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EXPLOSIVE SHOCK HARDENING OF MAGNESIUM ALLOY

Anthony L. Rafalski

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ERRATA

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The following correction should be made:

Page 2: Figure 1, Insert with MEAN HARDNESS (57.0), instead of 51.0.

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EXPLOSIVE SHOCK HARDENING OF MAGNESIUM ALLOY

Anthony L. Rafalski

Abstract. Using the commercial LA-141A alloy (magnesium-14 weight percent, lithium-1 weight percent aluminum), plate specimens were deformed by oblique explosive loading in an effort to obtain strengthening without a correspondent loss of ductility. Although ductility remained high, the maximum yield-strength increase produced was only about 20 percent. The absence of appreciable strengthening may be related to the temperature rise associated with shock compression or to insufficient pressure. Additional experiments using flyer plates for higher pressures and a water quench to reduce annealing appear necessary to achieve optimum results.

INTRODUCTION

The commercial LA-141A alloy (magnesium-14 weight percent, lithium-1 weight percent aluminum) is an important component in applications requiring a combination of low density and high formability. The alloy would be even more desirable if its strength properties could be enhanced without greatly sacrificing ductility. McDonald has shown that LA-141A is age-hardening and responds to cold working,[1] but in each case the attendant loss of ductility is prohibitive. Another approach, used with success on other metals is explosive shock hardening. Explosive loading is known to produce strengthening without drastically changing ductility properties.[2] The object of this work then was to investigate the feasibility of using shock loading as a method for increasing the strength of LA-141A.

EXPERIMENTAL

Experiments were carried out using as-received[3] LA-141A plate. By supplier analysis, the metal contained 13 to 15 weight percent lithium (wt % Li), 1.0 to 1.5 wt % aluminum (Al), and less than 0.6 wt % impurities [the balance of magnesium (Mg)]. The alloy is sold in a stabilized condition (T7), which means it had received a 6-hour heat treatment of 176.7 °C (350 °F) to prevent room temperature aging. Metallographic examination showed that the alloy was in a partially recrystallized state and contained a finely dispersed second phase. By X-ray diffraction, the second phase was identified as the intermetallic, AlLi. As expected, the primary phase was found to be the Li base solid-solution beta phase which is body centered cubic (bcc).

Plate specimens of LA-141A (2 by 6 by 0.25 inches) were explosively loaded by oblique detonation with DuPont's PETN containing charge densities of 0.25, 1, 2, 4, and 6 grams per square inch (one plate was deformed per charge). The peak pressures induced ranged from 30 to 110 kilobars. To prevent spalling, the specimens were appropriately trapped with Al. In addition a 0.125-inch Al sheet was inserted between the explosive and the specimen to limit the thermal effects of detonation. No attempt was made to quench the arrangement after detonation; consequently, the specimens experienced about a 176.7 °C (350 °F) temperature rise from the heat produced by adiabatic compression. These experimental conditions, although rather unsophisticated, are simple and economical.

After shocking, the blank edges were removed to produce 1 by 4-inch coupons which were subsequently machined into tensile specimens with a gauge section of 1 by 0.2 by 0.080 inches. Testing was performed at a strain rate of 0.0025 per minute Yield strengths were taken at 0.2 percent offset. The residual edge material was used for X-ray, metallography, and hardness determinations. Hardnesses were taken using two types of measurements: Knoop and R_E (Rockwell E). Knoop measurements were made with a 200-gram load to obtain hardness traverse data. The R_E determinations were used to provide additional data on the effects of shock hardening.

RESULTS

Metallographic inspection of the shocked specimens showed that no microstructural changes were induced by shock loading. The amount and distribution of the

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[1] J. C. McDonald. "Age Hardening of Magnesium Alloy LA-141A (magnesium + 14 weight percent lithium + 1 weight percent aluminum)." *Transactions of the American Society of Metals*, 61:505. 1968.

[2] A. H. Holtzman and G. R. Cowan. "Strengthening of Austenitic Manganese Steel by Plane Shock Waves," *Response of Metals to High Velocity Deformation*. Volume 9. Interscience Publishers, New York. 1960. Page 447.

[3] Supplied by Brooks and Perkins, Incorporated, Livonia, Michigan.

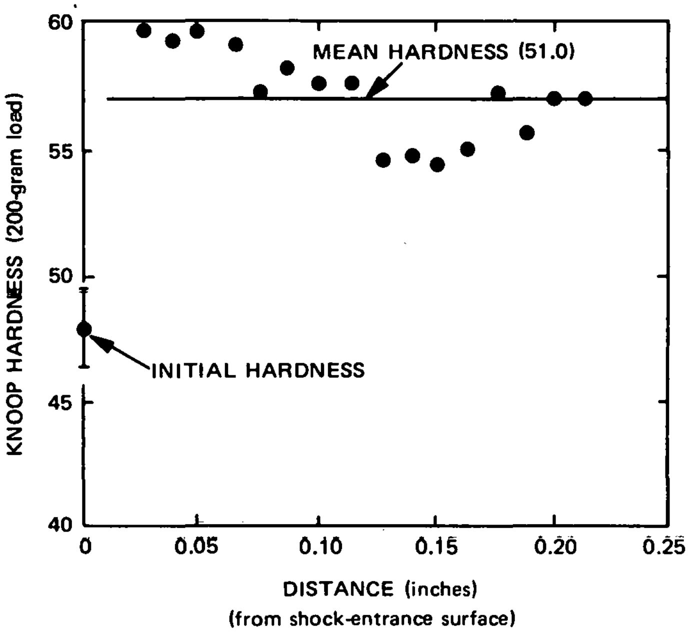

FIGURE 1. Microhardness Profile of Specimen after a 95-Kilobar Shock. (Shown also is hardness of as-received metal where limits are the standard deviation of measurement.)

intermetallic, AlLi, appeared unchanged. This observation was supported by X-ray diffraction measurements which yielded AlLi peak intensities of virtually the same magnitude as found in the as-received material. The LA-141A alloy is known to be susceptible to room temperature aging after plastic deformation.[4] Therefore, X-ray and hardness measurements were taken over a period of three months to check on the occurrence of aging. No evidence of aging (or softening) was detected.

A typical variation of hardness through the thickness of an as-deformed blank is shown in Figure 1. The progressive drop in hardness across the profile reflects the degree of shock attenuation associated with the detonation technique used. Since the variation about the mean hardness of the profile is on the order of the standard deviation of hardness measurement as found on the as-received material, the amount of attenuation was not considered prohibitive.

The mechanical properties of LA-141A before and after shock treatment are listed in Table I. Some strengthening was obtained, but it is readily apparent that the alloy (LA-141A) is not highly responsive to shock deformation since the maximum increase in strength properties is approximately 20 percent. In all instances, ductility was retained.

TABLE I. Mechanical Properties of Shock-Loaded Alloy (LA-141A).

Charge Density (grams per square inch)	Calculated Pressure (kilobars)	Rockwell Hardness (R_E)	Yield Strength (pounds per square inch)	Ultimate Strength (pounds per square inch)	Percent Elongation
0	–	56.3 ±1.5	15,900	18,700	29
0.25	30	59.5 ±1.9	17,200	19,400	29
1	60	60.8 ±1.7	17,900	19,800	30
2	80	62.0 ±1.2	18,000	20,300	28
4	95	64.1 ±1.6	19,100	20,600	27
6	110	63.5 ±3.2	19,100	21,000	25

NOTE:

Conversion, 1 psi = 0.0007 kilogram-force per square millimeter.

DISCUSSION

The lack of response of LA-141A to shock loading may be caused by certain experimental conditions utilized in this work. As mentioned previously, the specimens experienced a temperature rise to about 176.7 °C (350 °F) from shock compression and in the absence of a drastic quench, inadvertent annealing took place. Although the temperature, 176.7 °C (350 °F), is above the recrystallization temperature of conventionally deformed LA-141A, no recrystallization occurred as a result of shock deformation. The metal, however, is known[5] to soften by a recovery process at lower temperatures, so conceivably recovery could occur after shocking and would account for the relatively low strength levels observed.

Another consideration is that the pressure levels produced by the oblique detonation technique were simply not high enough to induce significant hardening. Strength is related to the defect density in the material, specifically in this case, the dislocation density. A calculation made to estimate the dislocation density of LA-141A after a 100-kilobar loading indicated that the dislocation density was about 10^9 to 10^{10} per square centimeter. This level is well below that required for full strengthening which is 10^{12} to 10^{13} per square centimeter, so at first glance it seems that much higher pressures are needed to produce the desired strength increases. High pressure, however, may not be the total answer. As pressure increases, the temperature associated with shock wave also increases and a large number of dislocations could be annihilated before a quench (if used) would be effective. To obtain a complete evaluation of the effects of shock loading on LA-141A, additional experiments are needed with flyer-plate loading techniques to reach higher pressures and include a water quench to inhibit annealing.

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[4] McDonald. *Loc. cit.*

[5] *Ibid.*