Crystallographic texture and the preferential orientation of a martensite in the polycrystalline Ni$_{2.08}$Mn$_{0.96}$Ga$_{0.96}$ alloy

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Abstract. A study of the relationship of the crystallographic texture, the preferential orientation of martensite twins and the geometry changes during the martensite transformation of polycrystalline NiMnGa alloy is shown. Two states of alloy are investigated: as-cast state and the state after annealing at 923 K for 5 hours. It is shown that in the initial state the austenite phase has crystallographic axial texture <001>, while martensite has the two-component texture of the <001> and <110>. The preferential orientation of the martensitic twins in the martensitic structure is found. The crystallographic texture of the alloy after annealing is not changed, however, no preferential orientation of the martensitic twins is observed. In the martensitic phase structure martensitic twins are oriented randomly. Anisotropy of the thermal expansion during the martensitic transformation is shown, while in the annealed state such effect is not found.

1. Introduction
The Heusler NiMnGa alloys attract attention in consequence of the martensitic transformation, which occurs in the material at the room temperature. Depending on the composition, alloy can proceed to the ferromagnetic or paramagnetic state. In the transformation temperature range alloys have the magnetic shape memory effect (or the effect of magnetic field induced deformation) [1-7], the giant magnetocaloric effect [8-11] and giant magnetoresistance [12-13]. Control of the shape and dimensions of the material by applying an external magnetic field opens prospects of using this material as a functional component for various kinds of microelectronic devices. The greatest effect of irreversible magnetic field induced deformation achieving up to 6% is observed on single-crystal samples [14]. On the polycrystalline samples, the reversible magnetic field induced deformation had a value less than 1% [15]. However, it would be very promising to obtain the significant magnetic deformation on polycrystalline materials, as they are cheaper to manufacture in comparison with single crystals.

In the process of martensitic transformation, on the single-crystal samples of alloys the anisotropy of the thermal expansion was observed [16]. In some cases, it was also observed in polycrystalline materials [17]. In literature such effect is explained by the formation of preferential orientation of martensitic twins [18], however, there is rather little experimental data. To clarify this, deeper study of the structure of polycrystalline materials in different structural states is required. In this paper, experimental data confirming the dependence of the formation of the martensite twins preferential orientation and the anisotropy of the thermal expansion of the material in the process of transformation are presented.

2. Material and methods
The polycrystalline Ni$_{2.08}$Mn$_{0.96}$Ga$_{0.96}$ alloy was selected for the investigation. The alloy was prepared by arc melting of high purity Ni, Mn and Ga in Ar atmosphere. To homogenize the structure, samples are annealed for 9 days at 1100 K, which is followed by quenching in ice water. The phase transformation temperatures are: $M_S=294$ K (martensite start); $M_F=267$ K (martensite finish); $A_S=287$ K (austenite start); $A_F=304$ K (austenite finish); $T_C=375$ K (Curie temperature).
Crystallographic orientations are measured by diffraction of back-scattered electrons (Electron Back-Scattered Diffraction - EBSD) at an accelerating voltage of 20 kV. EBSD analysis of texture by scanning electron microscopy is widely used to study the materials texture [19]. The mapping is carried out by the detector back-scattered electrons (Nordlys detector, Oxford Instruments) mounted on a high-resolution scanning electron microscope Mira-3LMH (Tescan) with a cold cathode field. Scanned area in the process of shooting typically is about 1.8 mm × 1.7 mm.

The alloy is investigated in two states: initial as-cast state and after annealing at 923 K (the temperature is below the “order-disorder” \(B_2'-L_2\)) temperature) for 5 hours followed by cooling to the room temperature in the furnace. Annealing is carried out for the possible removal of the internal stresses which may appear during the melt crystallization.

### 3. Results and discussion

The directions in the ingot were chosen so that the axis \(N_1\) is parallel to the ingot axis. The axis \(N_2\) is perpendicular to the axis \(N_1\) and lies in a horizontal plane of the ingot. The axis \(N_3\) is perpendicular to the axes \(N_1\) and \(N_2\). The sample was is cut so that its plane of investigation is parallel to plane \(N_1N_2\).

In the Fig. 1 (a) the pole figures (PF) for the \{100\} and \{110\} planes of the austenitic phase in the initial as-cast state are shown. These two planes fully reflect the structure of the austenite because of the cubic symmetry of the phase. Planes \{101\} and \{011\} are equivalent to \{110\}. Analysis of the figure shows that the structure of the austenite phase of the alloy in the initial state has a highly axial texture <001> in direction \(N_3\) of the ingot.

![Figure 1. PF of the austenite (a) and martensite (b) phases in the as-cast state, austenite (c) and martensite (d) phases of annealed alloy.](image)

In fig. 1 (b) the PF of the alloy martensitic phase in the initial state for the set of planes \{100\}, \{001\}, \{110\} and \{011\} are presented. The analysis of PF for the martensitic phase shows the two-component texture: <001> and <110> in the \(N_3\) direction.

The results of the structure investigation of austenite and martensite phases of the same sample after annealing at 923 K for 5 hours are presented on Fig. 1 (c, d). The PF for planes \{100\} and \{110\} of the austenitic phase of annealed alloy are presented in Fig. 1 (c). In Fig. 1 (d) the PF for planes \{100\}, \{001\}, \{110\} and \{011\} of the martensitic phase are presented. On the PF the equipotential contours of the alloy in the initial state and after annealing have the same the texture indexes. The comparison the PF of the austenite and martensitic phases of the alloy in initial and annealed states shows that after the heat treatment texture does not change. Only the slight diffusion of the intensity maxima is observed. Thus, annealing of the alloy at 923 K for 5 hours does not lead to the removal of the crystallographic texture.

The microstructure analysis of the martensite phase of both studied structural states is carried out by the optical methods. To study the microstructure from the ingot, the samples
with the size of 1 mm × 2 mm × 7 mm are cut in two mutually perpendicular directions. The long side of the first sample (the sample axis) coincides with the direction N1, in the second sample it coincides with the direction N2. The image of the martensite twin structure of both samples is shown in fig.2 (a) and 2 (b), respectively.

It is shown that the structure of martensite has the martensite plates with width from units to several tens of micrometers. The image contrast is observed due to the formation of micro-relief on the sample surface. There is the preferential orientation of martensite plates in both cases. The majority of the martensite twins of both samples lie along the direction N2. It should be noted, that upon the repeated cycles of martensitic transformation the distribution and size of twins are not changed.

In Fig. 2 (c) the martensite structure of annealed alloy is presented. The martensite plates have the width about 15 microns. The martensite twins have a random distribution. The absence of a preferential orientation of the twins in the martensite structure can be explained by the removal of internal stress as a result of the annealing.

From the above mentioned data, it can be seen that the martensitic structures of the alloy in the initial state and after annealing are different. It is necessary to take into account the sample geometry changes during phase transformation. These processes should be correlated.

The thermal expansion was investigated on the samples, which was used for the structure investigations. In all cases the measurements was carried out along the long side of the samples. The results for both types of the samples in the initial state are shown in Figs. 3 (a) and (b). As it can be seen from the figures, the length of the samples in the austenitic and martensitic phases is linearly reduced. In the transformation temperature range curves are different. The sample which is cut in the N1 direction is abruptly shortened on 0.35% as a result of the martensitic transformation. The sample which is cut in the N2 direction is elongated on 0.35%. The martensitic structure of the first sample has a preferential orientation of the martensitic twins which are oriented perpendicularly to the axis of the sample. The structure of the second sample has a preferential orientation of the martensitic twins which are oriented parallel to the sample axis [see Figs. 2 (a) and (b)]. It can be conclude that the abrupt length change during the martensitic transformation is caused by the formation of the preferential orientation of the twins.

Figure 3 (c) shows the results for thermal expansion of the annealed sample. The thermal expansion of both types of the samples after annealing does not show the abrupt length change. Over the whole cooling range, only the monotonous reduction of sample’s length is observed.
Figure 3. Thermal expansion curves of alloy in the initial state: a – the long side of the sample coincides with N1 direction, b – the long side of the sample coincides with N2 direction, c – alloy after annealing at 923 K (5 hr).

For the martensitic transformation, no abrupt change of the sample length is observed. It is shown that the preferential orientation of the martensitic twins of the annealed alloy is absent. Thus, if during the martensitic transformation the structure with a random distribution of twins is formed, then the abrupt length change of the sample is not occurred.

4. Conclusions
The polycrystalline $\text{Ni}_{2.08}\text{Mn}_{0.96}\text{Ga}_{0.96}$ alloy in the initial state has a crystallographic texture. The austenite phase has the crystallographic axial texture $<001>$, at the same time the martensitic phase has a two component crystallographic texture $<001>$ and $<110>$.

Annealing of the alloy at 923 K (5 hr) does not lead to removal of the crystallographic texture, but affects the distribution of the martensitic twins. The differences in the thermal expansion curves for the initial and annealed states can be explained by the formation of the preferential orientation of the martensitic twins.

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