SHAPE MEMORY EFFECT IN PULSE DISCHARGE SINTERED $Ni_{2.18}Mn_{0.82}Ga$

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In the studied PDS materials a two-way shape memory behavior can be induced by a load - unload cycle performed in the martensitic state, i. e. essentially without special training. These samples show significant enhancement in the magnitude of strain induced by a magnetic field.

Introduction

Beginning from 1996 when Ullakko and co-worker [1] reported on magnetic-field-induced strain of about 0.2% in a non-stoichiometric Ni–Mn–Ga single crystal, the research in this field has attracted considerable attention due to a great technological potential of this effect. Later this phenomenon was found in other compounds exhibiting shape memory effect when in the ferromagnetic state, such as Fe–Pd and Fe–Pt [2, 3]. Whereas Fe–Pt and Fe–Pd show magnetic-field-induced strains not exceeding 1%, in Ni–Mn–Ga single crystals the values of magnetic-field-induced strains can be as large as 6% [4]. The mechanism of this phenomenon is believed to be a redistribution of different twin variants under action of a magnetic field [5]. Since these giant magnetostrains are obtained by means of application of comparatively low magnetic fields (less then 1.5 T), they are easy suppressed by an external stress. For instance, the 6% field-induced strain was completely blocked by a compressive stress of order 2 MPa [4]. This suggests that the giant magnetostrains arising from the process of twin-boundary motion might be useful for large stroke/small force applications.

Another way to obtain a large magnetic-field-induced strain in ferromagnetic shape memory materials is a shift of the martensitic transition temperature caused by a magnetic field [6, 7]. However, in this case the magnitude of the applied field must be large in order to overcome the temperature hysteresis of martensitic transformation. From general consideration, it can be expected that the maximum achievable strain in this case is equal to the striction of the transition or even more if material is trained for a two-way shape memory effect. The work output has to be large (as in conventional shape memory alloys), which can be useful for mediate stroke/large force applications.

From the point of view of widespread use of magnetic-field-induced strain (MFIS) observed in ferromagnetic shape memory alloys, there is a need to investigate polycrystalline materials. For this purpose we have studied $Ni_{2.18}Mn_{0.82}Ga$ alloy prepared by a Pulse Discharge Sintering (PDS) process.

Samples preparation and measurements

Ingots of $Ni_{2.18}Mn_{0.82}Ga$ were prepared by arc-melting of high-purity initial elements. The ingots were annealed at 1100 K for 9 days and quenched in ice water. A part of the arc-melted ingots was used to fabricate PDS samples. For this the arc-melted ingots initially were crushed into particles and ground into fine powder with a particle size less than 53 μm.

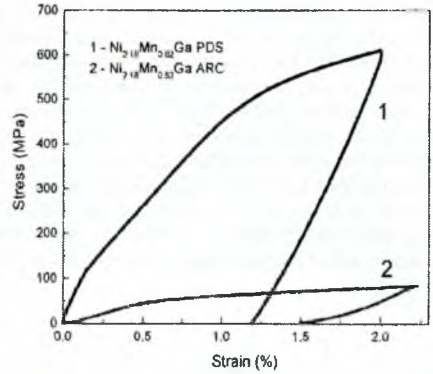

Fig. 1. Curves of compression test for a PDS sample (curve 1) and arc-melted sample (curve 2).

Meshed powder was filled in a graphite die with two graphite punches. The die was set in a pulse discharge system (Sodick Co., Ltd).

The pulse discharge system was evacuated to a vacuum of 3 Pa prior to the sintering process. At the beginning of the sintering, a pulse current of 800 A was charged for 30 s and then the dc and load were applied by a temperature and pressure control program. Maximum pressure and temperature during the PDS process were equal to 80 MPa and 1173 K, respectively. Disc-shaped billets with thickness of 6 mm were sintered. Samples with dimensions of 3×3×6 mm were spark-cut from the billets. Temperature and magnetic field dependencies of strain were measured by a strain gage technique. Stress-strain measurements were done at room temperature by an Instron machine. X-ray diffraction measurements performed in a wide temperature range showed that a high-temperature austenitic structure has a cubic modification whereas the low-temperature martensitic phase has a complex tetragonally based crystal structure.

Results and discussion

The results of compression tests for $Ni_{2.18}Mn_{0.82}Ga$ prepared by the PDS method and by a conventional arc-melting technique are shown in Fig. 1. The compression tests were done at room temperature with the same speed of compression for both samples. The comparison of these curves clearly indicates that the PDS material shows higher yield strength than the arc-melted one. This characteristic is of importance for practical applications, and it makes the PDS materials more attractive in this sense.

Figure 2 shows temperature dependencies of strain measured in a $Ni_{2.18}Mn_{0.82}Ga$ PDS sample at cooling and heating in zero and 5 T magnetic fields. In zero magnetic field the sample length monotonously increases upon heating up to the onset of the reverse martensitic transformation, A_S = 343 K. The martensite - austenite transformation is accompanied by a rapid increase in the sample length, which flattens out at austenite finish temperature A_F = 357 K. Subsequent cooling results in the direct martensitic transformation at M_S = 342 K, which is accompanied by a shortening of the sample. As evident from Fig. 2, the striction of the transition is approximately 0.18%.

The temperature dependencies of strain measured in a 5 T magnetic field revealed that the striction of the transition remains essentially the same as in the case of the measurements without magnetic field. Comparison of the measurements performed in zero and 5 T magnetic fields leads to a conclusion that the application of the magnetic field results in an upward shift of the characteristic temperatures of the martensitic transition with a rate of about 1 K/T.

This value agrees very well with the results reported for polycrystalline $Ni_{2+x}Mn_{1-x}Ga$ prepared by arc-melting [7]. An interesting feature of the PDS samples is that the two-way shape memory behavior can be induced in these materials by a simple loading – unloading cycle. This feature is presented in Fig. 3. Indeed, the increase in the length of the sample caused by the martensitic transition is approximately 0.18% in the case of a sample which was not subjected to compression. Another sample cut from the same ingot was compressed for

2% at room temperature in the martensitic state. After unloading the residual deformation was approximately 1.2% (Fig. 1). The sample restored approximately 75% of its initial length upon the first heating, showing shape memory effect. The subsequent cooling – heating process revealed that the change in the length associated with the martensitic transformation increased in two times as compared with uncompressed one and reached 0.4%. It is also seen from Fig. 3 that the change in slope of the curves at the characteristic temperatures of martensitic transformation in the compressed sample becomes less pronounced than in the compression-free sample. Further themocyclings demonstrated that this compression-induced two-way shape memory effect (TWSME) does not degrade and the 0.4% change in the length of the sample is very well reproducible at least up to the tenth heating – cooling cycle. It is worth noting that a well-defined two-way shape memory effect has been also found recently in Ni-Mn-Ga thin films [8].

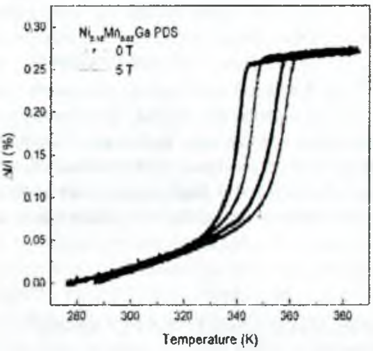

Fig. 2. Temperature dependencies of strain in a $Ni_{2.18}Mn_{0.82}Ga$ PDS sample measured in zero and 5 T magnetic fields.

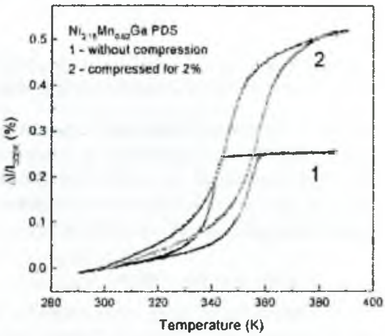

Fig. 3. Compression-induced two-way shape memory effect in a $Ni_{2.18}Mn_{0.82}Ga$ PDS sample (curve 2). Curve 1 represents temperature dependencies of strain for a stress-free sample

To study this compression-induced two-way shape memory behavior in more detail, several $Ni_{2.18}Mn_{0.82}Ga$ PDS samples were compressed for values of strain from 1 to 6 %. After unloading the residual deformation in these samples was from 0.4 to 4%, respectively. The behavior of the samples upon the first heating process was found to be dependent on the value of the residual strain. Thus, the sample with 0.4% residual strain showed a perfect shape memory effect whereas the sample with the largest residual strain did not exhibit shape memory effect which means that the residual deformation in this sample was essentially plastic one. The TWSME was found only in the samples compressed for 2 and 3%. Together with the observation that the sample compressed for 2 and 3% did not revert the original shape completely after the first heating, this fact evidences that the TWSME appears when applied stress exceeds some critical limit which is enough for occurrence of irreversible slip. It can be suggested that it arises from a strain field of dislocations induced during compression.

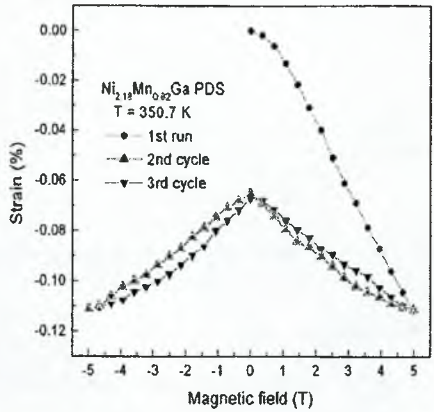

Fig. 4. Strain induced by a magnetic field in the temperature interval of the direct martensitic transformation in a sample, exhibiting two-way shape memory effect.

The measurements of magnetic-field-induced strain in a temperature interval of the martensitic transformation in the PDS-sintered $Ni_{2.18}Mn_{0.82}Ga$ samples showed that this material exhibits rather small values of MFIS even in high (up to 5 T) magnetic fields. For instance, in the compression-free $Ni_{2.18}Mn_{0.82}Ga$ sample this value is equal to 0.02% in a 5 T magnetic field. However, in the case of the samples which demonstrate the compression-induced two-way shape memory behavior the value of MFIS is increased in 6 times as compared to the samples without TWSME. In fact, such a tendency could be expected, since in this case the MFIS is due to the shift of the martensitic transition temperature caused by the applied magnetic field. The magnitude of MFIS is proportional to the relative change in the dimension of the sample per 1 K and this characteristic is much better in the samples with TWSME. It can be suggested that an appropriate training procedure of the PDS material will results in enhancement of the magnitude of the observed TWSME, leading to an increase in the value of MFIS.

It should be noted, however, that the strain of about 0.12% is not perfectly recovered. Fig. 4 shows that when we remove magnetic field and change its polarity, the reversible MFIS is equal to 0.06%. This value of MFIS is reversible for many cycles of application and removal of the magnetic field.

Conclusion

In conclusion, the most interesting findings of this study are that the two-way shape memory effect can be induced in PDS materials by an ordinary compression of the materials being in the martensitic state. The samples with TWSME show a significant enhancement in the magnitude of MFIS observed in the temperature interval of martensitic transformation.

Acknowledgements

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МОДЕЛИРОВАНИЕ ПЛАСТИНЧАТЫХ И СТЕРЖНЕВЫХ ЭЛЕМЕНТОВ КОНСТРУКЦИЙ БОРТОВОЙ РАДИОЭЛЕКТРОННОЙ АППАРАТУРЫ

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К разрабатываемой в настоящее время бортовой радиоэлектронной аппаратуре (РЭА) (самолетной, бронетанковой, автомобильной) предъявляются высокие требования по времени эксплуатации аппаратуры, в течение которого она должна сохранять работоспособность.

Для обеспечения длительной работоспособности радиоэлементов (РЭ) требуется предварительный анализ механических характеристик конструкций блока и печатного узла (ПУ), представленных в виде совокупности пластинчатых и стержневых элементов, с целью определения параметров вибрационных воздействий на РЭ, а затем анализ механических характеристик РЭ с целью определения времени до усталостного разрушения выводов, что, в конечном итоге, нужно для принятия решения о необходимости обеспечения длительной работоспособности РЭ при вибрационных воздействиях.

Таким образом, в настоящее время весьма актуальна задача математического моделирования РЭ в составе блоков бортовой РЭА для анализа длительной работоспособности РЭ при вибрационных воздействиях.

Используемые в настоящее время методы и модели для анализа механических характеристик конструкций РЭА, пакеты прикладных программ, созданные на их основе, а также методики для анализа и обеспечения механических характеристик конструкций РЭА применять для оценки длительной работоспособности РЭ в составе блоков РЭА при вибрационных воздействиях практически невозможно. В них предусмотрен только расчет механических напряжений в выводах отдельных конструкций РЭ, но отсутствует возможность для оценки времени до усталостного разрушения выводов РЭ.

Отсутствуют расчетные модели РЭ, позволяющие провести оценку времени до усталостного разрушения выводов РЭ, которые зависят от варианта установки, материала, геометрических размеров и формовки выводов. Отсутствуют необходимые расчетные модели блоков, позволяющие с достаточной для инженерных расчетов точностью получить параметры вибрационных воздействий на ПУ и РЭ, установленные на стенках блока, не проводя полного анализа блока.

В связи с вышеизложенным, в моей работе сформулирована и решается актуальная научная задача моделирования пластинчатых и стержневых элементов конструкций бортовой РЭА для оценки времени до усталостного разрушения выводов РЭ в составе блоков бортовой РЭА при вибрационных воздействиях.