Abstract

A large magnetic field induced strain is indicative of an ideal ferromagnetic shape memory alloy, especially, Heusler alloys. Therefore, ribbons of $Ni_{50}Mn_{28}Ga_{22}$ were prepared by melt spinning at two different wheel speeds of 1300 and 1600 RPM and annealed at different temperatures over different time periods to study the magneto-mechanical properties. Prior to this, the as-spun as well as annealed ribbons were characterized to study their microstructural and microtexture properties. Phase analysis done by X-ray diffraction technique showed the presence of modulated martensitic structures, which was confirmed from the appearance of the three (202) peaks in almost all the 1300 RPM melt-spun and annealed ribbons. The martensitic phase (modulated) had an orthorhombic crystal structure while the presence of a tetragonal structure was also confirmed. Manganese rich precipitates were observed along the grain boundaries and in the grain interior after annealing by Auger spectroscopy. TEM micrographs confirmed that the annealed specimens have both 5M and 7M modulated structures, according to the satellite spots observed in the electron diffraction patterns. EBSD scans revealed that the as-spun ribbons produced at 1300 and 1600 RPM had a predominantly <001>‖ND fibre texture. <001>‖ND fibre texture was also observed in the annealed ribbons of 1300 and 1600 RPM. <111>‖ND texture was obtained in the melt-spun ribbons produced at 1300 RPM annealed at 1000°C for 5 hours. Thermal analysis was done to obtain the transformation temperatures of the as-spun as well as annealed ribbons. The transformation temperatures were close to the room temperature in all the ribbons with an incremental dependence on the annealing temperature and annealing time. Besides the magnetic measurements, magnetic field induced strains were measured using strain gauges. The dependence of magnetic moment on the angle of alignment of the sample surface with respect to the field direction has been reported. The martensitic transformation temperatures obtained from the thermomagnetic curves were almost similar to those obtained from thermal analysis. There was an improvement in the saturation magnetization values after annealing whereas the Curie temperature was roughly similar for all the specimens. The annealed ribbons showed higher magnetic field induced strain (MFIS) than the as-spun ribbons; ribbons prepared at 1300 RPM and subsequently annealed at 900 °C for 5 hours showed the highest value of MFIS ~ 1547

$\mu\varepsilon$. To measure the magnetocaloric properties, the ribbons, both as-spun and annealed, were tested in SQUID to measure the magnetic properties at a field of 50 kOe with a temperature step of 3K in the temperature range of 355 to 385 K. The magnetic data from the isotherms were used to get the Arrott plots. Second order transition was observed in the materials at the T_C temperature. ΔS_m values were calculated from the magnetic data which was further used to calculate the RC (refrigeration capacity) values. The highest RC value was obtained for $^{1300}NMG_5^{800}$; 273 J/kg. At last, nano-mechanical properties were measured using Nano-indentation which included the Time dependent deformation (TDD) and other related mechanical properties of bulk $Ni_{50}Mn_{28}Ga_{22}$ alloy, such as indentation size effects. The measurement of TDD utilizes two different techniques namely: CRL (Constant Rate of Loading) and CSR (Constant Strain Rate) modes. Tests to measure the behavioral dependence on the holding time were also performed. The loading rates for CRL technique were varied from 0.1 mN/s to 1 mN/s. Strain rates for CSR mode were varied from 0.05 to 2. The tests were performed at room temperature on $Ni_{50}Mn_{28}Ga_{22}$ alloy which was prepared by TIG arc melting. Hardness and strain rate, both are inversely dependent on depth of indentation and time. The amount of plastic work was calculated and its dependence on loading rate, holding time and strain rate has been studied. The parabolic dependence of the fraction of plastic work to the time of holding was obtained by least squares method. The amount of recovery also declined as the loading rate and strain rates were increased. Microstructural studies were also performed to observe the changes that are inflicted underneath the surface during indentation. The microstructure was initially a twinned martensitic structure having two different variants which developed into a single martensitic variant under the influence of load. Nano twins were also observed in the microstructure.

Keywords: Heusler alloy; Modulated martensite; Texture; Twinning; Melt-spinning; Shape memory alloy; Magnetic field induced strain; Ferromagnetic; Nano-indentation; Indentation Creep; Indentation Size Effect; Strain rate; Magnetocaloric.