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Research Status of Preparation Technology for Amorphous Ultra-Thin Strips

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Abstract: As a new functional material, amorphous ultra-thin strip is widely used in high-tech fields such as aerospace equipment, power systems, new energy vehicles, medical devices and smart wearables. In industrial production, polished copper roller is used as the solidified base of metal melt, but the high temperature strength of copper is low, and it is easy to wear and fatigue failure under the combined action of molten metal injection force, alternating thermal stress and friction and wear, which becomes the main bottleneck of the preparation of amorphous ultra-thin strip.

Keywords: surface wettability; ultra-thin strips; amorphous material; cooling roll; rapid solidification

1. INTRODUCTION

Amorphous ultra-thin strip is a famous new functional material in the 21st century, its thickness is only 0.02 mm, with superconducting magnetic, low coercivity, low iron loss, high strength, high temperature corrosion resistance and other performance advantages. High performance amorphous ultra-thin strip is increasingly widely used in high-tech fields such as aerospace, intelligent connected vehicles, power transmission, intelligent medical treatment, intelligent manufacturing and robotics, and has become one of the hot spots in the field of metal forming, providing new opportunities for the development of Shandong power system, electronic information and new energy vehicles.

At present, the amorphous ultra-thin strip is prepared by a single roll quenching technology, in which the molten metal is sprayed onto the surface of a high-speed rotating cooling copper roll, and solidified to form a long-range disordered amorphous structure at a cooling speed faster than 10^6 K/s. The centrifugal force generated by the high-speed rotation of the cooling roll quickly throws the alloy melt out, and finally forms the amorphous ultra-thin strip. Scholars at home and abroad are committed to the optimization of strip preparation process parameters, and obtain amorphous ultra-thin strips with uniform composition, large width to thickness ratio and excellent properties. However, due to the low high temperature strength of the surface of the copper cooling roll, it is easy to wear the surface because of the long time in the harsh working environment such as high temperature friction and wear, alternating thermal stress and metal injection pressure, causing surface structure and local wettability changes.

The results show that the surface wettability of the cooling roller determines the spreading state of the metal melt. When the solidified base shows better lyophilicity to the metal melt, the contact area between the metal liquid and the roller surface increases, the heat exchange between the metal melt and the cooling medium is accelerated, and the solidification rate of the metal is increased. However, the intense friction and wear between the surface of the cooling roller and the high temperature solidified metal directly leads to the wetting difference in different areas of the surface, and the cooling speed of the molten metal in different areas of the roller surface is not uniform, and finally causes the formed strip to appear uneven amorphous, wavy thickness fluctuation, unstable bandwidth, poor surface quality and other product defects. At the same time, the service life of the cooling roller is significantly reduced, and the strip manufacturing cost is further increased. These problems highlight the urgency and importance of the research on the metal hydrophilicity and high temperature wear resistance of the cooling roller surface.

2. AMORPHOUS ULTRA-THIN STRIPS PREPARATION TECHNOLOGY

2.1 Basic Technique

In the atmosphere of inert gas or air, the molten metal in the nozzle is sprayed to the surface of the rapidly rotating cooling copper roller, and the liquid nitrogen is circulated inside the roller wheel as the cooling medium, and the metal melt is cooled rapidly at a speed of 10^6 K/s, and the temperature is reduced from 1575 K to below 575 K within 10^{-3} s. Then the cooling roller rotates at high speed to generate centrifugal force to spin the molten metal into shape, so as to quickly prepare amorphous ultra-thin strip. The width of the nozzle slit determines the width of the prepared thin strip, the width of the amorphous ultra-thin strip can reach a maximum of hundreds of microns, and the minimum thickness is generally tens of microns. At present, the most widely used single roll quenching technology is melt spinning and surface flow casting, the former is used to produce strips with a width of more than ten microns, while the latter is used to produce strips with a width of tens to hundreds of microns.

2.2 Research Progress of Preparation Technology

Ozturk[1] prepared an amorphous Fe-Co ultra-thin strip with a thickness of 0.025 mm and a width of 10 mm by plane flow casting method. After annealing, there were micro bulges on both sides of the roller side and the free side of the strip, but the size of the bulges on the roller side was much smaller than that on the free side. As shown in Figure 1, with the increase of annealing temperature, uniformly and randomly distributed ultra-fine nanocrystals are generated on both sides of the thin strip. When the annealing temperature is 635~695 K, the ultrathin strip has the best coercivity and saturation magnetization. Madireddi[2] used the plane flow casting method to prepare amorphous ultra-thin strip. Through numerical simulation, it was found that due to the difference in heat transfer efficiency between the two sides of the strip, amorphous structure was more likely to occur near the roll surface of the thin strip, while crystal structure was more likely to occur on the free side. Moreover, the temperature gradient distribution in the melt pool composed of molten metal and the roll surface was analyzed. Chihiro Saito et al. [3] studied the effect of different cooling rates on the microstructure properties of Fe-0.17Ga alloy thin strips prepared by melt spinning method, and found that when the cooling rate was greater than 10^6 K/s, the surface microstructure of the prepared thin strips was amorphous.

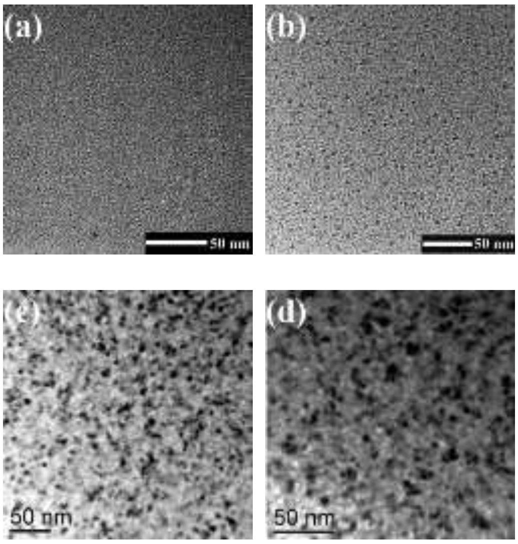

Figure. 1 TEM images of Fe-Co ultra-thin ribbons annealed at different temperatures[1]

(a) 575 K; (b) 635 K; (c) 795 K; (d) 825 K

With the increase of annealing temperature, the ultrafine nanocrystals with uniform random distribution are formed on both sides of the thin strip. When the annealing temperature is 360~420℃, the ultrathin strip has the best coercivity and saturation magnetization. Wang et al.[4] prepared Zr-Al-Ni-Cu ultra-thin strip with a thickness of 30 μm and a width of 1 mm, as shown in Figure 2, and studied the effects of liquid metal injection temperature on the structure, thermal stability and degree of amorphous strip. It is found that the atomic configuration changes from high coordination state to low coordination state during the rapid solidification of the metal, and there is no glass transition phenomenon and subcooled liquid region. Masood et al.[5] prepared an ultra-thin soft magnetic amorphous strip with a thickness of 5.5 μm, on which no large-scale crystal structure was observed and good soft magnetic properties were maintained. However, after quenching, the surface morphology of the thin strip shows significant heterogeneity, which affects the magnetic permeability of the amorphous strip. The experiment also proves that the surface amorphous degree of the amorphous strip is different due to the uneven cooling rate.

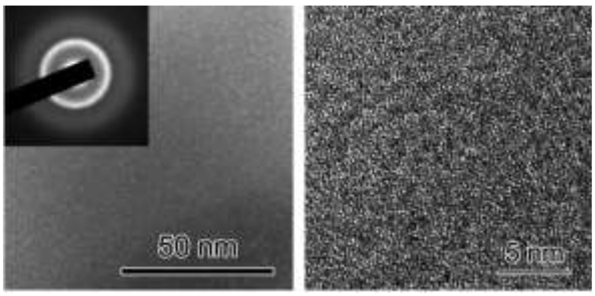

Figure. 2 TEM images of Zr-Al-Ni-Cu ultra-thin strip

Liang et al.[6] prepared Fe-0.65%Si thin strip with a thickness of 0.035 mm, a width of 60 mm and a length of 1000 m, as shown in Figure 3. The influences of nozzle shape, size, injection pressure, melt alloy superheat, distance from nozzle to roll, roll speed and a series of other parameters on the melt spinning process were studied. Because of the difference in heat transfer efficiency of the cooling rolls, the preformed strip on the roller side is equiaxed, while the free surface side is columnar.

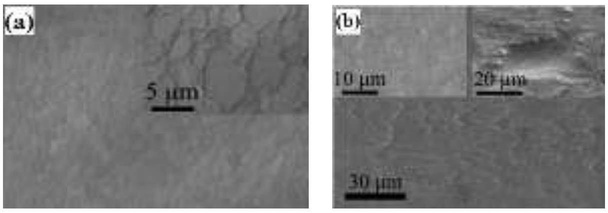

Figure. 3 Surface morphologies of Fe–6.5wt.%Si ribbon[6]:
(a) free surface; (b) wheel surface

Seino et al.[7] used rapid image processing technology to observe the spreading state of molten metal on the surface of the cooling roller after it was ejected from the nozzle, as shown in Figure 4. It is found that the forming thickness of the strip decreases with the increase of the cooling roller speed. The surface of the outer wall of the cooling roller must be maintained at a constant temperature of at least 573 K in order to prepare a continuous uniform amorphous ultra-thin strip.

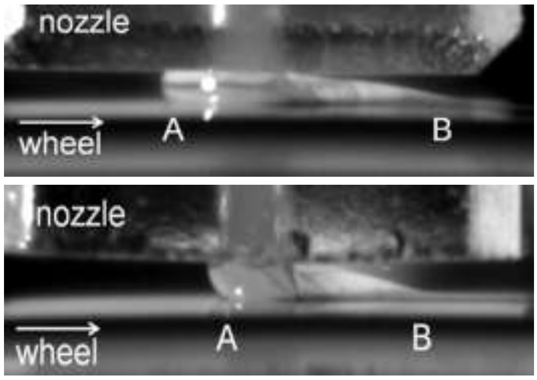

Figure. 4 Photographs of melt puddle on roll[7]

3. CONCLUISONS

The above research shows that the near roll side of the preformed strip is easier to form amorphous structure than the free side, and the possibility of crystal structure precipitation on the free side is higher. This is because the contact time between the metal melt and the cooling roll is extremely short, and the cooling rate of the near roll side of the strip is always greater than that of the free side. Because the center of the cooling roller is provided with a cooling medium channel, the distance from the outer wall surface is about 100 mm. In the process of strip preparation, there is intense heat exchange between the cooling medium and the metal melt. As the carrier of heat conduction, the temperature distribution of the cooling roll is different and the temperature gradient is large, which makes the surface temperature distribution of the preformed strip in contact with it uneven. In addition, the spread area of the metal melt on the cooling roll surface with poor wettability decreases, resulting in increased thermal resistance between the cooling roll surface and the metal melt, and a larger temperature gradient on the surface of the preformed strip, resulting in a decrease in the solidification rate of the metal melt and a significant decrease in the amorphous rate of the strip, especially on the free side.

4. REFERENCES

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