Critical concentrations of Zn and Mg for enhanced diamagnetism in Al-Zn-Mg alloys

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ABSTRACT

Temperature and time dependences of the magnetization of Al-Zn-Mg alloys with varying Zn to Mg ratios (Zn/Mg = 0.25, 0.5, 1, 2, 5.5, and 9, keeping the total concentration of Zn plus Mg to be 5 at.%) were studied in the range from 10 to 310 K after various periods of natural aging. In particular, for Al_{1-y}(Mg_{2}Zn_{11})_{y} alloys, the total concentrations of Zn and Mg were also varied from 2 to 20 at. % (y = 0.02, 0.03, 0.04, 0.05, 0.1, and 0.2). The largest time variant enhanced diamagnetism was observed for Al_{0.95}(Mg_{2}Zn_{11})_{0.05} as a result of solution heat treatment/quenching and natural aging. Isothermal measurements of magnetization vs time for natural aging temperatures from 260 to 300 K provided activation energies for solute clustering: 0.69 ± 0.05 eV (for stages I and II) and 0.78 ± 0.03 eV (for stages II and III). The mechanical hardness vs time at 273 K for Al_{0.95}(Mg_{2}Zn_{11})_{0.05} confirmed that the time variation of magnetization was related to the precipitation process of Zn/Mg/vacancy zones. Additionally, temperature dependences of the magnetization of Mg_{2}Zn_{25}, Mg_{2}Zn_{11}, Mg_{2}Zn_{12}, and Mg_{2}Zn_{11} were examined. The observed magnetization for the Mg-Zn compounds was found to be too small to account for the enhanced diamagnetic contributions to magnetization of Al-Zn-Mg alloys. A possible Zn-Mg-vacancy atomic arrangement responsible for the enhanced diamagnetism is discussed.

I. INTRODUCTION

High mechanical strength to weight ratio is a common and important criterion for metals used in industry, particularly useful to improve the energy efficiency of transportation systems. Al-Mg-Zn alloys (7000 series) are extensively used in aeronautical applications, due to exceptionally high mechanical strength that depends on the microstructure of the precipitation of solute Zn and Mg atoms. Hardening takes place via various aging processes after a quench into ice-water from a high temperature (T) of 753 K [solution heat treatment and quenching (SHTQ)], a process through which supersaturated solid solutions (SSSs) are introduced to the initial materials. The precipitation sequence from SSSS is usually presumed to be \( \text{SSSS} \rightarrow \text{VRC} \rightarrow \text{GPI} \) and/or \( \text{GPII} \rightarrow \eta' \rightarrow \eta \) (MgZn\(_2\)). The GPI zones, originated in solute-rich clusters, form on the \{001\}\(_{\text{Al}}\) plane at a low aging temperature including natural aging (NA) at room temperature. A high solution heat treatment temperature above 723 K results in vacancy-rich clusters (VRCs), and a subsequent artificial aging (AA) above 343 K leads to GPII zones on the \{111\}\(_{\text{Al}}\) plane.\(^{1}\) Intensive studies have been carried out in an attempt to understand the resulting composition, microstructure, and evolution of the alloys using techniques such as atom-probe tomography (APT)\(^{2-6}\) and high-resolution transmission electron microscopy (HRTEM).\(^{7-8}\) These techniques are useful to observe precipitation in the GP zones and \( \eta' \) and \( \eta \) phases but not very useful to investigate the early stage of solute clustering that proceeds quite quickly even at room temperature.

The early stage of Zn/Mg/vacancy clustering has been studied using positron annihilation-lifetime spectroscopy (PALS),\(^{9-12}\) resistivity,\(^{13-15}\) and differential scanning calorimetry (DSC).\(^{16}\) The previous reports from those studies concluded that the Zn/Mg/vacancy clustering process was highly sensitive to the Zn/Mg ratio and the
total concentrations of Zn and Mg. Recently, we have measured temperature and time (t) dependences of magnetization (M) of Al-Zn-Mg alloys to investigate such early stage clustering behavior. Abnormally large diamagnetic contributions to magnetization were found for the first time in the as-quenched (AQ) samples. Natural aging drastically decreased the diamagnetism of the Zn-rich samples, but little change occurred for Mg-rich samples. Artificial aging with peak-aged conditions for the samples largely suppressed the diamagnetism, indicating that the diamagnetic contributions were strongly related to the Zn/Mg/vacancy clusters and precipitation and thus mechanical hardness of the alloys. In this work, we continue the investigation of the magnetic properties of Al-Zn-Mg alloys and Mg-Zn compounds to study the Zn/Mg/vacancy structure in the early stage of clustering. The magnetization of the Mg-Zn compounds examined showed principally paramagnetic properties, the exception being Mg2Zn17 which produced diamagnetism. Our study includes temperature dependences of the magnetization for varying Zn/Mg ratios as well as varying total concentrations of Zn and Mg elements in Al-Zn-Mg alloys. In particular, we have seen the largest ever time variation of enhanced diamagnetism for the Al0.95(Mg2Zn11)0.05 alloy.

II. EXPERIMENTAL

The materials used in this study were prepared by melting Al (purity, 99.999%) and/or Mg (99.99%) and Zn (99.999%) in an argon gas atmosphere using an electric furnace and an alumina crucible. The single phase of Mg2Zn12 (C14 Laves phase) was then annealed at 588 K for one week. After melting, the ingot of Mg2Zn11 was annealed at 623 K for two weeks to promote crystallization into a single phase of the cubic structure. In contrast, postmelting heat treatment at 623 K of Mg2Zn11 resulted in an increase in the MgZn2 impurity phase, and therefore, as prepared, melted, and furnace-cooled samples were used for magnetization measurements of these compounds. X-ray powder diffraction measurements started from 10 K to 310 K in 10 K steps. Steps (3)–(5) were repeated twice to check the reproducibility using different pieces of the prepared Al-Zn-Mg ingots. The M vs T behavior for the two samples coincided within the uncertainty created by the size of the plot symbols in Figs. 1, 2, 3(a), and 4(a). Time (t) dependences of the magnetization for Al0.95(Mg2Zn11)0.05 were measured at least once for all natural aging temperatures, being repeated for only selected cases using two specimens cut from the prepared ingot. However, the observed M vs t curves appeared to change systematically with the temperature throughout and the initial M values within each isothermal measurement run were consistent with the appropriate M vs T data for Al0.95(Mg2Zn11)0.05 in the AQ condition. Magnetization for Mg-Zn compounds, however, showed sample preparation dependence, especially in the observed M vs T curves for MgZn2 and Mg2Zn7 where results were influenced by the presence of MgZn2 impurity, although no sample showed enhanced diamagnetism. The M vs T datasets for Mg-Zn compounds were selected by inspecting the X-ray diffraction patterns. The micro-Vickers hardness was measured using a MITSUTOYO HM-101 hardness tester (load: 0.98N, holding time: 15 s). After the magnetization measurements, the sample compositions were examined using SEM-EDS (HITACHI S-3500H).

III. RESULTS

The temperature dependent magnetization for a range of Mg-Zn compounds as well as the pure elements Al, Mg, and Zn is shown in Fig. 1. It can be seen that the M vs T curves of Mg2Zn25, Mg2Zn21, quenched directly and rapidly into ice-water [as-quenched (AQ) condition], followed by cooling below 250 K inside the magnetometer within 3 min; (2) M vs T measurements started from 10 K to 310 K in 10 K steps in an external field of 7 T; (3) when the measurement sequence came to the end at 310 K, the sample was maintained at this temperature for natural aging for 35 min; (4) the sample was again cooled down to 10 K; (5) then, further M vs T measurements started from 10 K to 310 K in 10 K steps. Steps (3)–(5) were repeated with different natural aging periods. These measurement sequences were repeated twice to check the reproducibility using different pieces of the prepared Al-Zn-Mg ingots. The M vs T behavior for the two samples coincided within the uncertainty created by the size of the plot symbols in Figs. 1, 2, 3(a), and 4(a). Time (t) dependences of the magnetization for Al0.95(Mg2Zn11)0.05 were measured at least once for all natural aging temperatures, being repeated for only selected cases using two specimens cut from the prepared ingot. However, the observed M vs t curves appeared to change systematically with the temperature throughout and the initial M values within each isothermal measurement run were consistent with the appropriate M vs T data for Al0.95(Mg2Zn11)0.05 in the AQ condition. Magnetization for Mg-Zn compounds, however, showed sample preparation dependence, especially in the observed M vs T curves for MgZn2 and Mg2Zn7 where results were influenced by the presence of MgZn2 impurity, although no sample showed enhanced diamagnetism. The M vs T datasets for Mg-Zn compounds were selected by inspecting the X-ray diffraction patterns. The micro-Vickers hardness was measured using a MITSUTOYO HM-101 hardness tester (load: 0.98N, holding time: 15 s). After the magnetization measurements, the sample compositions were examined using SEM-EDS (HITACHI S-3500H).

![FIG. 1. Temperature dependences of the magnetization for Mg2Zn25, Mg2Zn21, MgZn2, and Mg2Zn11 together with that of the pure elements Al, Mg, and Zn.](image-url)
However, at − values are not largely different from the observed values of − for Al-Zn-Mg alloys. The and Zn, are not considered to exhibit anomalous behavior. The responses from these materials, containing bulk quantities of Mg in comparison with pure Zn. Nevertheless, overall (dia)magnetic somewhat more negative (larger in magnitude) than predicted and increasing NA time. The overall behavior of these M vs T curves is similar to that observed previously for a Al-4.1%Zn-1.1%Mg alloy.\textsuperscript{20}

The precipitation process of Al-Zn-Mg largely depends on the Zn/Mg ratio. Figure 3(a) contains M vs T curves observed for the samples of the Zn/Mg ratios from 0.25 to 9.0 for which the total concentration of Zn and Mg was fixed to be 5 at. %. The data marked with black solid circles (AQ 5.5) are similar to the AQ result of Fig. 2, while the curve with open circles (NA 5.5) is the NA 500 min data of Fig. 2. Indeed, the labeling in Fig. 3(a) indicates the Zn/Mg ratios together with an AQ or NA (500 min) designation for each dataset. All AQ samples have enhanced diamagnetic contributions to M that increase with decreasing T. The M values observed at 10 K for both the AQ and NA cases are plotted in Fig. 3(b) on a logarithmic scale. From these plots, the effect of the Zn/Mg ratio on the enhanced diamagnetism can be noted. The M values of the AQ materials decreased with increasing Zn/Mg ratios (solid squares), i.e., the enhanced diamagnetic contributions increased with the Zn/Mg ratios, while the M values for the samples following NA increased significantly with the Zn/Mg (blue circles). In other words, the enhanced diamagnetism (M\textsubscript{AQ}-M\textsubscript{NA}) was most significantly decreased by NA for 500 min at 310 K when the Zn/Mg ratio was large. These results suggest that there is a specific atomic arrangement (thought to involve Zn and Mg associated with a vacancy) responsible for the enhanced diamagnetism. This atomic arrangement is produced to some extent across all the samples by SHTQ but the abundance, and hence the amount of diamagnetism, is generally larger in the AQ condition in the high Zn/Mg ratio samples (with Zn-rich clustering). The diamagnetism is also more readily removed via NA in that type of sample. In this study, the sample with Zn/Mg = 5.5 provides the largest observations on both counts. This ratio appears near optimal, exceeding the values at Zn/Mg = 9.0. It is noted that the presence of some Mg is essential to the process for enhanced diamagnetism was not observed in the magnetization measurement of an Al-5%Zn alloy.\textsuperscript{20} These observations that enhanced diamagnetism is larger but less stable in Zn-rich (5%)...
alloys while it is more stable, although smaller, in the Mg-rich alloys are consistent with those reported previously. Since the largest diamagnetism was observed in $\text{Al}_{0.95}(\text{Mg}_2\text{Zn}_{11})_{0.05}$ at 10 K, we examined the effect of the total solute concentration on the enhanced diamagnetism with this Zn/Mg ratio. Specifically, samples of the form $\text{Al}_{1-y}(\text{Mg}_2\text{Zn}_{11})_y$, ($y = 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.1$ and $0.2$) were studied. The selected $M$ vs $T$ curves observed for the samples are shown in Fig. 4(a). (The curves for $y = 0.06$ and 0.07 were not plotted in Fig. 4(a) to avoid overlapping with those for $y = 0.05$). The labeling of the curves in this case are the same as in Fig. 3(a), with the anneal state, AQ or NA(500 min), designated for each sample together with the concentration ($y$). The main trends from these data are summarized in Fig. 4(b) wherein $M$ values of the samples in the AQ condition plus the change in $M$ due to NA ($M_{\text{AQ}} - M_{\text{NA}}$), both at 10 K, are plotted against concentration $y$. There is little diamagnetic contribution to $M$ for the sample with $y = 0.02$ nor was there much change in $M$ as a result of NA at this concentration. This rapidly changes as $y$ is increased to 0.05, at which point the diamagnetic AQ $M$ becomes large and also the largest change in $M$ through NA is observed. Further increase in $y$ leads to a slight (only modest initial) increase in the AQ $M$ (reduction in magnetic component) but also a notable trend toward more stable diamagnetism, with essentially zero change in $M$ caused by 500 min of NA, at $y = 0.20$. Once again the early trend in the observations suggests that the enhanced diamagnetism requires particular concentrations of Zn and Mg to form the critical Zn/Mg/vacancy atomic arrangement. Moreover, there is a second trend that exists whereby a further increase in the solute concentration beyond $y = 0.05$ serves to stabilize these arrangements. The two different regimes could be interpreted as a sign of more than one group/type of atomic arrangement underlying the enhanced diamagnetism.

Figure 5(a) contains the plots of magnetization as a function of time post-SHTQ ($M$ vs $t$) for $\text{Al}_{0.95}(\text{Mg}_2\text{Zn}_{11})_{0.05}$ samples aged under isothermal conditions at various temperatures between 260 and 300 K. The shape of the curves suggest that there are at least three stages for solute clustering in the natural aging process. To quantify and evaluate this proposal, an attempt was made to estimate the stage transition times, e.g., for the $M$ vs $t$ curve at 273 K, the time windows of the data points were set (1) below 10 min, (2) from 80 to 160 min, and (3) above 800 min for stages I, II, and III, respectively. In each time window, the $M$ vs $t$ data were fitted with logarithmic functions: $M(t) = M_0 + M^* \log(t)$. The arrows in Fig. 5(a) point out to the intersections of the functions fitted to adjacent regions in the 273 K data, which are considered to be the stage boundaries. The stage transition times ($\tau$) estimated from the data in Fig. 5(a) are...
given in Table I and shown in the Arrhenius plots of logarithmic $\tau$ against reciprocal NA temperature, $\ln(\tau) = Q/kT_{NA}$, in Fig. 5(b). The least squares fit of the estimated transition times for stages I and II and stages II and III to a straight line yielded activation energies $Q_1 = 0.69 \pm 0.05$ eV and $Q_2 = 0.78 \pm 0.03$ eV, respectively. These $Q$ values are well correlated with those of $Q_1 = 0.64 \pm 0.04$ eV and $Q_2 = 0.93 \pm 0.06$ eV, respectively, for Al-2.6%Zn-3.2%Mg obtained from resistivity measurements. The effect of solute clustering on the time dependent magnetization during NA has been studied for Al-Mg-Si alloys, in which the magnitudes of the time variations of $M$ values were approximately one fortieth of those in Fig. 5(a), but the estimated activation energies were comparable to those of Al-Zn-Mg alloys.

A comparison of the selected stage transition times can be made with those derived from the time dependence of the resistivity for Al-2.6%Zn-3.2%Mg in Table I. In that study, for experimental reasons, only specific transitions could be accessed at specific temperatures. The period for stage I (Zn-vacancy pairs and Zn-complexes forming) to II (Zn-rich cluster forming) was found to be approximately 53 min at 280 K, and the transition time stage from II to III (Zn-Mg-vacancy cluster zone forming) was approximately 82 min at 280 K. Also showing reasonable agreement with the present data are the results of PALS studies of the NA process at room temperature for Al-1.7%Zn-1.9%Mg and Al-2.1%Zn-1.5%Mg. These demonstrated significant changes in the lifetime vs $t$ curves around 60 min, ascribed to changes in Zn/Mg/vacancy cluster formations (stage II to III).

Finally, the isothermal development of mechanical hardness for Al$_{0.95}$(Mg$_2$Zn$_{11}$)$_{0.05}$ during NA was measured at 273 K. The evolution of micro-Vickers hardness during NA is compared with magnetization against NA time on a logarithmic scale in Fig. 6. It is clear that the hardness changed slightly during stages I and II but increased markedly in stage III. This result suggests that the time dependent magnetization is strongly associated with solute clustering and precipitation processes in Al-Zn-Mg alloys. During a NA period in which the enhanced diamagnetic contributions are evident in this Al-5 at. % (Zn+Mg) alloy, its mechanical hardness is slightly changed. In stage III, when solute element clusters/zones appear, these apparently increase the mechanical hardness.

### Table I: Transition times between stages I and II and stages II and III. Mg$_2$Zn$_{11}$ denotes the sample of Al$_{0.95}$Zn$_{0.04}$Mg$_{0.06}$, while ZnMg is Al$_{0.942}$Zn$_{0.026}$Mg$_{0.032}$.

| Alloy          | $t$ (min) stages I and II | $t$ (min) stages II and III |
|---------------|---------------------------|----------------------------|
| Mg$_2$Zn$_{11}$ | 201 68 35 17 8.2          | 1350 717 338 131 38.5 15 10 |
| ZnMg          | 420 159                  | 82                         |
| NA T (K)      | 260 267 270 273 280 290 300 310 320 |

This work.

1Reference 18.

18Reference 18.

IV. DISCUSSION

The present results confirm that both the Zn/Mg ratio and the total concentrations of Zn and Mg in Al alloys can have significant effects on the time and/or temperature dependent enhanced diamagnetism, as shown in Figs. 3(b) and 4(b). Moreover, the measured magnetization is also correlated with the mechanical hardness (see Fig. 6). The largest change of the diamagnetism following natural aging (NA), compared to as quenched (AQ), was observed for Al$_{0.95}$(Mg$_2$Zn$_{11}$)$_{0.05}$. The expected magnetization for this alloy as estimated by the magnetization of pure elements is $5.0 \times 10^{-2}$ Am$^2$/kg at 10 K in 7 T, but the observed one is $1.7 \times 10^{-2}$ Am$^2$/kg. The enhanced diamagnetic contribution to $M$ for Al$_{0.95}$(Mg$_2$Zn$_{11}$)$_{0.05}$ is $3.3 \times 10^{-2}$ Am$^2$/kg at 10 K, which is comparable to the observed $M$ value for the bulk Mg$_2$Zn$_{11}$ compound. It would seem unlikely that the magnetic behavior of bulk Mg-Zn compounds can be directly linked to the enhanced diamagnetism of the Al-Zn-Mg alloys. A density functional theory (DFT) calculation predicted a small band dip at the Fermi level of Mg$_2$Zn$_{11}$, which, in turn, can cause a reduction of the Pauli paramagnetic susceptibility. Smontara et al. measured the magnetic susceptibility of the Bergman phase Mg$_{83.2}$Al$_{32.2}$Zn$_{11.7}$ compound, reporting the Pauli paramagnetic susceptibility of $2.6 \times 10^{-7}$ m$^3$/kg (after a correction of the Larmor diamagnetic susceptibility of $1.6 \times 10^{-7}$ m$^3$/kg). This value is, however, more than an order of magnitude larger than that of the pure aluminum susceptibility ($7.9 \times 10^{-9}$ m$^3$/kg), which, in turn, can cause a reduction of the Pauli paramagnetic susceptibility. Smontara et al. measured the magnetic susceptibility of the Bergman phase Mg$_{83.2}$Al$_{32.2}$Zn$_{11.7}$ compound, reporting the Pauli paramagnetic susceptibility of $2.6 \times 10^{-7}$ m$^3$/kg (after a correction of the Larmor diamagnetic susceptibility of $1.6 \times 10^{-7}$ m$^3$/kg). This value is, however, more than an order of magnitude larger than that of the pure aluminum susceptibility ($7.9 \times 10^{-9}$ m$^3$/kg), which, in turn, can cause a reduction of the Pauli paramagnetic susceptibility.
aluminum at 300 K. According to these parameters, a Zn atom needs a few tens of minutes to move to the next nearest-neighbor lattice site in aluminum, while a Mg atom needs more than an hour. These estimates for the diffusivity of Zn and Mg perhaps seem a little slow compared to the stage transition times derived above; however, the notion that solute elements need vacancies to move and form clusters is sound. Immediately after SHTQ, excess vacancies of approximately 10 ppm are considered to be present in aluminum alloys. This concentration is about one thousandth of the solutes. Some of these vacancies will form solute-vacancy pairs, while others will be absorbed in lattice imperfections such as grain boundaries, dislocation loops, and impurities. Based on this, Zn-vacancy/Mg-vacancy pairs and Zn-Mg-vacancy triples are produced after SHTQ. During NA in stage I, mobile Zn-vacancy pairs will encounter other Zn-vacancy pairs, starting to form mobile Zn complexes of a few Zn atoms, releasing some vacancies, which, in turn, allow new solute-vacancy pair formations. The enhanced diamagnetism will not change in stage I since Zn clusters were known to have little effect on the magnetization in binary Al-5%Zn alloys. The enhanced diamagnetism is only observed for alloys with a mix of Mg and Zn.

As the Zn complexes grow larger in size, the vacancies will have difficulties to escape from the aggregates. Consequently, at the end of stage I, some of the quenched-in vacancies are either trapped in the clusters or lost at imperfections. Since the Mg-vacancy pairs and Zn-Mg-vacancy triples move slowly, formation of Mg containing Zn complexes proceeds in a slower rate. Once stage I ends, however, the Mg-vacancy pairs and Zn-Mg-vacancy triples play an important role to grow clusters and release vacancies to transport solute atoms in stage II in which the enhanced diamagnetism was decreased due to the enrichment of Zn atoms. This scenario can explain the time variant and temperature dependent diamagnetism shown in Fig. 3(a).

Dlubek et al. claimed that the coherent Zn-rich zones formed in the binary Al-4.5%Zn alloy, and adding Mg gradually increased the Zn/Mg-vacancy zones in which a vacancy trapped ~1–3 Mg atoms and ~9–7 Zn atoms. In the Al-4.5%Zn-2.5%Mg alloy, only the Zn/Mg-vacancy zones remained after NA for 1 h. Therefore, the vacancy traps containing ~1–3 Mg and ~9–7 Zn atoms could be a stable atomic arrangement leading to the diamagnetism observed in Al_{0.8}(Mg_{0.2}Zn_{1.2})_{30} sample.

It should be noted that the enhanced diamagnetism disappeared after the peak-hardening aging for Al-Zn-Mg alloys, in which precipitation of the η phase (MgZn_{2}) and/or T phase (Al_{2}Mg_{5}Zn_{3}) was observed. Enhanced diamagnetism was relatively stable during NA for Mg-rich alloys but unstable in Zn-rich alloys. This suggests a possible atomic arrangement underlying the observed time variant and temperature dependent enhanced diamagnetism: Suppose after SHTQ, there are specific Zn-Mg-vacancy triples/clusters having an unusual electronic configuration resulting in the enhanced diamagnetism in stage I. In stage II, if plenty of Zn-rich complexes remained, slowly moving Zn-Mg-vacancy triples/clusters would be combined with them to form larger clusters that are richer in Zn and the unusual electron configuration nullified; thus, the diamagnetic contribution seen in magnetization is decreased. This hypothesis should be tested by experiments, such as x-ray absorption fine structure (XAFS) measurements for Zn and Mg in Al-Zn-Mg.

V. CONCLUSION

We have investigated the magnetic properties of the Mg-Zn compounds and Al-Zn-Mg alloys. The magnetization values of Mg_{2}Zn_{5}, Mg_{2}Zn_{7}, and MgZn_{2} were found to lie between those of paramagnetic Mg and diamagnetic Zn. The magnitude of the diamagnetic M value of Mg_{2}Zn_{11} was approximately double of that of Zn but was too small to explain the observed enhanced diamagnetism of Al-Zn-Mg alloys. The enhanced diamagnetism, and how it varies with natural aging, depends on both the Zn/Mg ratio and the total concentration of Zn and Mg. It was found to be unstable for the Zn/Mg ratios of 2–9.0, while relatively stable for a ratio below 1 when the total concentration of Zn and Mg was 5 at %. For the Zn/Mg ratio = 5.5, the enhanced diamagnetic contributions to M increased with the increase in the total concentration from 2 to 5 at %. and then remained at a relatively steady value of approximately ~0.02 Am^{2}/kg across concentrations of ~5–20 at %. The largest time variant and temperature dependent enhanced diamagnetism was observed for Al_{0.95}(Mg_{0.05}Zn_{11})_{0.05}. Isothermal measurements of magnetization vs time (t) at NA temperatures from 260 to 300 K for Al_{0.95}(Mg_{0.05}Zn_{11})_{0.05} provided activation energies for solute clusterings: 0.69 ± 0.05 eV for stages I and II and 0.78 ± 0.03 eV for stages II and III. The mechanical hardness vs t at 273 K confirmed that the time variation of the magnetization is correlated with the precipitation process of Zn/Mg/vacancy zones. The enhanced diamagnetism possibly originates in a small atomic arrangement (cluster) of Zn and Mg atoms together with a vacancy.

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