The Corrosion Behaviour of Amorphous Metal Fiber Compared With That of Stainless Steel Fiber

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Abstract. Amorphous metal fiber exhibits high corrosion resistance, excellent mechanical properties and is good material for reinforcing concrete matrix. To compare with the corrosion behaviour of amorphous metal fiber and stainless steel fiber, the corrosion resistance was investigated by electrochemical polarization in 0.5 M H2SO4, 0.1 M FeCl3 and 3.5 wt% NaCl solutions, respectively. The results show that amorphous metal fiber exhibits more superior corrosion resistance than that of stainless steel fiber. The amorphous metal fiber has excellent pitting corrosion resistance in 3.5 wt% NaCl solution, and the stainless steel fiber is susceptible to pitting corrosion. The amorphous metal fiber is spontaneously passivated in 0.1 M FeCl3 solutions, and the stainless steel fiber doesn’t form passivation.

1. Introduction
Since the extremely high corrosion resistance of iron-chromium-based amorphous alloys was reported [1], much attention has been paid to them [2-4]. Their corrosion resistance is attributed to the formation of a protective hydrated chromium oxyhydroxide passive film [5]. Besides the good corrosion resistance, iron-chromium-based amorphous alloys also have excellent mechanical properties and relatively low material cost. They are very suitable for reinforcement function in composite materials.

Amorphous metal fiber composed iron, chromium, carbon, silicon and phosphorus is believed to be good material for reinforcing concrete matrix [6, 7]. Amorphous metal fiber-reinforced concrete exhibited superior flexural strength and flexural toughness than steel fiber-reinforced concrete [8, 9]. Amorphous metal fiber simultaneously has good corrosion resistance in the various acid, alkali, and salt solutions [7, 10-13]. Mixing amorphous metal fiber into the concrete can improve durability of concrete especially under the moisture, marine and chemical environments. The stainless steel fiber is another fiber-reinforced concrete material. To compare with the corrosion behaviour of amorphous metal fiber and stainless steel fiber, the corrosion resistance is investigated and discussed in 0.5 M H2SO4, 0.1 M FeCl3 and 3.5 wt% NaCl solutions, respectively.

2. Experimental Procedures
Ingot of chemical composition of Fe73Cr6C9Si1P11 (at %) alloy was prepared by induction melting mix of high purity iron, chromium, carbon, silicon and phosphorus in argon atmosphere, and re-melted several times in order to chemical homogenization. The ingot was used for fabricating amorphous metal fiber by the single-roller melt-spinning. The amorphous metal fiber had a length of 30 mm, a width of 1.6 mm and a thickness of 30 μm. Stainless steel fiber was purchased from the market. The
chemical compositions of the stainless steel fiber are as follows (wt%): 18.61Cr, 0.52C, 2.44Si, 1.05Mn, 0.04P, 0.03S and balance Fe.

The structure of amorphous metal fiber was examined by X-ray diffraction (Bruker D8) using Cu-Kα radiation. The thermal properties of amorphous metal fiber were measured by differential scanning calorimetry (Netzsch DSC404) at a heating rate of 10 K/min.

The electrochemical measurement was carried out with three electrodes system at room temperature of 25 °C. Three electrodes system consisted of a working electrode, a graphite cylinder counter electrode and a saturated calomel reference electrode (SCE). The specimens were used as working electrode and coated with epoxy resin except for a measurement area. The electrolytes were 0.5 M H₂SO₄, 0.1 M FeCl₃ and 3.5 wt% NaCl solutions. The potentiodynamic polarization and cyclic polarization were tested at scan rate of 1mVs⁻¹ by the PARSTAR 2273 potentiostat after specimens were immersed in solutions for 60 min.

3. Results and Discussion

Figure 1a shows the XRD patterns of the wheel-side surface and the air-side surface of amorphous metal fiber. As can be seen clearly, there is only one broad amorphous peak of 2θ ranging from 40° to 50°, ensuring the fully amorphous state of amorphous metal fiber relative to thickness.

Figure 1b shows the DSC curve of amorphous metal fiber at 10 K/min heating rate. The DSC curve displays a process of amorphous structural relaxation and transformation during heating. It has a broad exothermic region in the temperature range 150-400 °C, which is attributed to the structural relaxation process. Following this region, there are three exothermic peaks (T_p1, T_p2 and T_p3) in the temperature range 400-615 °C indicating a stepwise crystallization process. The peak temperatures of the first, second and third crystallization are 454, 496 and 575 °C respectively. At the heating rate of 10 K/min, the amorphous metal fiber maintains amorphous structure till the temperature of 400 °C, revealing a high thermal stability against crystallization.

![Figure 1. XRD patterns (a) and DSC curve (b) of the Fe₇₃Cr₆C₉Si₃P₁ metal fiber](image-url)

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**Figure 1.** XRD patterns (a) and DSC curve (b) of the Fe₇₃Cr₆C₉Si₃P₁ metal fiber.
Figure 2. Potentiodynamic polarization curves of Fe$_{73}$Cr$_6$C$_9$Si$_1$P$_{11}$ amorphous metal fiber and stainless steel fiber in 0.5 M H$_2$SO$_4$ solution (a) and 0.1 M FeCl$_3$ solution (b)

The corrosion behavior of amorphous metal fiber was evaluated by electrochemical measurements. For comparison, stainless steel fiber was tested under the same conditions. The potentiodynamic polarization curves of amorphous metal fiber and stainless steel fiber in 0.5 M H$_2$SO$_4$ and 0.1 M FeCl$_3$ solutions are shown in Figure 2. The main electrochemical parameters obtained from the potentiodynamic polarization curves (including the corrosion potential $E_{\text{corr}}$, the passivation current density $I_{\text{pass}}$, the critical potential $E_{\text{crit}}$ and the passivation width $\Delta E = E_{\text{crit}} - E_{\text{corr}}$) are gathered in Table 1.

From Figure 2(a) and Table 1, it can be seen that amorphous metal fiber is spontaneously passivated with a low passivation current density of about $10^{-6}$ A·cm$^{-2}$ and a wide passive region larger than 1.3 V, indicating its high corrosion resistance in 0.5 M H$_2$SO$_4$ solution. Stainless steel fiber is also spontaneously passivated with a wide passive region, while the passivation current density is about $10^{-5}$ A·cm$^{-2}$ which is above that of amorphous metal fiber, implying that the corrosion resistance of amorphous metal fiber is higher than that of stainless steel fiber in 0.5 M H$_2$SO$_4$ solution.

From Figure 2(b) and Table 1, it is seen that amorphous metal fiber is spontaneously passivated with a low passivation current density of about $10^{-6}$ A·cm$^{-2}$ and a passive region larger than 0.8 V in 0.1 M FeCl$_3$ solution. Stainless steel fiber does not form passivation displaying the sharp increase of current density above the corrosion potential, and it shows less corrosion potential compared to amorphous metal fiber. Therefore, it is obviously that amorphous metal fiber has superior corrosion resistance than that of stainless steel fiber in 0.1 M FeCl$_3$ solution.

Table 1. Electrochemical parameters obtained from the polarization curves in 0.5 M H$_2$SO$_4$ solution and 0.1 M FeCl$_3$ solution

| Solution   | Specimen            | $E_{\text{corr}}$/mV | $E_{\text{crit}}$/mV | $\Delta E$/mV | $I_{\text{pass}}$/A·cm$^{-2}$ |
|------------|---------------------|----------------------|----------------------|---------------|-------------------------------|
| 0.5 M H$_2$SO$_4$ | amorphous metal fiber | -315                 | 1067                 | 1382          | $3.4 \times 10^{-6}$         |
|            | stainless steel fiber | -475                 | 915                  | 1390          | $3.5 \times 10^{-5}$         |
| 0.1 M FeCl$_3$ | amorphous metal fiber | 489                  | 1375                 | 886           | $3.2 \times 10^{-6}$         |
|            | stainless steel fiber | -98                  | -                    | -             | -                             |

Cyclic polarization is an efficient electrochemical technique to evaluate the pitting corrosion susceptibility. Pitting corrosion susceptibility can be predicted from the reverse anodic scan curve. If in the reverse anodic scan the current density is less than that for the forward scan (negative hysteresis), no pitting corrosion is expected; whereas if in the reverse anodic scan the current density is greater than that for the forward scan (positive hysteresis), pitting corrosion is expected. Figure 3 shows the cyclic polarization curves of amorphous metal fiber and stainless steel fiber in 3.5 wt%
NaCl solution. The cyclic polarization curve of amorphous metal fiber shows a greatly wide passive region and negative hysteresis. The cyclic polarization curve of stainless steel fiber exhibits a narrow passive region and positive hysteresis; moreover, its protection potential $E_{\text{prot}}$ is below its corrosion potential $E_{\text{corr}}$. This clearly indicates that amorphous metal fiber has excellent pitting corrosion resistance, while stainless steel fiber is highly susceptible to pitting corrosion.

![Cyclic polarization curves](image_url)

**Figure 3.** Cyclic polarization curves of the Fe$_{73}$Cr$_6$C$_9$Si$_1$P$_{11}$ amorphous metal fiber and 430 stainless steel fiber in 3.5 wt% NaCl solution

Above all, the amorphous metal fiber shows a more superior corrosion resistance compared with the stainless steel fiber in 0.5 M H$_2$SO$_4$, 0.1 M FeCl$_3$ and 3.5 wt% NaCl solutions. The excellent corrosion resistance of amorphous metal fiber is attributed to the formation of a hydrated chromium oxyhydroxide passive film which is also a common major constituent of passive film on crystalline stainless steel [5]. The higher corrosion resistance of amorphous metal fiber than that of stainless steel fiber additionally attributed to the following factors. Firstly, the amorphous alloy is the chemical homogeneous amorphous structure without crystalline defects such as grain boundaries, dislocation and precipitates which are more susceptible to chemical attack. Secondly, amorphous alloy can rapidly format passive film and recover invasion sites because of its high energy state. Thirdly, the presence of phosphorus enhances the amorphous-forming ability and promotes rapid formation of protective passive film [3].

4. Conclusions
The corrosion behavior of amorphous metal fiber has been studied in comparison with stainless steel fiber in 0.5 M H$_2$SO$_4$, 0.1 M FeCl$_3$ and 3.5 wt% NaCl solutions. The amorphous metal fiber is spontaneously passivated with a low passivation current density and a wide passive region in three aggressive solutions, and has excellent pitting corrosion resistance in 3.5 wt% NaCl solution. The stainless steel fiber doesn’t form passivation in 0.1 M FeCl$_3$ solution, and is susceptible to pitting corrosion in 3.5 wt% NaCl solution. The higher corrosion resistance of amorphous metal fiber than that of stainless steel fiber is attributed to rapid formation of a uniform passive film.

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6. References
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