Rare Metal Materials and Engineering
Volume 49, Issue 9, September 2020
Available online at www.rmme.ac.cn

Science Press

Cite this article as: Rare Metal Materials and Engineering, 2020, 49(9): 3035-3044.

ARTICLE

Steel Fiber-reinforced Nonferrous Metal Matrix Composites: A Review

Fu Shuren[1,2], Yang Lijing[2], Li Huan[2], Li Zhengxian[1,2]

[1] School of Material Science and Engineering, Northeastern University, Shenyang 110819, China; [2] Northwest Institute for Non-ferrous Metal Research, Xi'an 710016, China

Abstract: Compared with the traditional nonferrous materials, nonferrous metal matrix composites have good oxidation resistance, high heat resistance, high specific strength, high specific modulus, high wear resistance and high service life. Among the various reinforcements of nonferrous metal matrix composites, the compatibility of the interface between the non-metallic fiber (C/C, SiC) and the metal matrix is the key problem for restricting the performance of metal matrix composites. Meanwhile, the performance of metal matrix composites can be effectively improved by the favorable compatibility between the metal fiber and the metal matrix. The preparation technology of metal fiber reinforced nonferrous metal matrix composites mainly includes diffusion bonding method, liquid infiltration method, pressure casting method, coating hot pressing method and double roll rolling method. In this paper, the preparation methods, microstructure, interface characteristics and mechanical properties of steel fiber reinforced non-ferrous metal matrix composites (Al, Mg, Cu, Zn and Zr) were summarized. Some future researches and developments of steel fiber reinforced non-ferrous metal matrix composites were highlighted.

Key words: steel fiber; nonferrous metal; metal matrix composites; interface; reinforcements

Composites are composed of two or more different properties materials, which consist of multiphase materials with new properties at the macroscopic or microscopic level by means of physical or chemical methods[1, 2]. For example, the C/C composites have been successfully applied to aerospace thermal protection components[3]. As a new generation of thermal-structured materials, the silicon carbide ceramic matrix composites (CMC-SiC) are adopted in high thrust-weight ratio aero-engine[4]. Based on the unique performance of composites, a variety of methods have been used to produce novel composites with superior comprehensive properties such as significant impact strength, fatigue strength and fracture toughness, especially excellent thermal expansion property, thermal and electrical conductivity. In order to enhance both the damage sensing capabilities and structural integrity of the microwire composites, Zhao et al.[5] designed a dual-interface optimization approach with the purpose of improving the magnetic features of wires via the inner interface (glass shell/metallic core) and outer interface (glass shell/epoxy matrix). Wang et al.[6] claimed that the resourceful dielectric properties of APu/Al percolative composites could be used as the potential alternatives for capacitors and metamaterials. Nguyen et al.[7] declared that a polyethylene glycol diglycidyl ether (PEGDGE) matrix reinforced with carbon aerogel (CAG) exhibited a fourfold increase in interlaminar shear strength, compressive modulus and strength. Cho et al.[8] prepared titanium carbide (TiC) reinforced stainless steel composites by liquid pressing infiltration process, which shows great promise in high-temperature applications.

In various composites, the metal matrix composites (MMCs) with excellent thermal expansion coefficient, high

Received date: March 17, 2020
Foundation item: National Natural Science Foundation of China (51701165); Shaanxi Postdoctoral Science Foundation (2018BSHQYXMZZ36); Shaanxi Science and Technology Innovation Team Project (2017KCT-06)
Corresponding author: Li Zhengxian, Ph. D., Professor, Northwest Institute for Nonferrous Metal Research, Xi'an 710016, P. R. China, Tel: 0086-29-86231077, E-mail: lzxqy725@163.com

heat resisting, strength rate, modulus rate and wear resistance, have shown great potential in solving the performance limitations of traditional metal alloys[9]. According to the types of reinforcements, the MMCs can be classified into non-continuous fiber reinforced, continuous fiber reinforced and in-situ reaction reinforced MMCs. The non-continuous fibers of MMCs are mainly hard particles and whiskers. The hard particles are rigid ceramic particles such as SiC, TiB_2, Si_3N_4, Al_2O_3, B_4C, TiO_2, and diamond, graphite[9-11]. Masoud Anijdan et al.[12] prepared the 7050Al/SiC composites by adding 3wt%SiC particles into molten bath, which shows the effective enhancements in the yield strength, impact energy and micro-hardness of the 7050Al. Pang et al.[13] prepared the nano-Al_2O_3 particles reinforced 6061Al/12wt%B_4C composites by hot isostatic pressing (HIP), whose tensile strength and yield strength are increased by 27.0% and 62.8% compared with those of 6061Al/12wt%B_4C, respectively. Yao et al.[14] deposited the diamond/Ni60 composite coatings by cold spray (CS) with the assistance of laser irradiation.

The whiskers include oxide whiskers (MgO, ZnO, BeO, ZrO_2, Al_2O_3, etc.), ceramic whiskers (SiC, TiC, WC, B_4C, TiN, BN, etc.), boride whiskers (TiB, ZrB_2, TaB_2, etc.), and inorganic salt whiskers (K_2TiO_{13}, $Al_{18}B_4O_{33}$, etc.)[15-18]. Abdullah et al.[16] reported the effect of whisker concentration on flexural strength of Al_2O_3/ZrO_2 (TZ-3Y) composites. Luo et al.[17] designed a novel mullite-bonded SiC-whisker-reinforced MMCs. Feng et al.[18] fabricated the oriented TiB whisker reinforced TA15 MMCs by pre-sintering canned extrusion. At present, non-continuous fiber reinforced MMCs have been widely used in cycling industrial, electronic communication and aviation industry. For example, the Al/B_4C MMCs have been concerned as thermal neutron shielding material for high-density of spent nuclear fuel[19].

The continuous fibers include non-metallic (such as carbon fiber and silicon carbide fiber) and metallic fibers (such as steel fiber and copper fiber). The continuous fiber reinforced MMCs have been applied to aeroengine blade, rocket parts, antenna framework, piston and connecting rod[20]. In order to enhance corrosion and wear resistance properties of 1Cr13 stainless steel, Lei et al.[21] fabricated the carbon fibers reinforced Ni-based composite coatings (CFs/Ni) on the 1Cr13 substrate by laser cladding (LC). Qi et al.[22, 23] studied the tensile and fatigue behavior of carbon fiber reinforced magnesium composites (C_f/Mg composites). Liu et al.[24] explored the effect of carbon fiber bundles spacing on mechanical properties of C_f/Al composites. Tao et al.[25] reported that the SiC_f/SiC composites exhibited thermal conductivity of 26.7 $W\cdot m^{-1}\cdot K^{-1}$ at room temperature by adding about 4 vol%SiC nanowires (NWs). Zhang et al.[26] studied the effect of temperature on mechanical properties of graphite fiber reinforced Al matrix composites. Zhou et al.[27] fabricated Mg(AM60)-based metal matrix hybrid nanocomposites reinforced with alumina fiber and nano-sized Al_2O_3 particles, which showed the appreciable increase in strengths of ultimate tensile and yield of the matrix alloy from 171 and 81 MPa to 192 and 142 MPa, respectively.

In-situ reaction of reinforcements can effectively avoid the segregation of the reinforcements in MMCs, due to the process of nucleation and growth mechanism inside the matrix. Therefore, there is no physicochemical incompatible phenomenon occurring between reinforcement and matrix, guaranteeing the excellent wettability, bonding strength and the purity of the in-situ reaction reinforced MMCs[28]. Chen et al.[29] discovered the load transfer efficiency of carbon nanotube (CNT) reinforced Al-based MMCs prepared by powder metallurgy can be noticeably enhanced by introducing in-situ Al_2O_3 nanoparticles at Al/CNTs interface. Zhang et al.[30] demonstrated the nano-hardness of MMCs can be increased 9.5 times by in-situ synthesis of the TiB particles at high angle grain boundaries (HAGBs) of Al-based MMCs.

The metal fiber is a fibrous material with a certain length-diameter ratio prepared by the metal via a certain processing procedure, and the diameter of the wire is generally in the range of 10 ~ 1000 μm. With high-strength and toughness, excellent impact resistance and wettability, metal fibers are used as reinforcements to improve the strength and toughness of MMCs. For example, the fracture strength of W and W-THO_2 fibers reinforced high-temperature alloys are about 1.5 and 2 times as high as that of no fiber reinforced high-temperature alloy, respectively[31,32]. The iron fiber with 190 GPa modulus, 2 GPa tensile strength and elongation of more than 10% can significantly improve the strength and toughness of the resin materials[31]. Steel rebar can significantly enhance the tensile strength, bending strength, impact strength and spalling resistance of concrete, which has been widely used in building tunnels and airstrips[33]. MMCs have shown bright application prospects in weight saving applications of aerospace and automotive industries as replacement of traditional structural metal.

In conclusion, although the non-metallic fiber like carbon fiber and carbide fiber can significantly improve the properties of MMCs, the poor compatibility between non-metallic fiber and metal matrix is still a key problem. Meanwhile, metal fiber reinforced MMCs maybe effectively solve the poor wettability and compatibility between metal fiber and metal matrix. In this paper, the research progress of steel fiber reinforced nonferrous MMCs will be summarized in industrial applications.

1 Preparation Methods

1.1 Diffusion bonding technique

Diffusion bonding technique is a process of mixing and arranging metal powder, foil and fiber in a certain proportion, distribution and direction according to the design requirements, which is heated under high pressure to form composites in solid state. The interface reaction occurs between the metal matrix and the reinforcement under the low temperature in the whole process. Diffusion bonding technique can be classified into foil-fiber-foil (FFF), powder cloth and pulse current hot pressing (PCHP). FFF method is probably the most original technique for producing fiber reinforced MMCs, as shown in Fig.1. In the consolidation process, the temperature and pressure are applied to a composite lay-up of metal foils and the fiber mats usually by hot isostatic pressing (HIP). FMW company improved the foil-fiber-foil by replacing the titanium foil with titanium wire, which has been adopted in producing vector nozzles and connectors of GE engine F110 and F119.

1.2 Liquid infiltration technique

The manufacturing procedure of liquid infiltration technique contains the forming of porous preform and infiltration. The porous preform with spatial network structure is fabricated by compaction following with sintering of mental fiber, then the liquid metal is infiltrated into the porous preform with no pressure participate, which can produce large and complex molded parts without forming defects such as movement of prefabricated blocks and fiber damage[34]. Li et al.[34] prepared steel fiber reinforced Mg matrix composites by liquid infiltration technique as shown in Fig. 2.

The liquid infiltration process has to be finished in vacuum environment or inert gas protection. In order to ensure the wettability and interfacial reaction between metal matrix and metal fibers, specific alloying elements need to be added into the metal matrix for the appropriate modification of the fiber surface. However, the shrinkage of the liquid metal is beneficial to form cavities and porosities in the composites. The fiber bundle spacing and space within the bundle, temperature gradient and solidification pressure play a significant role in improving the properties of MMCs.

1.3 Squeeze casting technique

The processing procedure of the fiber reinforced MMCs produced by squeeze casting technique are exhibited in Fig. 3. First, the prefabricated fiber preform is put into a steel die, then the liquid metal is poured into the die and infiltrated into the preform under the high pressure applied by upper punch,

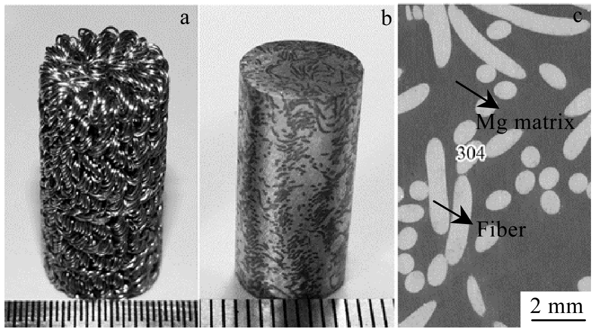

Fig.2 Macrographs of pure 304 stainless steel fiber (a), Mg/304 stainless steel fiber composites (b) and cross section image of composites (c)[34]

so that the liquid metal penetrates into the preform and solidifies into a dense MMCs[22, 23, 35]. Zhou et al.[35] prepared 304 stainless steel fiber reinforced ZA8 zinc alloy interpenetrating phase composites by squeeze casting technique. However, the disadvantage of this technique is prone to deform the fiber prefabricated preform due to the high pressure, resulting in damage of the fiber. It is difficult to achieve the near-net shaping of small and medium castings.

1.4 Coating hot-pressing technique

In coating hot pressing process, the reinforcing fibers coated with metal by a coating technique are compounded into dense MMCs under the action of thermocompression, as shown in Fig. 4. In order to avoid fibers damage in the molten metal, the physical vapor deposition (PVD), which is the most popular technique to coat fiber, is used to deposit the metal alloy on the surface of a single fiber[36, 37]. The coated fibers are together clustered to form the fiber reinforced MMCs by means of thermal isostatic pressure or thermal pressure technique. The coating hot pressing technique can not only deposit any metal matrix onto the reinforcing fiber, but also achieve the deposition of high melting point metal. It also can accurately control the chemical composition of the coating to reduce the impurities of the layer. However, the high cost will occur during the PVD process. The German aerospace center prepared CSC-6/Ti6242 composites with 35% content of metal fiber, significantly increasing the service temperature of the MMCs.

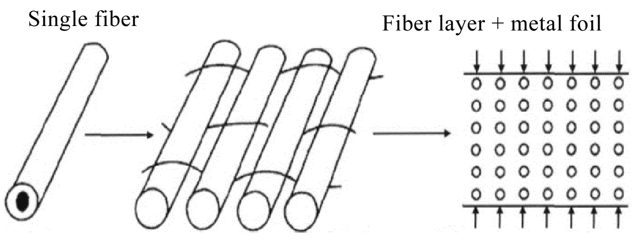

Fig.1 Sketch of composites preparation by FFF

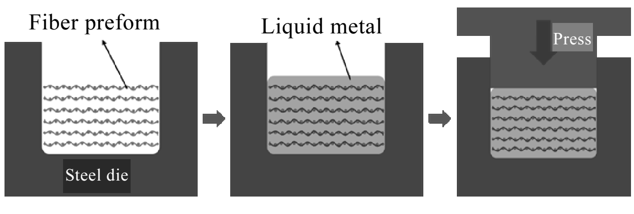

Fig.3 Sketch of composites preparation by squeeze casting technique

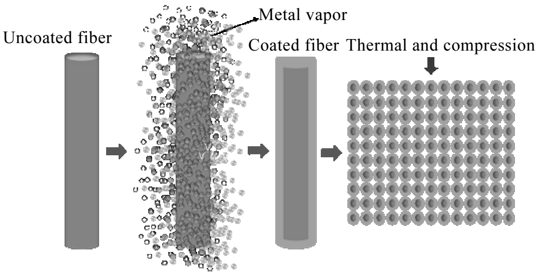

Fig.4 Sketch of MMCs preparation by coating hot pressing technique

1.5 Downward melt drag twin roll caster technique

Fig.5 shows a schematic illustration of the downward melt drag twin roll caster (DMDTRC) that is a technique to cast the long-fiber-inserted strip. A nozzle is attached to the upper roll, which is different from the conventional twin roll caster. The nozzle has a channel at the surface that ensures the solidification layer and melt are easily dragged by the rotation of the upper roll[38, 39]. A puddle of melt forms on the lower roll, and the temperature of the puddle are lower than that of the melt in the nozzle since the melt cools in the channel. Therefore, the damage of the fiber could be limited to very low level when fiber is inserted into the puddle. This is one of the superiorities of DMDTRC[38, 39].

2 Steel Fiber Reinforced Nonferrous MMCs

The bearing capacity of the steel fiber reinforced MMCs is mainly determined by the uniform distribution of steel fibers in the MMCs. To ensure the synergistic effect of steel fibers, the reasonable gap among the stainless fibers should be retained. In the preparation of MMCs, the steel fibers should be protected from chemical corrosion and mechanical damage. Steel fiber reinforced MMCs have been concerned by more and more scholars, which can be divided into the following categories according to the different metal matrices.

2.1 Al matrix composites

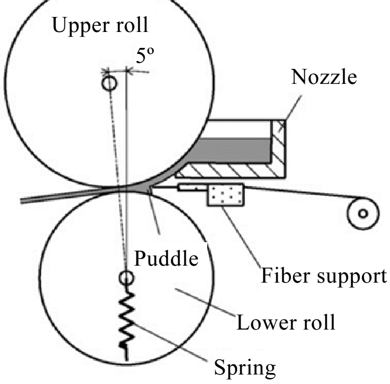

Fig.5 Schematic illustration of the DMDTRC[39]

With the advantages of good machinability, low weight, non-low temperature brittleness, non-magnetic and nontoxicity, aluminum alloys have already been a vital material of electronic products, automobiles, airplanes and bullet trains[40-42]. However, the low melting point, low hardness, low strength and high expansion coefficient of aluminum alloys also limit its wider industrial applications. Therefore, Al-based composites have become an effective way to break through the performance bottleneck of aluminum alloys. Among the types of Al-based composites, the continuous fibers reinforced Al-based MMCs are widely used in aerospace, communication, automobile sectors and other structural applications due to the excellent properties of lightweight, high strength and stiffness. Haga et al.[38] produced the steel fiber with the diameter of 0.3 ~ 0.6 mm reinforced Al-12mass%Si composites strip by downward melt drag twin roll caster. Pakzaman et al.[43] reported that Ni-coated steel mesh reinforced A356 composites show considerable improvement in strength from 147.17 MPa to 232.36 MPa with good ductility, because of a good interface diffusion between A356 aluminum alloy and steel wire, as illustrated in Fig. 6. Szczepanik[44] reported that the stainless steel mesh reinforced Al9Si3Cu composites prepared by hot processing show the bend strength of 431 MPa. Chang et al.[41] prepared stainless steel fiber reinforced NiAl composites by reactive hot pressing (RHP) and investigated the formation mechanism of the NiAl matrix composites. Agarwala et al.[42] fabricated mild steel wire incorporating Al alloy (LM11) composites by casting technology and the microhardness of the composites showed the variation from 150 ~ 45 VHN in the as-cast composites to 350 ~ 420 VHN after annealing (500~525 °C) across the interface indicating the effectiveness of the heat treatment. Bhagat[45] established two equations for the growth kinetics of the interface intermetallic in stainless steel fiber reinforced aluminum matrix composites fabricated by the P/M hot pressing, squeeze casting and infiltration techniques. The maximum strength of the composites occurs when the rate constant of hot-pressed composites is 0.7×10^{-16} $m^2 \cdot s^{-1}$. Bakarinova et al.[46] investigated pure Al and Al-Zn-Mg alloy reinforced using stainless steel wire with the diameter of 0.15 mm. The comparison of the growth rates of the transition zone showed that the growth rate in Al-Zn-Mg matrix composites is higher than that of pure aluminum matrix. According to above studies, the materials, preparation method, interface and mechanical properties of steel fiber reinforced Al-MMCs are summarized in Table 1.

2.2 Mg matrix composites

Magnesium (Mg) and its alloys offer a high lightweight potential due to the high specific strength and stiffness, low density (1.7 kg/m^3), high thermal and electric conductivities, and excellent shock absorption. Nevertheless, the low strength of magnesium is the main factor restricting its

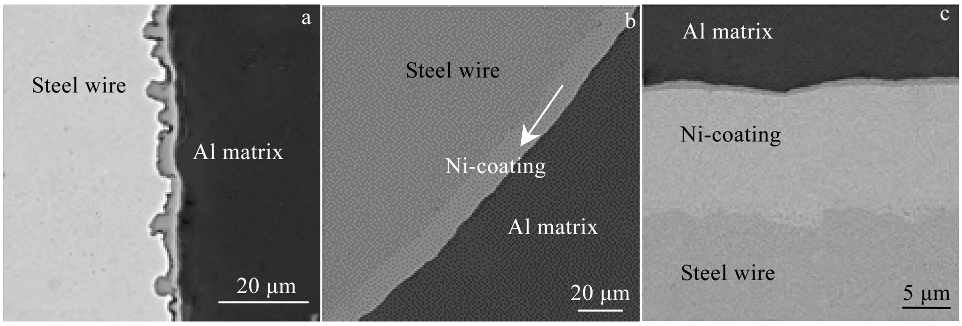

Fig.6 SEM images of Al matrix/steel wire interface in composite: (a) uncoated wire and (b, c) nickel-coated wire[43]

Table 1 Production method and mechanical properties of steel fiber reinforced Al-MMCs

Author	Fiber	Fiber diameter	Matrix	Preparation method	Interface	Property
Haga [38]	Mild steel	0.3 mm 0.6 mm	Al12Si	Downward melt-drag twin roll caster	Fe_xAl_y layer 1~5 µm	
Pakzaman [43]	Uncoated steel mesh Ni-coated steel mesh	1.1 mm	Al356	Lost foam casting process	Uncoated $Fe_{25}Al_{60}Si_{15}$ layer 2~6 µm Coated $NiAl_3$ layer 0.5~2 µm	Uncoated Y.S. 118.13 MPa U.T.S. 191.02 MPa EI 1.30% Coated Y.S. 154.04 MPa U.T.S. 232.36 MPa EI 2.07%
Szcpanik [44]	Stainless steel	1.2 mm	Al9Si3Cu	Forging	No obvious reaction layer	Bend strength: 431 MPa Nucleation of cracking: 262 MPa Deflection: 1.75 mm
Chang [41]	304 stainless	225 µm	AlNi	Hot isostatic pressing	Interface evolution Al/Ni→Ni_2Al_3→ NiAl	
Agarwala [42]	Mild steel	0.4 mm	LM11	Casting technique	500 ℃ 15 h Fe_xAl_y layer 60 µm 252 ℃ 15 h Fe_xAl_y layer 77 µm	As-cast condition: microhardness 150~45 VHN After annealing: microhardness 350~420 VHN
Bakarinova [46]	Stainless steel ÉP322	0.15 mm	Pure Al Al-Zn-Mg	Hot rolling	Pure aluminum low generation rate of layer Al-Zn-Mg high generation rate of layer	

lightweight performance advantage[34, 47, 48]. The preparation of composites has become an important way to improve the properties of magnesium alloys. The preparation method, microstructure and performance of steel fiber reinforced magnesium matrix composites have been developed. Li et al.[34] prepared Mg matrix composites reinforced with continuous 304 stainless steel wire using an infiltration casting process. The results demonstrated that the compressive strength and elastic modulus of 304/Mg MMCs were 42.8% and 55.6% higher than those of pure Mg, respectively. The energy absorption capability of 304/Mg was 2.5 times as high as that of pure Mg, as shown in Fig.7. The preparation method of 304/Mg composites could be used as a reference for improving the damping capacity and strength of Mg. Hufenbach et al.[47] investigated the effects of steel wires with surface modification and optimized production methods to improve the quality and type of adhesion with selected industrial magnesium alloys. They reported that intermetallic interface and acid etching of steel wires are beneficial to improve the connection between steel wires and magnesium matrix. The Zn-coating of steel wires is more attractive for Al-Mn precipitations in contrast to the clean Fe-surface of wires which provides favorable conditions for separation of Al-Mg phase. This discovery is extremely important for manufacturing high impact resistance of composites. Reeb et al.[48] studied the sensitivity of an unreinforced and steel wire reinforced AZ31 magnesium alloy to stress corrosion cracking by means of static stress corrosion testing and cyclic stress corrosion testing. The authors concluded that the composites show a higher sensitivity with earlier crack initiation than AZ31 alloy, and suggested exposure of the steel wire-matrix interface to maritime environments has to be avoided due to a quick anodic dissolution of the matrix material under exposure of sodium chloride solution.

2.3 Cu matrix composites

With the excellent ductility, electrical conductivity, thermal conductivity, anti-corrosion and a relatively low price compared to gold and silver, Copper (Cu) and its alloys have become an indispensable material in industrial applications[49-51], especially the strength of copper and its alloys are frequently required in structural applications. Copper matrix composites reinforced with various materials such as SiC, TiC, SiO_2, graphite, WC, TiB_2, ceramic fibers and carbon fiber have performed remarkable wear resistance and strength[52-58]. However, the increase in the wear resistance and strength of the composites is at the expense of the electrical, thermal conductivity and corrosion resistance of copper, owing to the presence of additional reinforcements. Researchers have been trying to overcome this negative situation by adding metal fibers in copper. The interface between metal fibers and copper matrix and homogeneous distribution of metal fibers in the composites are still the key problem of copper matrix composites preparation. Bakkar et al.[59] prepared the stainless steel fiber reinforced copper-based MMCs by coating hot-pressing technique, and investigated the corrosion behavior of this composites in chloride media at different temperatures and pH values using electrochemical techniques. The optical microstructure of composites exhibited that corrosion behavior initiates in the copper matrix of the composites, as shown in Fig.8.

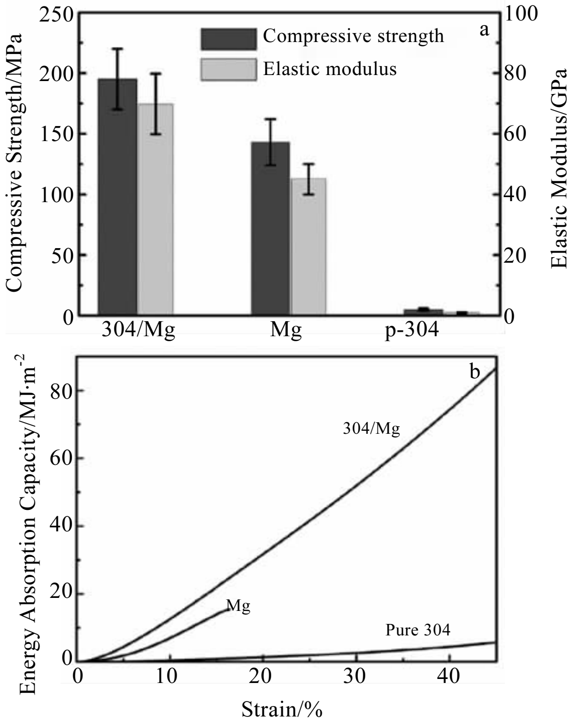

Fig.7 Performance comparison of 304/Mg and pure Mg: (a) compression strength and elastic moduli and (b) energy absorption capacity [34]

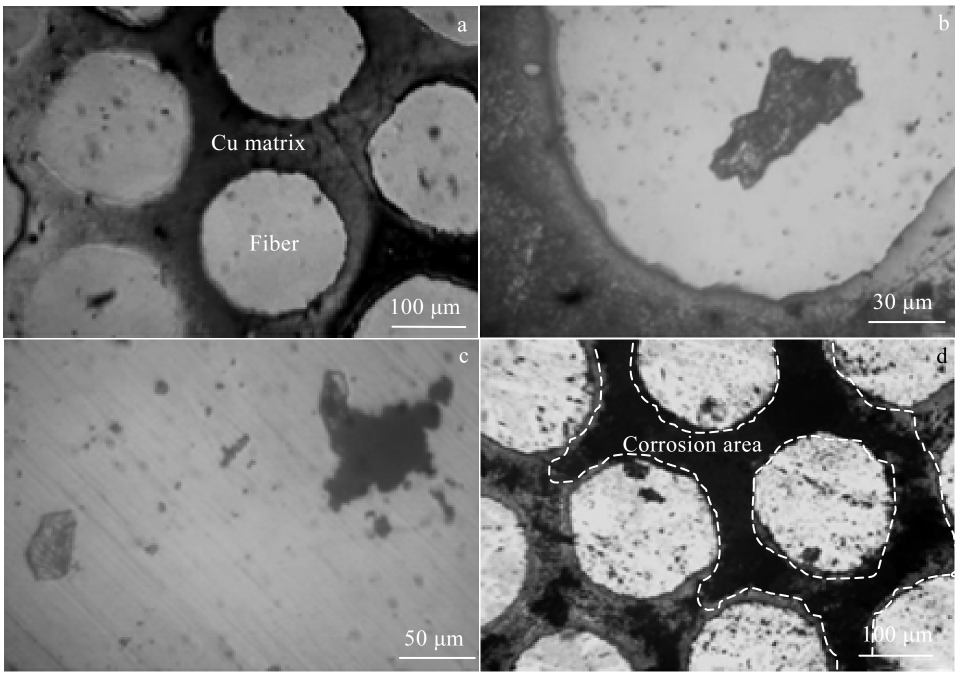

Fig.8 Optical micrographs of corrosion surfaces following free immersion in 30 g/L NaCl solution: (a) stainless steel fiber/Cu MMC specimen for 2 h, (b) stainless steel fiber/Cu MMC specimen for 3 h, (c) monolithic stainless steel specimen for 2 h, and (d) high corroded area in stainless steel fiber/Cu MMC specimen after immersion for 6 h[59]

2.4 Zn matrix composites

The zinc (Zn) alloys with high-aluminum content such as ZA8, ZA12 and ZA27 show good physical, mechanical and tribological properties in various industrial applications[60]. However, it has already been confirmed that the mechanical properties of ZA alloys drop significantly with the increment of temperature about 100 °C[61, 62]. In order to improve the performance of high-aluminum Zn-based alloys, ceramic particles, whiskers, and metal fibers are used as reinforcements of the ZA alloys to form ZA-based MMCs, demonstrating the effective improvement of the dimensional stability and mechanical properties. Zhou et al.[35] used 304 stainless steel short fibers to produce preforms with difference porosity by solid-sintering technology. ZA8 zinc alloy was chosen as matrix to infiltrate the preforms using sequence casting to produce a novel 304 stainless steel fiber/ZA8 zinc alloy interpenetrating phase composites (IPCs), as shown in Fig. 9a. The results show that the hardness and compressive strength at room temperature of IPCs increases with the increasing of fiber content and the IPCs exhibit anisotropy in the longitudinal and radial directions, as shown in Fig. 9b. The higher compressive strength and larger elastic stage appear in longitudinal direction, as shown in Fig. 9c. In the hot compression deformation, steady stress and peak stress are significantly improved by adding fibers. Compared with longitudinal direction, the IPCs in radial direction have higher steady stress and peak stress, as indicated in Fig. 9d.

2.5 Zr amorphous alloy matrix composites

With lack of long-range translational symmetry and crystalline defects, amorphous alloys have large elastic strain limit, superb strength, excellent thermo-plastic formability and good corrosion/wear resistance[63-66]. Therefore, amorphous alloys were once considered as alternative structural alloys. Zr-based amorphous alloys with excellent hardness, stiffness, strength, and corrosion resistance have been partly applied to high-performance structural components[67]. However, owing to poor ductility and toughness, the brittle fracture readily occurs by the formation of localized shear bands under tensile or compressive loading conditions. The poor ductility and toughness of the amorphous alloy can be solved when the reinforcements such as fibers or particles are homogeneously distributed in the amorphous matrix.

Kim et al.[68] investigated the effect of diameter on quasi-static and dynamic compressive properties of Zr-based amorphous matrix composites, which was reinforced with stainless steel continuous fibers with the diameters 110 and 250 μm, as shown in Fig. 10a and 10b. Due to the sufficient

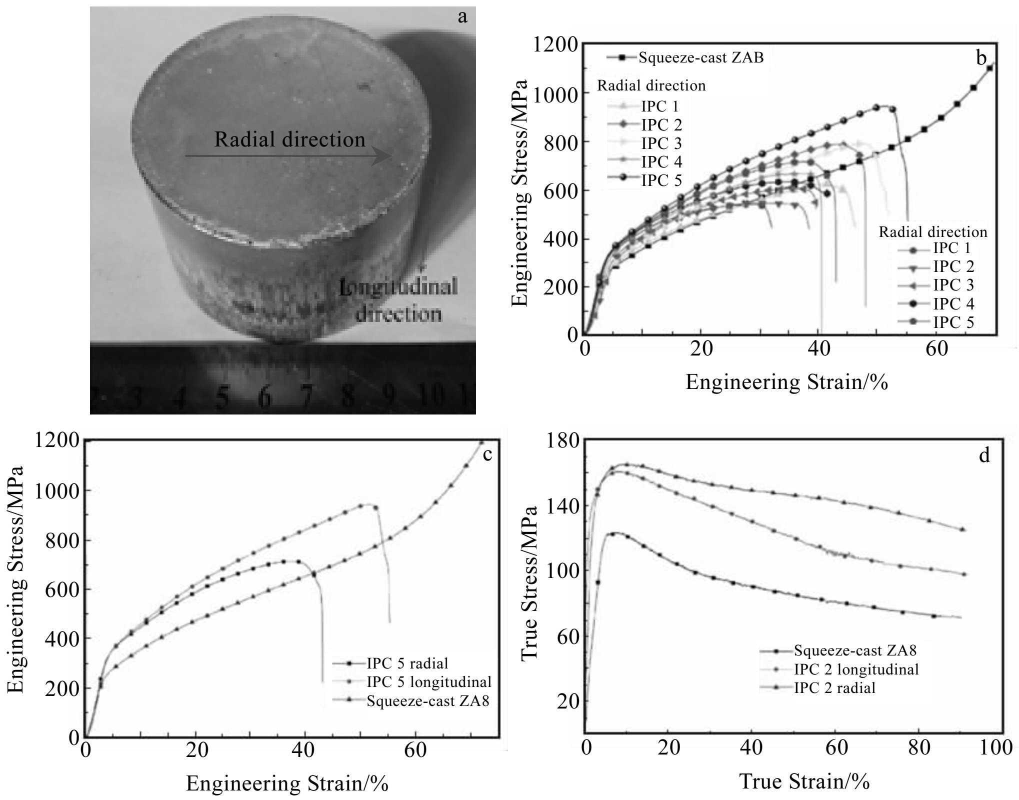

Fig.9 IPCs block sample (a), contrast compressive stress-strain curves of the IPCs in different directions at ambient temperature (b), compressive tress-strain curves of the squeeze-cast ZA8 and the IPCs in radial and longitudinal sections (c), and stress-strain curves during hot compression deformation of the squeeze-cast ZA8 and the IPCs in radial and longitudinal sections (d)[35]

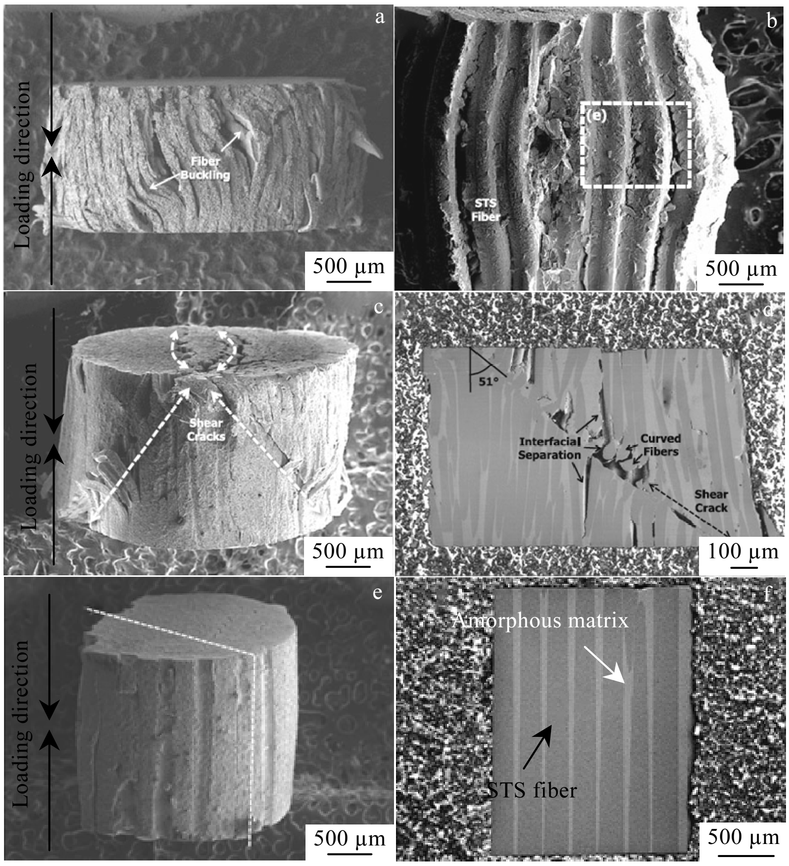

Fig.10 SEM images of deformed compressive specimens: (a) the quasi-statically deformed 110 μm-fiber-reinforced composites, (b) the quasi-statically deformed 250 μm-fiber-reinforced composites, (c, e) the dynamically deformed 110 μm and 250 μm-fiber-reinforced composites, (d, f) cross-section area of the dynamically deformed 110 μm and 250 μm-fiber-reinforced composites[68]

deformation of small-diameter fibers during bending and bucking under the quasi-statically deformed compressive test, the results indicate that the plastic strain of the 110 μm-diameter-fiber-reinforced composites is over 32% more than that of 250 μm-diameter-fiber- reinforced composites. Because the crack mainly propagates along the amorphous matrix, the plastic strain of large-diameter-fiber-reinforced composites was lower than that of the small-diameter-fiber-reinforced composites. Compared to the small-diameter-fiber-reinforced composites, the large-diameter-fiber-reinforced composites showed the higher yield strength, maximum compressive strength and plastic strain under the dynamic compressive loading, due to the sufficient ductility of 304 stainless fibers. The effective interruption of shear cracks propagation and the strain hardening of fibers themselves were shown in Fig.10d and 10f.

3 Summary and Outlook

As the reinforcement, steel fibers are added into the nonferrous metal matrix to form MMCs with the unique performance. Much MMCs research has revealed the strength of MMCs increases with adding steel fibers, especially for aluminum alloy and magnesium alloy. However, there are some essential problems of steel fiber reinforced MMCs:

1) The steel fibers reinforced nonferrous MMCs have excellent properties in the tensile direction, but the strength will be significantly decreased for the anisotropy of steel fibers under the shear force.

2) The non-uniform distribution of the steel fibers in nonferrous MMCs is prone to cause the concentration of local stress and strain.

3) Due to the generation of new phase at the interface between fibers and metal matrix during the preparation, the corrosion resistance of the steel fibers reinforced nonferrous MMCs is weakened.

4) In order to avoid excessive damage of the fibers, the selection of appropriate preparation process from various methods is important for the steel fiber reinforced nonfer-

rous MMCs.

5) The interface between the steel fibers and the nonferrous metal matrix has been concerned by researchers. The interface reaction and bonding between steel fiber and nonferrous metal matrix are significant for further improving the performance of the steel fiber reinforced nonferrous MMCs.

6) With the rapid development of additive manufacturing research, more and more new technologies can be used in the preparation of MMCs, such as cold spray, thermal spray and laser cladding. The unique characteristics of these technologies are expected to provide new ideas for the preparation of metal fiber reinforced nonferrous MMCs.

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钢纤维增强有色金属基复合材料综述

付树仁[1,2]，杨理京[2]，李 欢[2]，李争显[1,2]
(1. 东北大学 材料科学与工程学院，辽宁 沈阳 110819)
(2. 西北有色金属研究院，陕西 西安 710016)

摘 要：有色金属基复合材料相对于传统有色金属材料而言，具有更好的抗氧化性、高耐热性、高比强度、高比模量、耐磨损和高使用寿命。在有色金属基复合材料的众多的增强体中，非金属纤维（C/C、SiC）与金属基质结合界面的相容性是制约金属基复合材料性能的关键问题，而金属纤维与金属基质之间良好的相容性能够有效改善金属材料的性能。金属纤维增强有色金属基复合材料的制备工艺主要有扩散粘结法、液态渗透法、压力铸造法、涂层热压法、双辊轧制法。 本文主要总结了钢纤维增强有色金属基（Al、Mg、Cu、Zn 和 Zr）复合材料的制备方法、微观组织、界面特征和机械性能，指出了钢纤维增强有色金属基复合材料进一步研究发展所需要解决的问题。

关键词：钢纤维；有色金属；金属基复合材料；界面；增强体

作者简介：付树仁，男，1995 年生，硕士，东北大学材料科学与工程学院，辽宁 沈阳 110819，E-mail: fushuren07@126.com