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MAGNETISM AND MECHANICAL PROPERTIES OF NiFeSiB GLASSES

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Abstract. – A systematic investigation of the magnetization and mechanical properties of amorphous Ni_xFe_{80-x}B_{18}Si_2 is reported. The magnetization showed strong depression for x ≥ 50. The alloys with x ≥ 65 are paramagnetic at room temperature but the Young’s modulus (as well as microhardness) decreased almost linearly with x at 77 and 300 K. It was concluded that bonding was primarily due to d-electrons reflecting the band filling both for ferromagnetic and paramagnetic alloys.

The magnetism of amorphous alloys has attracted considerable interest over the last decade. Although some amorphous alloys based on magnetic transition metals (Fe, Co, Ni) with about 20 at. pct. of metalloids (B, Si, P, C) have already important technological applications, the understanding or the nature of magnetism in these alloys is still far from being complete. Whereas their transport properties are best interpreted in terms of a strong itinerant ferromagnetism [1, 2] the interpretations of their magnetic properties are rather ambiguous, the outcome often depending whether the static (magnetic moments) or dynamic (temperature dependence) effects are measured [3]. Since both the magnetic and mechanical properties (via cohesive energy) of the transition metals depend on their valency electrons a direct comparison between these properties is apparently desirable.

Here we report the results of a systematic investigation of the magnetisation and mechanical properties of amorphous Ni_xFe_{80-x}B_{18}Si_2 alloys (0 ≤ x ≤ 80). The amorphous ribbons were prepared by the melt-spinning technique in vacuum. Carefully controlled quenching conditions resulted in ribbons with the same crosssection (1.6 × 0.023 mm²) and thus with probably the same degree of disorder. The amorphicity of the samples was checked by the X-ray diffraction and DSC measurements.

The density of all samples was measured by the Archimedes method to an accuracy of 0.5 %. It increases with x and has somewhat concave shape as in other Fe-Ni based glasses (the density results are not shown here). The magnetisation was measured with an induction magnetometer [4] at 4.2 K. The results are shown in figure 1. We note a strong depression of the magnetisation for the alloys with x ≥ 50. In this region the magnetic moment per transition metal atom strongly deviates from the Slater-Pauling curve [3] and becomes zero [5] for x ≈ 2. The alloys with x ≥ 65 are paramagnetic at room temperature.

The Young’s modulus E was determined from the relationship \( E = \rho V_E^2 \) where \( \rho \) is the ribbon density and \( V_E \) the velocity of ultrasonic waves through the ribbon. \( V_E \) was measured both at 77 and 300 K with a pulse-echo technique [6]. For ferromagnetic samples, \( V_E \) was measured in a saturating magnetic field parallel to the sample length. As shown in figure 2, E decreases almost linearly with x both at 77 and 300 K. The values of E at 77 K (corrected for thermal expansion effects) are however about 5 % higher than those at 300 K.
The relative change in \( E \) from \( x = 0 \) to \( x = 80 \) agrees well with that in \( \text{Ni}_x\text{Fe}_{78-x}\text{B}_{12}\text{Si}_{10} \) alloys [7], but the \( E \) values for this system are about 4% lower than ours. A linear change of \( E \) with \( x \) both at 77 and 300 K rules out the direct magnetic contribution to \( E \) proposed by Chou [8] (the alloys with \( x \geq 65 \) are nonmagnetic at 300 K). Instead the results indicate a smooth variation of \( E \) (determined primarily by the bond stiffness) with the effective number of d-electrons. The variation of \( E \) with \( x \) in \( \text{M}_x\text{T}_{78-x}\text{B}_{12}\text{Si}_{10} \) alloys [7] indicates that this conclusion also holds for \( \text{M} = \text{Cr} \) and \( \text{Cu} \). Thus the results outlined above are in qualitative agreement with the Friedel's model of bonding in transition metals [9]. However the relative size of variation of \( E \) (assumed to be proportional to bulk modulus in an amorphous alloy) with \( x \) is considerably smaller than the model prediction. This discrepancy can probably be removed by taking into account the correlation effects [10] (including magnetism) neglected in reference [9]. These effects decrease the cohesion and elastic modula towards the middle of 3d-series. Since correlations increase the atomic volumes we estimated the average atomic volumes \( (V) \) from our densities (not shown here). Indeed \( V \) increases for about 4% from \( x = 80 \) to \( x = 0 \). This small change in \( V \) together with increasing rather than decreasing \( E \) on going from Ni to Fe-rich alloys may indicate that the correlation effects in amorphous alloys are weaker than in their crystalline counterpart.

In figure 3 we show the microhardness data \( (H_v) \) for our alloys. \( H_v \) follows the same trend with \( x \) as \( E \) values. Rather simple correlation of \( E \) with \( H_v \) (also observed in other amorphous alloys) may seem suprising since plastic properties of crystalline metals are primarily due to extended defects. In an amorphous metal however the absence of grain boundaries and of well defined line defects enables the nature of bonding to show up even in plastic properties.

Our study of magnetic and mechanical properties of amorphous NiFeBSi alloys shows that bonding is primarily due to d-electrons and simply reflects the band filling both for ferromagnetic and paramagnetic alloys. Furthermore the correlation effects in these alloys seem to be of less importance, than in corresponding crystalline metals. It is therefore hoped that studying mechanical properties could help the understanding of the electronic structure of these alloys and at the same time the nature of ferromagnetism in amorphous ferromagnets.

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