euspen's 24rd International Conference &
Exhibition, Dublin, IE, 2024
www.euspen.eu

Mechanical machining of a Ni-Mn-Ga alloy with magnetic shape memory effect

E. Uhlmann[1,2], J. Polte[1,2], B. Hein[1], Y. Kuche[2]

[1]*Fraunhofer Institute for Production Systems and Design Technology IPK, Germany*
[2]*Institute for Machine Tools and Factory Management IWF, Technische Universität Berlin, Germany*

benjamin.hein@ipk.fraunhofer.de

Abstract

Actuator elements are essential components of micro-mechanical systems with application areas in the automotive industry, medical technology or mechanical and plant engineering. Magnetic shape memory alloys (MSMA) based on the alloying elements Ni-Mn-Ga offer an industrial alternative to piezo actuators, but are cost-intensive to manufacture. They react sensitively to higher machining temperatures and pressures, which makes it difficult to mechanically produce the required final contours. This article shows that, under certain conditions, grinding and lapping enable the production of flat surfaces and surface roughnesses of Rz ≤ 0.1 µm can be realized.

Keywords: magnetic shape memory, double face grinding, lapping, mechanical machining

1. Introduction

Against the background of short switching times t_s, high energy densities, low wear and without direct electrical contact, actuators with magnetic shape memory effect are relevant for a variety of applications [1, 2, 3]. One specific magnetic shape memory alloy (MSMA) consist of nickel (Ni), manganese (Mn) and gallium (Ga). The alloy can be manufactured with a single crystalline martensite structure with distinct twin boundaries, shown in Figure 1a. When a magnetic field is applied, the lattice is displaced and the motion of the twin boundaries results in magnetic field-induced strains (MFIS) [4, 5].

For use as actuators, the MSMA must be processed into small rectangular sticks. Due to its physical properties, however, both higher temperatures ϑ and pressures p are critical for producing the final contours and ensuring high dimensional accuracy. Depending on the material composition, higher temperatures ϑ during processing can lead to a transformation from martensite to austenite. Furthermore, increased pressures p during mechanical processing or clamping of the semi-finished products lead to the indication of cracks and also an offset of the twin boundaries, shown in Figure 1b [6]. Machining processes such as milling, grinding or lapping offer an economical series production of the sticks if a precise production of functional final contours with high plane parallelism and low edge layer damage can be achieved. In this paper, different approaches for one-sided grinding and lapping of the MSMA are presented and discussed.

2. Experimental setup

For the investigations, sticks of MSMA were prvided by the company Eto Gruppe Technologies GmbH, Stockach, Germany. The sticks have a length of l = 15 mm, a width of b = 3 mm and a thickness of t = 2 mm. As can be seen in Figure 1a, the sticks supplied have no damaged edge zones due to electro-chemical pre-treatment, which makes the individual twin boundaries of the alloy visible.

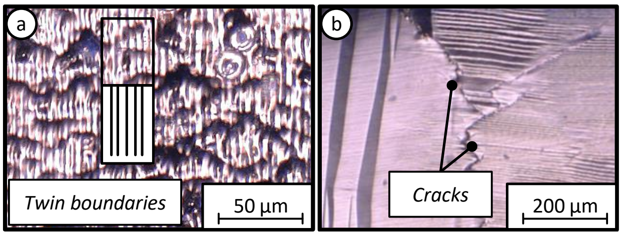


Figure 1. a) Visible twin boundaries on the top of a Ni-Mn-Ga stick; b) Cracks after mechanical processing.

A Saphir 360 E disc grinding machine tool was used for the grinding experiments. A speed of n = 150 rpm was specified. Furthermore, silicon carbide-based abrasive paper of the types P1.200, P2.500 and P4.000 was used. Due to the decreasing material removal rate Q_w with the grain size d_s used in the abrasive papers, the processing time t had to be successively increased, whereby a processing time of t = 2.0 min was set for the use of P1.200, t = 10.0 min for P2.500 and t = 15.0 min for P4.000. For the machining process, the sticks were fixed on a sample holder and pressed onto the grinding surface with a homogeneous contact force of approximately F ≈ 5 N using the weight m of the holder.

Furthermore, a single disc lapping machine tool of the type 4R40GR from the company Wentzky, Stuttgart, Germany, was used. A speed of n = 60 rpm was specified for the experiments. A lapping oil of the type OL 20 PLUS from the company FLP Microfinish GmbH, Zörbig, Germany, was used. The lapping mixture consists of the lapping powder and the lapping oil, whereby four different lapping powders with different grain size d_s were used in accordance with Table 1. The MSMA sticks were centred by a guide system on the lapping disc and a surface pressure of $p = 0.03\ N/mm^2$ was achieved using a defined weight m.

Table 1. Abrasive powder for investigation of the lapping process

Abrasive powder	SiC F500	SiC F1.200
Grain size d_s	6 µm ≤ d_s ≤ 8 µm	2 µm ≤ d_s ≤ 4 µm
Abrasive powder	Tetratbor Boron carbide F500	Tetratbor Boron carbide F1.200
Grain size d_s	5 µm ≤ d_g ≤ 25 µm	1 µm ≤ d_g ≤ 7 µm

The processed Ni-Mn-Ga sticks were analysed tactilely using a HOMMEL nanoscan 855 measuring system from JENOPTIK INDUSTRIAL METROLOGY GMBH, Jena, Germany, and optically using a JCM-5000 NeoScope scanning electron microscope (SEM) from the company JEOL LTD, Akishima, Japan. A VHX-5000 digital microscope from the company KEYENCE DEUTSCHLAND GMBH, Neu-Isenburg, Germany, was also used.

3. Results and discussion

Figure 2 and Figure 3 show the results of the roughness measurements using the arithmetical mean deviation Ra and the mean roughness depth Rz. The two graphics above show the results of the single-sided lapping process, while the graphs below show the results of the grinding experiments.

The results of the roughness measurements of the MSMA sticks processed by lapping show an increase in the roughness values compared to the initial state. In some cases, considerable grooves were detected, which had a particularly strong influence on the measured values of the mean roughness depth Rz. In contrast to grinding, lapping results in non-directional grain movement, which has an effect on the grinding pattern of the machined surfaces. In combination with the process parameters and lapping grains used, it was not possible to produce polished surfaces and visualise the twin boundaries.

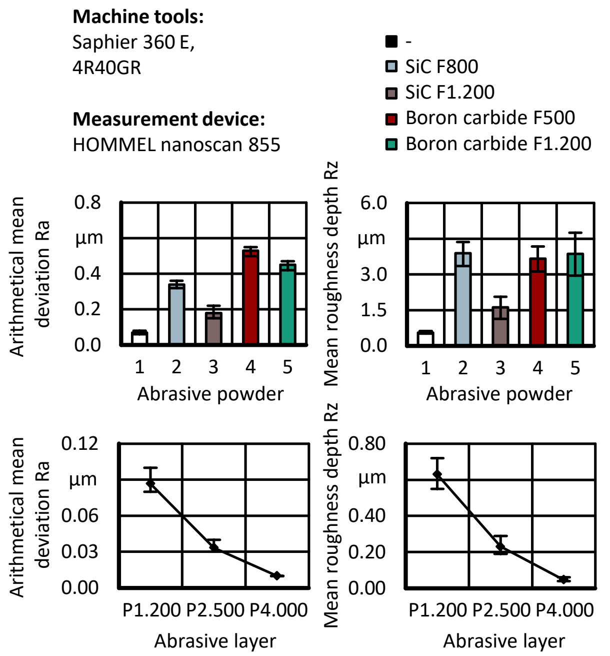


Figure 2. Surface roughness of the machined Ni-Mn-Ga sticks

The roughness measurements after grinding the NiMnGa alloys show surface improvements with reduced abrasive grain size d_s. A high surface quality with a arithmetical mean deviation of Ra = 0.08 µm and a mean roughness depth of Rz = 0.62 µm was achieved, even when using the coarser grain with P1200 abrasive paper. With decreasing grain size d_s and increased processing times t, the surface quality can be further improved, whereby the grinding grooves are only very slightly pronounced when using the P4.000 abrasive paper and the twin boundaries are easily recognisable. This indicates that with a very low mechanical load and corresponding process conditions similar to polishing, it is possible to reduce mechanically impaired edge zones by grinding. At the same time, however, the selection of different processing surfaces was observed along the machined stick surface, which suggests a geometric change in the sticks during the process and thus fluctuating grinding conditions. The boundaries between dissent areas were identified as being susceptible to cracking and therefore a challenge for homogeneous mechanical processing.

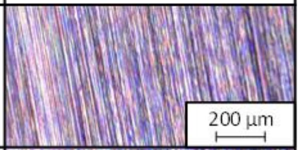
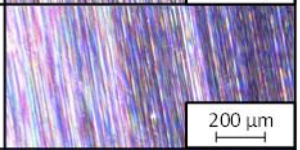
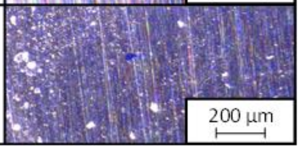
	Surface roughness	Microscope image
P1.200	*Arithmetical mean deviation Ra = 0.08 µm Mean roughness depth Rz = 0.62 µm*	
P2.500	*Arithmetical mean deviation Ra = 0.06 µm Mean roughness depth Rz = 0.29 µm*	
P4.000	*Arithmetical mean deviation Ra = 0.01 µm Mean roughness depth Rz = 0.06 µm*	

Figure 3. Images of the surfaces of grinded Ni-Mn-Ga sticks

4. Conclusion

Optical analyses and roughness measurements show that high surface qualities with roughness values of Rz ≤ 0.1 µm can be achieved and mechanical machining is basically possible. On the one hand, the results demonstrated the careful mechanical processing of the Ni-Mn-Ga alloy, which can be used as a basis for future process design. At the same time, however, the generation of cracks in the edge zone and the development of individual machining areas on the flat surfaces of the sticks could also be observed, which significantly compromises the stability of the sticks and impairs their function. In future, these must be further analysed during mechanical processing and avoided when establishing the processes for manufacturing the Ni-Mn-Ga sticks.

Acknowledgements

This article is based on investigations, which were kindly supported by the Federal Ministry for Economic Affairs an Climate Action on the basis of a resolution of the German Bundestag.

References

[1] Gabdullin, N.; Khan, H.: Study of Non-Homogeneity of Magnetic Field distribution in Single-Crystal Ni–Mn–Ga Magnetic Shape Memory Element in Actuators Due to Its Anisotropic Twinned Microstructure. IEEE Transactions on magnetics, vol. 53, No. 3, 03/2017.

[2] Hutter, M.; Raab, M.; Kazi, A.; Wolf, F.; Gundesweiler, B.: Magnetic Flux Control through Magnetic Shape Memory Alloys in Reluctance Actuators. ETG-Fachbericht 159: IKMT 2019, p. 58 – 63.

[3] Ullakko, K: Magnetically controlled shape memory alloys: a new class of actuatormaterials, J. Mater. Eng. Perform. 5 (1996), p. 405 – 409.

[4] Dunand, D.C.; Müllner, P.: Size Effects on Magnetic Actuation in Ni-Mn-Ga Shape-Memory Alloys. Advanced Materials 23 (2010) 2, p. 216 – 232.

[5] Sozinov, A.; Lanska, N.; Soroka, A.; Zou, W.: 12% magnetic field-induced strain in Ni-Mn-Ga-based non-modulated martensite. Applied Physics Let-ters 102(2013).

[6] Chmielus, M.; Witherspoon, C.; Ullakko, K.; Müllner, P.; Schneider, R.: Effects of surface damage on twinning stress and the stability of twin microstructures of magnetic shape memory alloys. Acta Materialia 59 (2011) 8, p. 2,948 – 2,956.