influence on nanoparticles suspended in a high-temperature melt. When Al_2O_3 nanoparticles are suspended in the melt, they are struck by atoms or atomic groups from different directions in the melt. Because the nanoparticles are very small, the impacts they receive at each instant cannot cancel one another, so the nano-Al_2O_3 particles continuously change their velocity and direction of motion, thereby producing Brownian motion. According to the Langevin theory [26], the mean distance S of Brownian motion of nanoparticles in a fluid in any direction is:

$$S^2 = 2Dt \tag{2}$$

$$D = \frac{K_B T}{3\pi\eta l} \tag{3}$$

In the equation, D is the particle diffusion coefficient, t is time, l is the particle diameter, $K_B = 1.381 \times 10^{-23}$ J/K is the Boltzmann constant, and T is the thermodynamic temperature. When the temperature is 2000 K, the time required for nano-Al_2O_3 particles to move 50 nm under the influence of Brownian motion is 2.56×10^{-5} s. That is to say, within 10^{-5} s in the melt, nano-Al_2O_3 particles can move from Fe- and Cr-rich regions to Ni- and Al-rich regions. Owing to the effect of interfacial energy, the probability that nano-Al_2O_3 particles bound to Ni- and Al-rich regions will move out of those regions is much smaller than the probability that they will enter those regions. As solidification proceeds, a plate-like structure in which nano-Al_2O_3 particles are combined with NiAl is ultimately formed, and the overall morphology is woven-like.

2.3 Mechanical properties of the composite materials

Figures 7 and 8 show the tensile curves, tensile strength, and elongation of the Fe-based ODS alloys as functions of the TiO_2 xerogel content in the thermite agent. Compared with the FeNiCrAl-NiAl phase without nano-Al_2O_3 reinforcement, the tensile strength and fracture strength of the Fe-based ODS alloy strengthened by Al_2O_3 nanoparticles are significantly improved. The tensile strengths of the Fe-based ODS alloys prepared with 0.87% and 1.24% TiO_2 xerogel are increased by 1.5 and 1.8 times, respectively, compared with the Fe-based ODS alloy prepared without xerogel addition. When the addition amount is 1.24%, the tensile strength reaches 849 MPa, and the elongation also reaches 13%. When the TiO_2 xerogel addition amount is 1.98%, the tensile strength of the alloy decreases slightly to 720 MPa, and the elongation also decreases slightly.

Fig. 7 Stress-strain curves for Fe-based ODS alloys synthesized by thermite reaction process with different contents of TiO_2 xerogel addition

Fig. 8 Effect of different contents of TiO_2 xerogel on tensile strength and elongation for Fe-based ODS alloys synthesized by thermite reaction process

Fig. 7 Stress-strain curves for Fe-based ODS alloys synthesized by thermite reaction process with different contents of TiO2 xerogel addition

Figure 6: Fig. 7 Stress-strain curves for Fe-based ODS alloys synthesized by thermite reaction process with different contents of TiO2 xerogel addition

Fig. 8 Effect of different contents of TiO2 xerogel on tensile strength and elongation for Fe-based ODS alloys synthesized by thermite reaction process

Figure 7: Fig. 8 Effect of different contents of TiO2 xerogel on tensile strength and elongation for Fe-based ODS alloys synthesized by thermite reaction process

Figure 9 shows the tensile fracture morphologies of the Fe-based ODS alloys at different TiO_2 xerogel addition amounts. The fracture morphology of the xerogel-free FeNiCrAl-NiAl composite is a typical brittle fracture (Fig. 9a). Obvious river patterns and spherical Al_2O_3 inclusion particles can be observed on the fracture surface. During tensile deformation, these large Al_2O_3 inclusion particles become crack sources, which is the main reason for the reduced tensile strength of the composite. After adding TiO_2 xerogel, the number of Al_2O_3 nanoparticles gradually increases, and the fracture morphology gradually changes to plastic fracture characteristics. When 0.87% TiO_2 xerogel is added (Fig. 9b), both equiaxed dimpled regions and cleavage-fracture regions are present on the fracture surface. When 1.24% TiO_2 xerogel is added (Fig. 9c), the entire fracture surface exhibits uniformly sized dimples, and no brittle-fracture regions are observed. Grain refinement may be the main reason for the increase in strength and plasticity. Combined with the OM images in Fig. 3b and c, it can be seen that when 1.24% TiO_2 xerogel is added, the alloy microstructure is further refined, producing extremely fine dendrites. The refinement of the microstructure may be related to the fact that, during solidification of the alloy, nano-Al_2O_3 provides a large number of nucleation sites for the NiAl phase. In addition, the nano-Al_2O_3 particles are dispersed on the NiAl phase, which can effectively hinder dislocation motion and also strengthen the alloy. Part of the fracture surface of the sample with 1.98% TiO_2 xerogel added is a ductile fracture (Fig. 9d). As the xerogel content in the thermite agent increases, the amount of gas released during the reaction increases, and small shrinkage pores form in the cast sample; these shrinkage pores reduce the mechanical properties of the material.

In general, for most metallic materials, the elongation decreases as the content of second-phase particles increases. This is because conventional second-phase particles are on the micrometer scale. When an external load is applied, the load is transferred to the particles through the composite interface, causing residual stress to concentrate on the second-phase particles and making voids and cracks easy to form [27]. In the present work, the main reasons why the mechanical properties of the Fe-based ODS alloy co-strengthened by Al_2O_3 and NiAl prepared by the thermite process increase with increasing TiO_2 xerogel

Fig. 9

Figure 8: Fig. 9

content are as follows: (1) after TiO_2 xerogel is added to the thermite agent, Al_2O_3 nanoparticles are generated; these nanoparticles refine the grains of the synthesized material while improving the strength and toughness of the composite; (2) the diameter of the Al_2O_3 nanoparticles is about 10 nm, and they are all combined with NiAl, which also improves the strength of the NiAl reinforcing phase and increases the strength of the composite material.

Fig. 9 SEM images of fractographs of Fe-based ODS alloys synthesized by thermite reaction process with addition of 0 (a), 0.87% (b), 1.24% (c) and 1.98% (d) TiO_2 xerogel

3 Conclusions

(1) An iron-based oxide-dispersion-strengthened (ODS) alloy with bcc-structured elemental iron as the matrix and co-strengthened by NiAl and Al_2O_3 was prepared by thermite synthesis.

(2) In the high-temperature melt, the motion of nano-Al_2O_3 is jointly affected by Brownian motion and interfacial energy. Because the interfacial energy ratios of Al_2O_3 nanoparticles with NiAl are lower than those with α-Fe, the Al_2O_3 nanoparticles combine with NiAl.

(3) Adding a certain amount of TiO_2 xerogel to the thermite agent leads to grain refinement, and the tensile strength and elongation of the composite material also gradually increase. When the TiO_2 xerogel content in the thermite agent reaches 1.24%, the tensile strength reaches a maximum value of 849 MPa, and the elongation is 13%.

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(Responsible editor: Luo Yanfang)

Note: Figure translations are in progress. See original paper for figures.