Study on martensitic transformation, magnetic and compressive properties of spray casting Ni-Mn-Ga alloys

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Keywords: Ni-Mn-Ga ferromagnetic shape memory alloy, spray casting, martensitic transformation, magnetic property, compressive property.

Abstract. The influence of spray casting technique on martensitic transformation temperature, magnetic properties and compressive properties of Ni50Mn25+xGa25–x (x = 0, 1.25, 2.5, 3.75 and 5) alloys was investigated. With the increase in Mn content, martensitic transformation temperature of the spray casting samples is increased, but slightly lower than that of the corresponding as-cast ones. The saturation magnetization test shows the opposite tendency and proves the spray casting technique can effectively enhance the magnetic properties. Compression experiments showed that the spray casting process did not change the fracture strain, but lead to the greatly increase in the compressive strength and improve the brittleness of the Ni-Mn-Ga alloys. This study may offer a new processing technique for developing high performance ferromagnetic shape memory alloys.

Introduction

Since large magnetic field induced strain (MFIS) was discovered in the ferromagnetic martensitic phase of near stoichiometric Ni_2MnGa alloys [1], there has been an increasing interest in research and development of such alloys, due to its potential application as a magnetically driven shape memory alloy which is more efficient than temperature or stress driven shape memory devices [2-4]. They are very attractive for applications as different kinds of actuators, sensors, magnetic micro-electromechanical systems. The most investigated Haussler alloy is Ni_2MnGa single crystal since it possesses huge recoverable MFIS up to 9.5% [1-5].

However, single crystal has some disadvantages, such as the preparation time is long, high cost and low repetition rate. This situation impedes the improvement of such material. Highly oriented polycrystalline alloy which has the similar performance to the single crystal could be a choice to solve this problem. Nevertheless, the high brittleness of Ni–Mn–Ga polycrystalline alloy restricts its practical applications. For now, one of the feasible method is using special processing technology to improve the high brittleness of the Ni-Mn-Ga alloy.

In this paper, a new method called spray casting has been used for preparing a series of polycrystalline Ni-Mn-Ga samples. The martensitic transformation, the magnetic and compressive properties of the as-cast samples and the spray casting samples has been investigated. This study aims to offer a new processing technique which can improve the brittleness of the Ni-Mn-Ga alloys with suitable martensitic transformation temperature and good magnetic properties.

Experimental

High purity metal elements (Ni~99.99%, Mn~97%, Ga~99.99%) are selected as the raw materials to synthesis the designed alloys. High vacuum non consumable arc melting furnace has been used to smelt and get a button ingot with the diameter of about 40mm and weight about 80g. the ingots have been homogenized in 900℃×24h to remove the composition segregation.

Table. 1 shows the nominal composition of as-cast $Ni_{50}Mn_{25+x}Ga_{25-x}$(x=0, 1.25, 2.5, 3.75, 5) (at. %) alloys and the actual composition of the alloy measured by EDS. It can be seen that the difference between the nominal composition and the actual composition is reasonable. The content of Ni keeps almost invariant, the content of Mn increases and the content of Ga decreases gradually. It's called Mn_{Ga} series. To be convenient, the serial numbers Mn_{Ga}-0, Mn_{Ga}-1 … Mn_{Ga}-4 were used to replace the composition of the sample below.

Table 1 the composition of $Ni_{50}Mn_{25+x}Ga_{25-x}$ (x=0, 1.25, 2.5, 3.75, 5) alloy

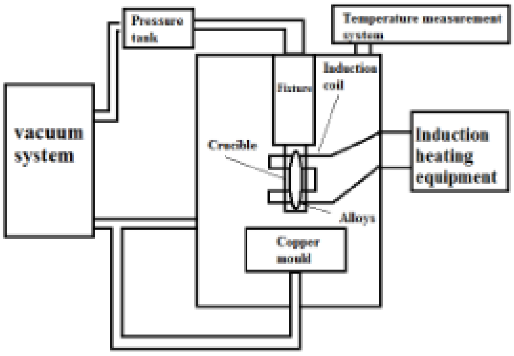
Serial number and Nominal composition (at %)		Actual composition measured by EDS		
		Ni (at %)	Mn (at %)	Ga (at %)
Ni2MnGa	Ni50Mn25Ga25	50.46	24.89	24.65
MnGa-1	Ni50Mn26.25Ga23.75	49.89	26.31	23.80
MnGa-2	Ni50Mn27.5Ga22.5	49.82	27.79	22.39
MnGa-3	Ni50Mn28.75Ga21.25	50.08	28.81	21.11
MnGa-4	Ni50Mn30Ga20	50.42	29.37	20.21

A special process called copper mound spray casting technique has been used in this study. Put the as-cast alloys placed in a quartz tube with a round hole at the bottom and the copper mound placed exactly under the quartz tube. The whole device is spaced in a vacuum system. Melt the ingot by high frequency induction heating, after the ingot molten completely, load argon with particular pressure into the quartz tube from the top. The molten alloy has been sprayed cast into the copper mound. Finally get a cylinder with the diameter of Φ8 mm. Fig.1 shows the copper mound spray-casting method and the alloy rod got by spray casting process. Spray casting alloy rod is brighter and much compact than traditional button as-cast ingot.

Results and discussion

Martensitic transformation. We investigated the effect of composition on the martensitic transformation temperature of the spray casting and as-cast $Ni_{50}Mn_{25+x}Ga_{25-x}$(x=0, 1.25, 2.5, 3.75, 5) alloys, the results have been shown in Fig. 2 (a).

As seen from Fig. 2 (a), the martensitic transformation temperature increased gradually with the increase of Mn. Furthermore, the martensitic transformation temperature of the spray casting alloy is slightly lower than that of the as-cast alloy.



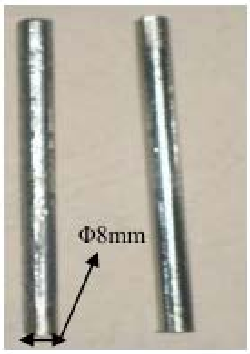


Fig. 1. Processing diagram of copper mound spray-casting method and rod got by spray casting.

Magnetic properties. The saturation magnetization of the spray casting sample and the as-cast sample of the $Ni_{50}Mn_{25+x}Ga_{25-x}$ (x=0, 1.25, 2.5, 3.75, 5) alloys has shown in Fig. 2(b). With the increase of Mn content, the saturation magnetization is generally decreased. Through the first-principles calculations we know that Mn atom is the mainly element who carrying the magnetic moment (about 3.5 μB). When the content of Mn is excess, the magnetic moment of the extra-Mn atom is antiparallel to that of the normal-Mn, leading reduce of the magnetic property [6].

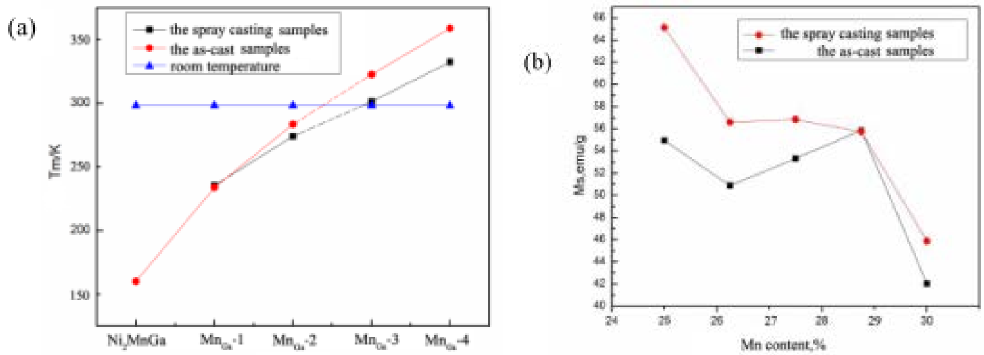


Fig.2. Martensitic transforming temperatures (a) and saturation magnetization (b) of spray casting and as-cast Ni50Mn25+xGa25-x (x=0, 1.25, 2.5, 3.75, 5) alloys

Although adjusting the Mn content can improve the martensitic transformation temperature above the RT, it also will lead the decrease of the magnetic property. It can be seen from Fig. 2(b), the saturation magnetization of the spray casting sample is slightly higher than that of the as-cast one. This is mainly due to the high degree of supercoiling of the spray casting process increases the magnetic order degree of this magnetic material. Therefore, the spray casting process is helpful to improve the magnetic order degree and hence the magnetic properties.

Compressive properties. The compressive stress versus strain curves of the spray casting and as-cast Mn_{Ga}-4 alloys are illustrated in Fig. 3 (a) and (b), respectively. The compressive strength and fracture strain for the Mn_{Ga}-4 spray casting alloy are 673.2MPa and 16.32%, respectively. For the Mn_{Ga}-4 as-cast alloy, the compressive strength and fracture strain are 390.41MPa and 16.53%, respectively. The spray casting process did not change the fracture strain, but greatly increased the compressive strength by 283MPa. The spray casting technique greatly increases the compressed capability and improves the brittleness of the Ni-Mn-Ga alloys.

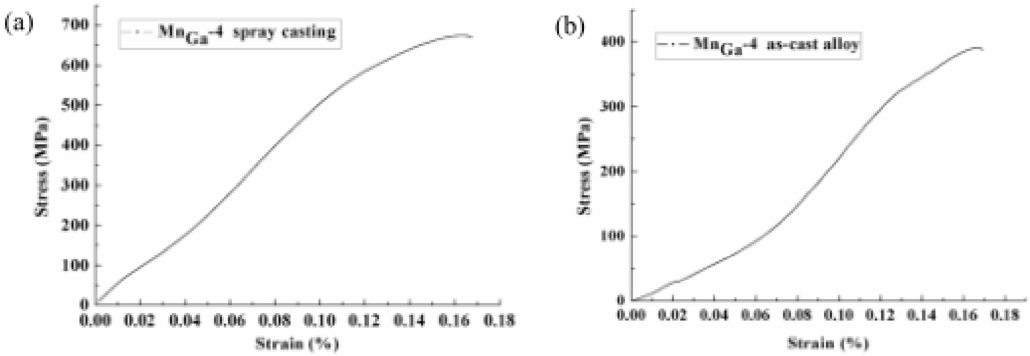


Fig. 3. Compressive stress vs. strain curves of
(a) Spray casting MnGa-4 and (b) as-cast MnGa-4 alloys.

Conclusions

The influence of spray casting technique on martensitic transformation temperature, magnetic properties and compressive properties of $Ni_{50}Mn_{25+x}Ga_{25-x}$ (x = 0, 1.25, 2.5, 3.75 and 5) alloys was investigated. 1. With the increase of the Mn content, the martensitic transformation temperature increased, and the martensitic transformation temperature of the spray casting sample is lower than that of the as-cast one. 2. The saturation magnetization of the spray casting sample is slightly higher than that of the as-cast one. This is mainly due to the high degree of supercoiling of the spray casting process increases the magnetic order degree of this magnetic material. 3. The spray casting process did not change the fracture strain, but greatly increased the compressive strength by 283MPa. The spray casting technique greatly increases the compressed capability and improves the brittleness of the Ni-Mn-Ga alloys.

Acknowledgements

This work is supported by the National Natural Science Foundation of China (Grant No. 51301036), the Fundamental Research Funds for the central Universities of China (Grant No. N130523001), the Research Fund for the Doctoral Program of Higher Education of China (Grant No. 20120042110021), the Natural Science Foundation of Hebei Province (No. E2013501089).

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