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HIGH STRENGTH-HIGH DAMPING CAPACITY WROUGHT MAGNESIUM ALLOYS

October 1975

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Pitman-Dunn Laboratory

U.S. ARMY ARMAMENT COMMAND
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An investigation was carried out to provide information regarding the alloying elements and the strengthening processes that must be utilized to obtain wrought magnesium alloys having high strength and high damping capacity for use in structural applications in missiles and aircraft. To this end, wrought magnesium alloys containing such solute elements as Al, Cd, In, Li, Mn, Pb, Y, Zn, and Zr were prepared and evaluated with respect to strength and damping capacity. The commercial alloy, AZ31,

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composite materials of magnesium containing borsic fibers, and a magnesium alloy strengthened by MgO particles were also evaluated. The effects of solute type and concentration, degree of cold work and grain size on the damping capacity of the alloys were investigated. Results are presented showing that the damping capacity of each material increases with increasing stress. For any given alloy, results indicate that the damping capacity is greater in the annealed condition than in the cold worked condition and increases as the concentration of solute decreases and as the grain size increases. An inverse relationship exists between damping capacity and the strength of the materials. This relationship holds for different types and concentrations of solute and for different degrees of cold work. The significance of this relationship is discussed. The Mg-Cd, Mg-Mn and Mg-Zr alloys have the highest damping capacity of the alloys investigated. Possible mechanisms for the strength-damping capacity behavior in wrought magnesium alloys are presented.

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INTRODUCTION

An area of significant importance to the US Army is the development of high strength-to-weight ratio materials for structural use in missiles and aircraft. In addition to the strength requirements, many of the advanced designs call for materials which also possess a high damping capacity in order to reduce potentially destructive forces produced by excessive vibrations.

Published work has shown that magnesium alloys have much better damping capacity than do other lightweight structural materials such as aluminum or titanium. [1-4] However, most of these studies have been carried out on cast Mg alloys. It has also been reported that the damping capacity decreases when strengthening procedures such as alloying additions, heat treatments and mechanical working operations are applied to the alloys. [5,6] Although cast Mg and the cast Mg alloys, K1X1(Mg-0.6%Zr), S1X1(Mg-0.75%Si) and M1A(Mg-1%Mn) have the highest damping capacities, their yield strengths are extremely low (3-8 ksi), making them undesirable for structural applications. [7,8] Hence, there is an evident need for developing wrought magnesium alloys having adequate strength as well as high damping capacity.

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[1] High Damping Characteristics of Magnesium, Dow Chemical Co. Bulletin No. 181-194.

[2] D.F. Walsh, J.W. Jensen, and J.A. Rowland, Vibration Damping Capacity of Magnesium Alloys, Proc 14th Annual Convention, the Magnesium Association, Oct 1958.

[3] J.C. Kaufman, Damping of Light Metals, Materials in Design Engineering, Vol 56. No 2 (1962) pp 104.

[4] J.W. Jensen, Magnesium Damping Capacity - Causes and Effects, Metalscope (May 1965), pp. 7-10.

[5] Dow Chemical Co. op. cit.

[6] E.F. Emley, Principles of Magnesium Technology, Pergamon Press, Oxford (1966) pp 771-773.

[7] Damping Characteristics of Some Magnesium Alloys, Dow Chemical Co., August 1957.

[8] G.F. Weismann and W. Babington, A High Damping Magnesium Alloy for Missile Applications, Proc. ASTM 58 (1958) pp. 869-892.

Although there is much information on the mechanical properties of wrought Mg alloys,[9] data on their damping capacities are limited.[10, 11,12] Thus, the available information does not provide specific answers regarding the alloying elements and strengthening processes that must be utilized to obtain alloys with high strength together with high damping capacity. The objective of this work was to provide this information by interrelating the metallurgical factors of composition, heat treatment and mechanical work.

EXPERIMENTAL PROCEDURE

Alloy Selection and Preparation

In this study, wrought Mg and several wrought Mg-base binary alloys were produced and evaluated. The alloying additions selected consisted of such commonly utilized materials as aluminum and zinc, as well as the following additions that were chosen for specific reasons: manganese, zirconium, mischmetal (high damping properties in the cast alloys), yttrium (strength),cadmium, indium, lithium (extensive solid solulibility in magnesium), and lead (excellent damping properties of the pure element). Several ternary and quaternary alloys were also prepared using these alloying additions. Cast Mg and cast K1X1 alloy were prepared and evaluated for comparison purposes. Finally, different amounts of MgO were added to a Mg-1%Mn matrix to produce dispersion strengthened alloys. The nominal composition of all the alloys produced are listed in Table 1. In addition to the laboratory produced alloys, materials for evaluation were also obtained from the Dow Chemical Company. These included extruded Mg-10%Y alloy and two Mg-borsic composites, one with longitudinal and one with transverse fibers. Since AZ31 is the most widely used commercial Mg alloy, samples of this alloy were also obtained from the Dow Chemical Company for inclusion in the study.

Cast billets of the magnesium alloys were prepared as 3 lb heats by melting the appropriate materials in an iron crucible under an argon atmosphere and then pouring through air into a heated iron mold. After scalping off 0.5 inch to a thickness of 1 inch, the billets were reduced to a final thickness of 0.072 inch by hot rolling. The rolling temperatures, reduction per pass, and reheating times for the various alloys are included in Table 1. Following rolling, one half of the sheet of each alloy was annealed at 800°F for one hour and air cooled.

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[9] E.F. Emley, op. cit.

[10] D.F. Walsh, op. cit.

[11] J.W. Jensen, op. cit.

[12] Dow Chemical Co., op. cit.

Table 1. Nominal Compositions and Rolling Procedure Used For Laboratory Produced Wrought Magnesium Alloys

Alloying Addition, wt% (nominal)	Rolling Temp, °F	Reduction per Pass, in.	Reheat Time Between Passes min.
1, 3 Al	750	.025	5
4, 15 Cd	950	.035	3
1, 2, 3 Li	750	.030	5
25 In	950	.015	3
1, 2, 5 Mn	950	.035	3
3, 5, 15 Pb	800	.030	5
.3, 5 Misch	900	.025	5
2 Y	950	.025	3
3 Zn	900	.025	3
.6 Zr	1000	.050	3
1 Al-2 Y	950	.050	5
1 Mn-3Al	750	.025	5
1 Mn-1 Zn	750	.025	5
1 Mn-.5 MgO	950	.025	5
1 Mn-2 MgO	950	.025	5
1 Mn-5 MgO	950	.025	5
1 Mn-.5 Al-.2 Zn	750	.025	5
1 Mn-1.5 Al-.5 Zn	750	.025	5
1 Mn-3 Al -1 Zn	750	.025	5

Damping Capacity Measurements

The method employed to determine damping capacity was to measure the decay characteristics of a freely vibrating cantilever beam using an SR-4 strain gage (gage factor = 2.08%, resistance = 120 ohms) attached to the specimen and recording the output of the gage with an oscilloscope. The strain gage served as the active arm of a Wheatstone bridge circuit. A schematic diagram of the experimental set-up is shown in Figure 1. One end of the cantilever beam sample was mounted rigidly in a vise. To carry out the test, the free end of the sample was displaced a small amount and then released with the trigger circuit of the oscilloscope set for a single time sweep. Care was taken to insure that measurable plastic deformation did not occur.

A typical decay curve for a freely vibrating cantilever beam sample is shown in Figure 2. The abcissa represents the time axis. The ordinate scale represents the output (strain) of the gage. It can be shown that the ordinate scale represents the bending stress in the specimen. As can be seen from Figure 2, the stress changes with time.

The quantity which specifies damping capacity is the logarithmic decrement of the stress in the sample. The decrement is determined from the decay characteristics of the vibrating sample (Figure 2). The logarithmic decrement, Δ, can be expressed as:

$$\Delta = \ln \frac{A_0}{A_1} \qquad (1)$$

where A_0 and A_1 are the amplitudes of vibration of successive cycles. Since it is often difficult to determine accurately the decrement from successive amplitudes, the usual method of determining the decrement involves measuring the ratio of the amplitudes at a given cycle and then n cycles later. It can be shown that

$$\Delta = \frac{1}{n} \ln \frac{A_0}{A_n} \qquad (2)$$

where A_n is the amplitude of vibration at the nth cycle.

Generally, the damping capacity is expressed in terms of the specific damping capacity, SDC, since this quantity provides a better basis than does logarithmic decrement for comparing the damping characteristics of various materials. The SDC is defined as the percentage loss in energy per cycle in the sample. The SDC is obtained from the logarithmic decrement using the following equation:

$$SDC = 100\,(1 - e^{-2\Delta}) \qquad (3)$$

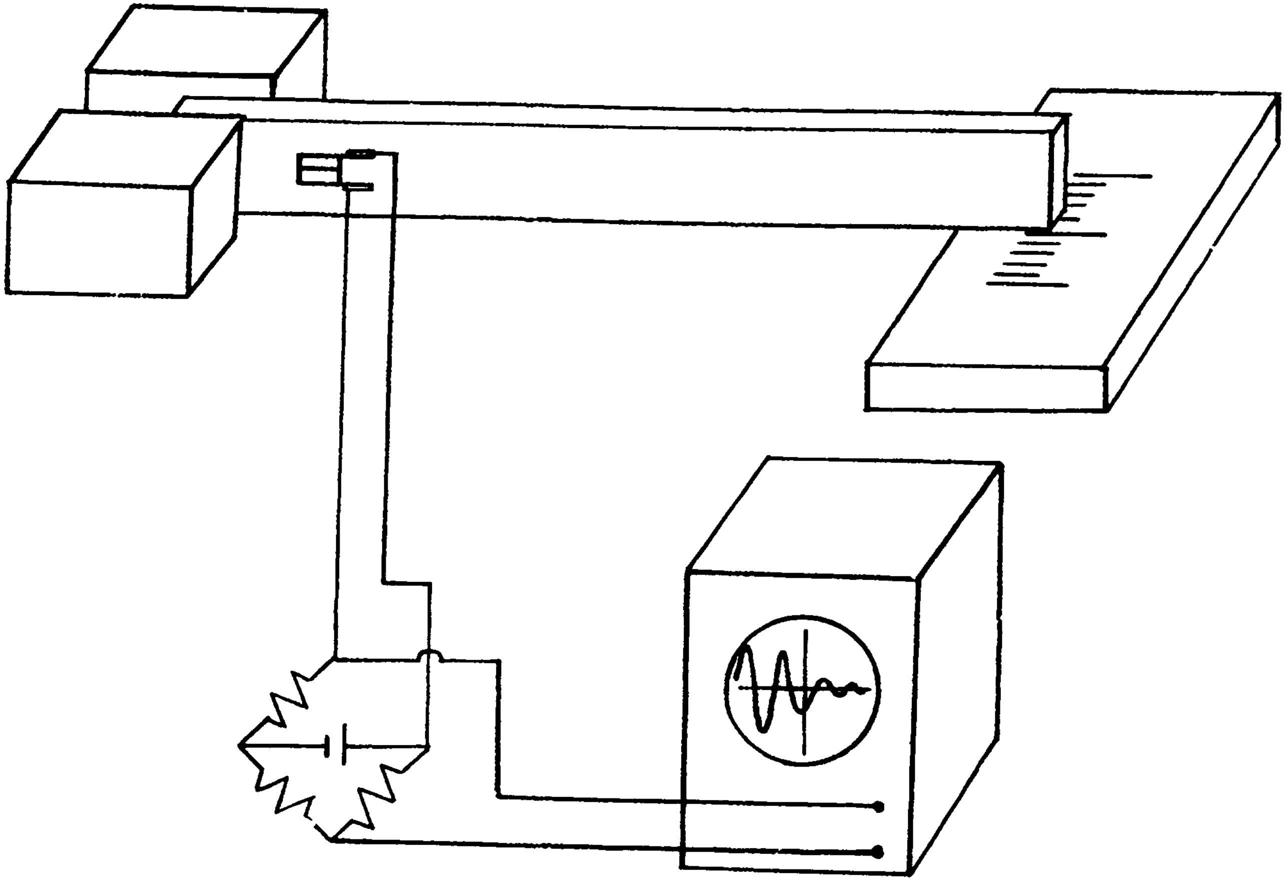

Figure 1. Schematic Diagram of Apparatus Used to Measure Damping Capacity

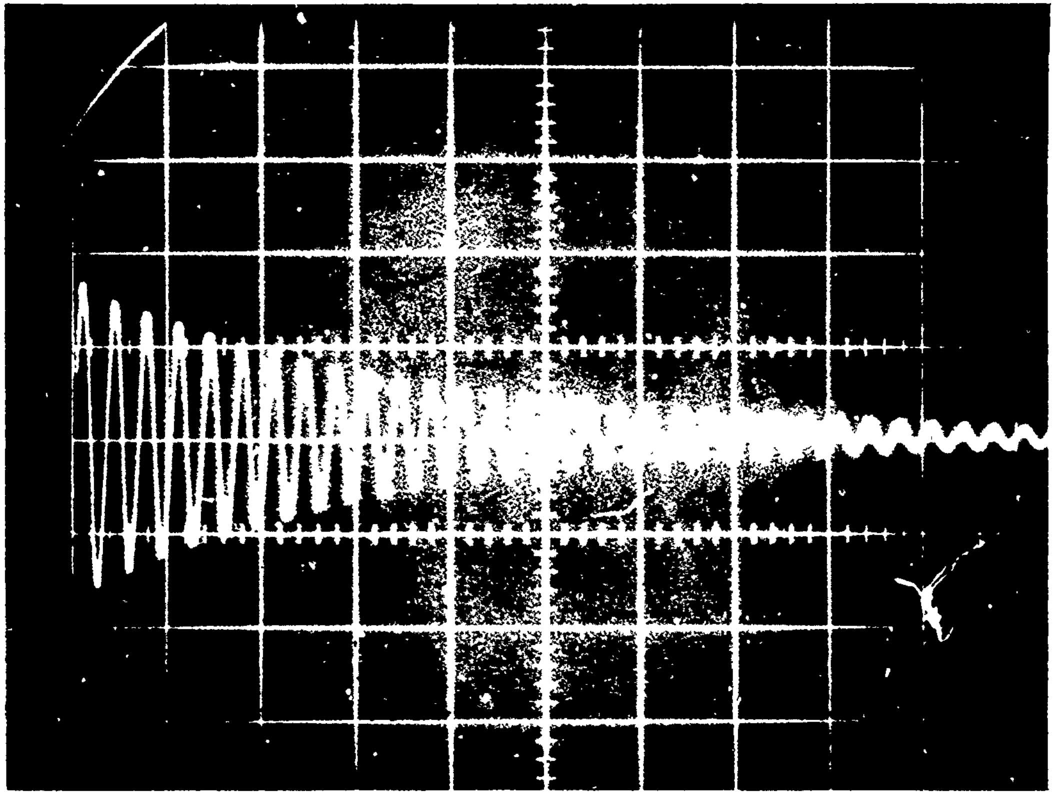

Figure 2. A Typical Decay Curve for a Freely Vibrating Cantilever Beam.

Mechanical Testing

The yield strength, ultimate tensile strnegth and elongation were determined for all the magnesium alloys in both the as-fabricated and annealed conditions. Flat longitudinal tensile bars (1 in. gage length) were prepared from the rolled sheets. The tensile tests were conducted on an Instron testing machine using a strain rate of 0.05/min.

Metallography

Standard metallographic polishing and etching techniques were used for all the magnesium alloys. Longitudinal cross sections were polished and then etched in a nital solution. All alloys were examined using conventional light with the exception of the Mg-Cd alloys for which it was necessary to use polarized light to reveal the structure.

RESULTS AND DISCUSSION

Effect of Bending Stress on Damping Capacity

The SDC of the Mg alloys as a function of bending stress is shown in Figure 3. It can be seen that for a given alloy the SDC increases with stress. At a given stress level the SDC of the annealed material is equal to or greater than that of the as-fabricated material

The increase of the damping capacity with stress is gradual in all the alloys in the as-fabricated condition. However, two types of behavior are noted in the annealed condition: (1) in the high damping capacity alloys, such as Mg-1% Mn, Mg-4%Cd, and Mg-0.6%Zr, the SDC increases sharply with stress; (2) in the low damping capacity alloys, such as Mg-1%Al and Mg-3%Zn, the SDC increases only slightly.

Since the damping capacity of an alloy varies with bending stress, the SDC of the alloys should be compared at a given stress level. However, it has been pointed out that the yield strength of the alloys must also be considered in order to prevent selecting a reference stress which is greater than the yield strength of the material.[13] It has been suggested by Jensen that the SDC be calculated at a measuring stress that is a given fraction of the yield strength of the material. This measure of damping capacity is referred to as damping index (DI), and it is the SDC of a material at a stress corresponding to 10% of its tensile yield strength. Comparing alloys either on the basis of the SDC at a given stress or on the basis of the DI has merit, and both techniques should be considered in an alloy development program. The former method gives a direct comparison whereas the latter technique has a normalizing effect on the damping values. For example, pure cast Mg has the highest value of SDC, i.e. 52.2%,compared to any other alloy at a stress of

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[13] J.W. Jensen, op. cit.

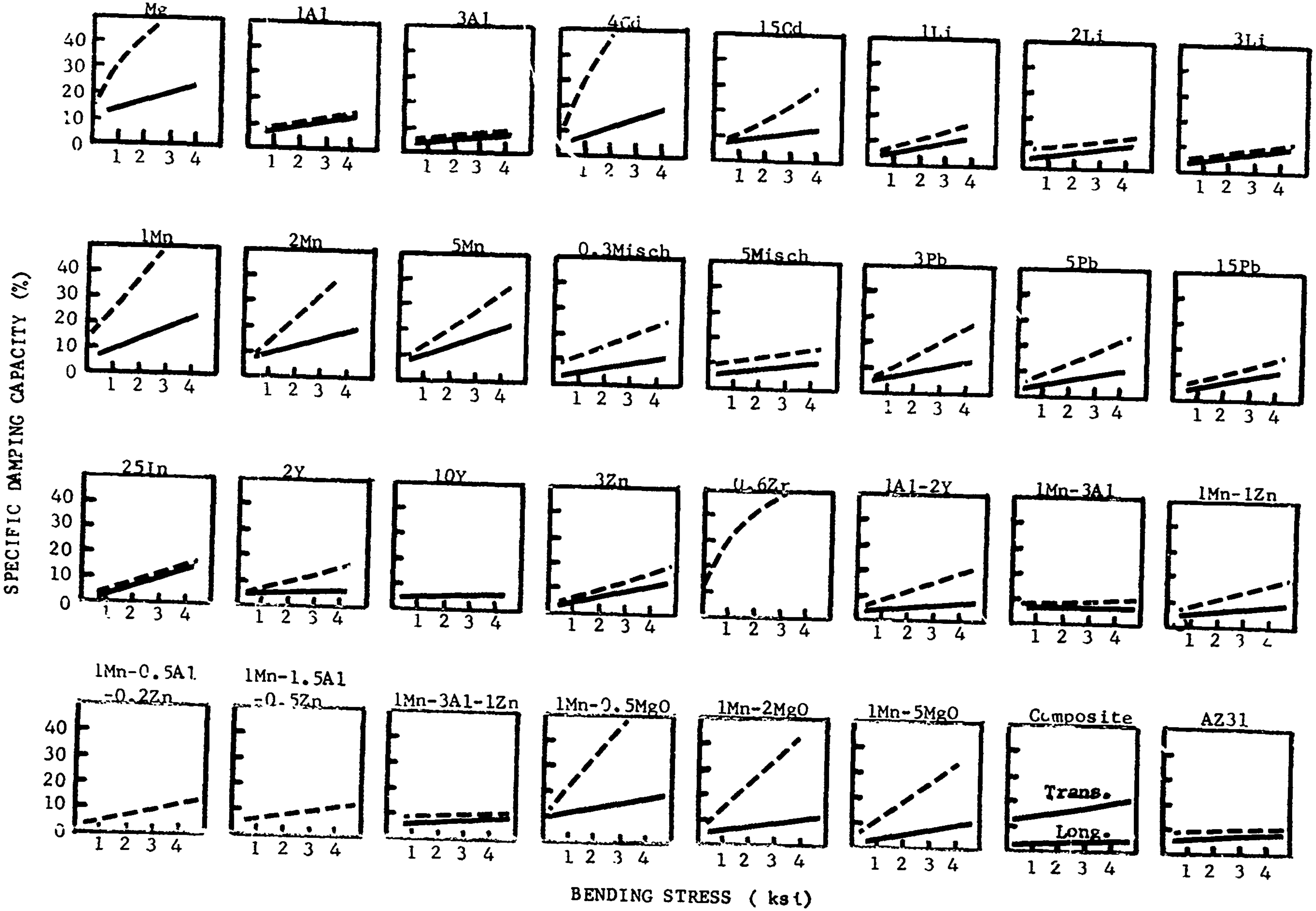

Figure 3. Specific Damping Capacities of As-Fabricated (Solid Line) and Annealed (Dashed Line) Magnesium, Its Alloys, and Composites as a Function of Bending Stress. (The Nominal Additions in Weight Percentage Appear Above Each Graph)

2.5 ksi. However, its DI is 28.5% which makes other wrought annealed alloys such as Mg-1%Mn (DI=32.2%), Mg-4%Cd (DI=34.0%) and Mg-0.6%Zr (DI=33.8%) competitive with it. Also, if the SDC had been compared at a stress which exceeded the yield strength of cast Mg (3 ksi), it could not even be considered since it would already have undergone plastic deformation. Unless the actual design criteria and the stress analyses of the structures are known, it is difficult to decide which method to use. Most of the comparisons made in this paper use the damping index since its normalizing effect on damping capacity values tends to emphasize those alloys that have superior damping properties.

Effect of Alloying Elements on Damping Capacity

Tables 2 to 4 present the concentration of solute, the damping capacity and the mechanical properties of the various alloys tested in both the as-fabricated and annealed conditions. The damping index and yield strength of the alloys as a function of solute concentration are shown in Figures 4 and 5. It can be seen that the DI of the as-fabricated magnesium alloys decreases only slightly with increasing solute concentration (Figure 4). In contrast, the decrease in damping index of the annealed alloys with increasing solute concentration is more pronounced, especially in the case of the Mn and Cd additions (Figure 5). As expected, the strengths of the alloys increase with increasing solute content in both the as-fabricated and annealed conditions. (Figures 4 and 5). The only exception is the annealed Mg-Li alloys where the yield strengths decrease with increasing atomic percent solute. (Figure 5). The reasons for this behavior are not apparent at this time.

In addition to solid solution alloys, composite materials were also investigated. This work was carried out to determine if the addition of fibers or dispersed particles to the matrix of the high damping capacity materials, such as pure Mg or Mg-1%Mn, would strengthen them without reducing their damping capacity. To this end, Mg-borsic composites and the annealed Mg-1%Mn-MgO dispersion hardened alloys were evaluated.

The Mg-borsic composite with the fibers oriented in the longitudinal direction had a yield strength of 100 ksi with a DI of 3.9%.[14] With the fibers oriented in the transverse direction, the yield strength was 12 ksi. This is equivalent to the yield strength of wrought Mg, but the DI was 16.5%, which is only about 1/3 that of wrought Mg. Although the utilization of the Mg-borsic composites does not appear promising, a final decision regarding their usefulness for high strength applications requiring high damping capacity materials cannot be made until a Mg-borsic composite with randomly oriented fibers has been evaluated.

The strength and DI of the annealed Mg-1%Mn-MgO alloys are shown as a function of MgO content in Figure 6. It can be seen that the DI

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[14] B. Peters, Dow Chemical Co. (private communication).

Table 2. Atomic Percent Solute, Damping Capacity and Mechanical Properties of Binary Magnesium Alloys in the As-Fabricated Condition

Alloy	Solute a/o (nominal)	DI %	SDC @ 2.5 ksi %	Tensile Y.S. .2% offset ksi	T.S. ksi	Elong. in 1 in. %
Mg - 1% Al	0.92	8.8	8.8	26.6	31.5	9.5
Mg - 3% Al	2.77	6.0	5.4	32.2	36.9	4.5
Mg - 4% Cd	1.03	10.0	13.5	16.4	23.6	11.5
Mg - 15% Cd	4.22	8.1	7.7	18.2	28.5	11.0
Mg - 1% Li	3.89	6.9	7.3	22.1	28.3	7.5
Mg - 2% Li	7.55	6.6	6.4	23.0	-	-
Mg - 3% Li	11.00	6.6	6.8	23.7	29.9	9.0
Mg - 1% Mn	0.48	10.8	13.5	13.2	20.0	11.0
Mg - 2% Mn	0.98	9.5	13.3	14.6	20.6	10.0
Mg - 5% Mn	2.46	11.9	13.6	14.4	20.6	8.0
Mg - 0.3% Misch	0.05	6.9	5.5	21.6	25.0	17.0
Mg - 5% Misch	0.92	6.9	6.3	27.1	32.9	7.0
Mg - 3% Pb	0.45	6.8	8.6	18.4	26.1	12.5
Mg - 5% Pb	0.76	6.4	7.0	20.6	24.8	-
Mg - 15% Pb	2.52	7.2	7.3	24.0	29.0	6.5
Mg - 2% Y	0.63	6.5	5.8	30.6	33.2	9.5
Mg - 3% Zn	1.22	12.5	8.2	38.2	45.0	2.0

Table 3. Atomic Percent Solute, Damping Capacity and Mechanical Properties of Binary Magnesium Alloys in the Annealed Condition

Alloy	Solute a/o (nominal)	DI %	SDC @ 2.5 ksi %	Tensile Y.S. 0.2% offset ksi	T.S. ksi	Elong. in 1 in. %
Mg - 1% Al	0.92	6.9	8.0	17.0	29.1	15.0
Mg - 3% Al	2.77	6.0	5.7	18.2	--	6.0
Mg - 4% Cd	1.03	34.2	45.0	11.9	24.4	7.5
Mg - 15% Cd	4.22	10.9	32.0	12.3	26.6	12.0
Mg - 1% Li	3.89	8.2	14.4	16.4	25.1	9.5
Mg - 2% Li	7.55	8.7	11.6	14.0	21.6	14.5
Mg - 3% Li	11.00	5.1	7.9	10.4	19.7	19.0
Mg - 1% Mn	0.48	32.0	50.0	11.2	22.4	7.5
Mg - 2% Mn	0.98	16.0	36.2	12.8	23.4	8.0
Mg - 5% Mn	2.46	14.8	28.8	12.6	23.4	7.5
Mg - 0.3% Misch	0.05	13.8	17.5	15.2	28.9	21.0
Mg - 5% Misch	0.92	10.9	11.8	20.8	29.9	11.5
Mg - 3% Pb	0.45	11.5	24.4	14.4	25.6	4.8
Mg - 5% Pb	0.76	11.2	22.0	14.7	26.8	6.0
Mg - 15% Pb	2.52	7.5	13.0	16.6	28.9	5.8
Mg - 2% Y	0.63	6.0	13.0	6.6	12.2	28.0
Mg - 3% Zn	1.22	5.5	11.0	10.9	28.6	10.0
Mg - 0.6% Zr	0.19	33.8	38.0	12.7	25.0	4.0

Table 4. Damping Capacity and Mechanical Properties of Ternary and Quaternary Magnesium Alloys in the As-Fabricated and Annealed Conditions

Alloy	Temper	DI %	SDC @ 2.5 ksi %	Tensile Y.S. 0.2% offset ksi	T.S. ksi	Elong. in 1 in. %
Mg-1% Al-2% Y	As-Fab	4.9	6.0	26.2	33.2	7.5
	Ann.	10.4	13.0	17.3	30.1	15.0
Mg-1% Mn-3% Al	As-Fab	6.0	5.8	35.5	40.8	5.0
	Ann.	7.1	7.2	22.3	34.9	18.3
Mg-1% Mn-1% Zn	As-Fab	7.7	7.8	26.6	31.3	12.5
	Ann.	8.2	9.5	18.1	30.5	13.2
Mg-1% Mn-0.5% MgO	As-Fab	13.1	14.7	15.3	22.0	8.8
	Ann.	26.6	36.8	13.1	20.7	3.0
Mg-1% Mn-2% MgO	As-Fab	7.7	8.6	19.4	23.8	12.7
	Ann.	17.4	28.4	13.4	25.5	7.5
Mg-1% Mn-5% MgO	As-Fab	3.9	6.8	17.3	23.4	3.8
	Ann.	16.5	22.9	16.8	25.7	3.5
Mg-1% Mn-0.5%Al-0.2%Zn	Ann.	7.3	8.2	19.3	30.8	16.0
Mg-1% Mn-1.5%Al-0.5%Zn	Ann.	7.3	8.2	20.6	31.6	17.0
Mg-1% Mn-3% Al-1% Zn	As-Fab	6.2	6.8	34.5	45.1	5.0
	Ann.	8.2	8.5	22.2	36.4	18.0

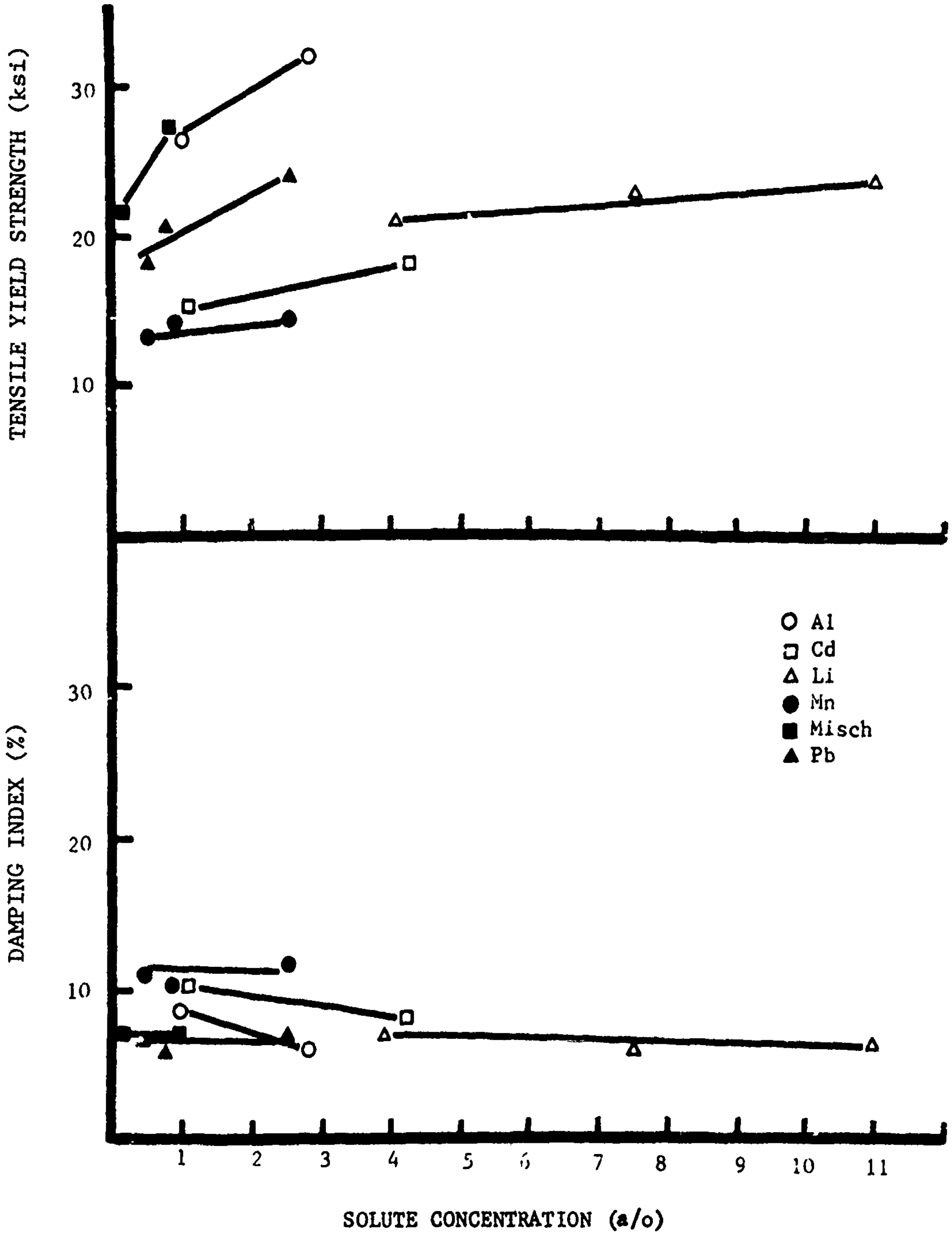

Figure 4. Damping Index and Yield Strength of As-Fabricated Binary Wrought Magnesium Alloys as a Function of Solute Concentration.

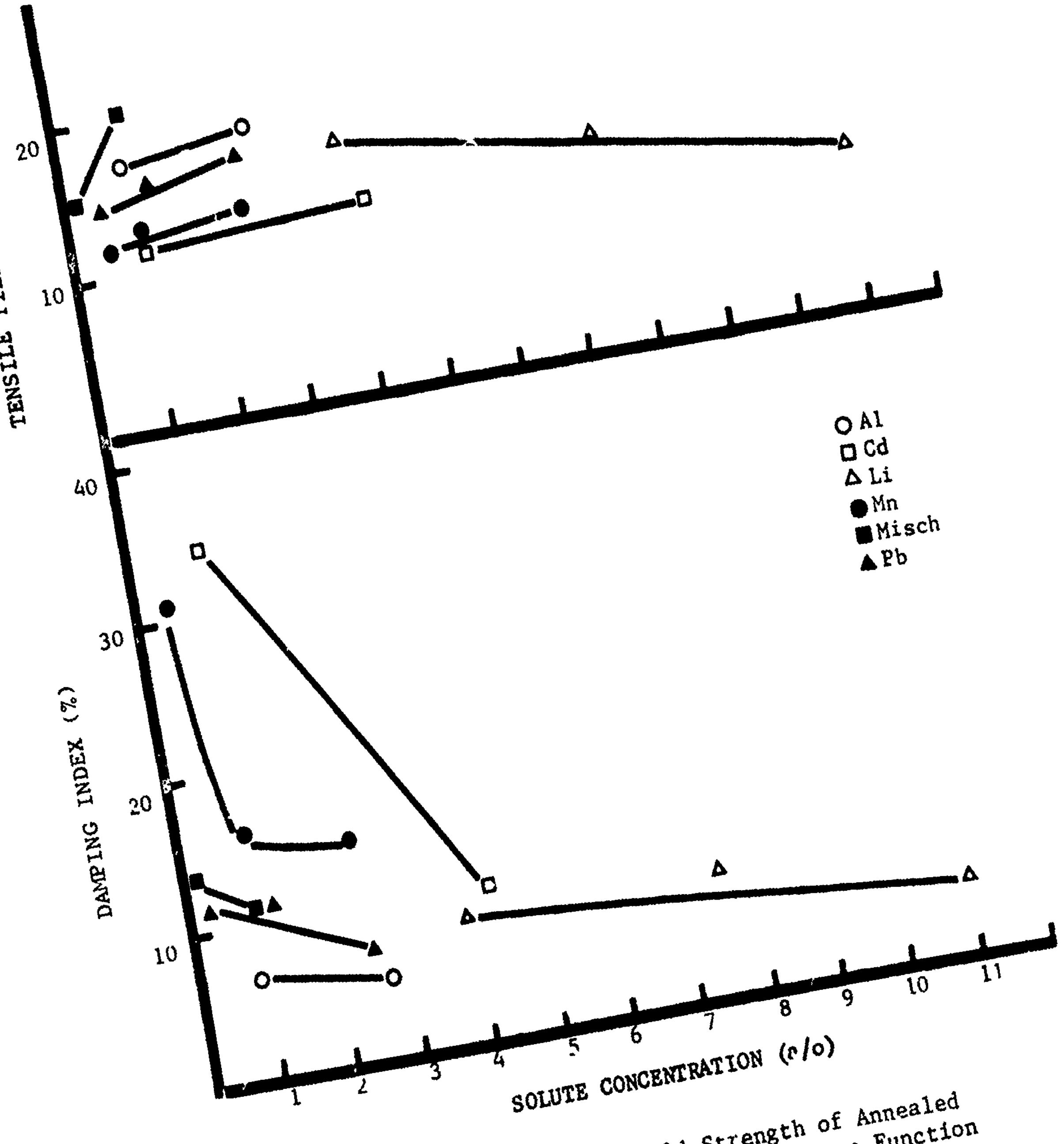

Figure 5. Damping Index and Yield Strength of Annealed Binary Wrought Magnesium Alloys as a Function of Solute Concentration.

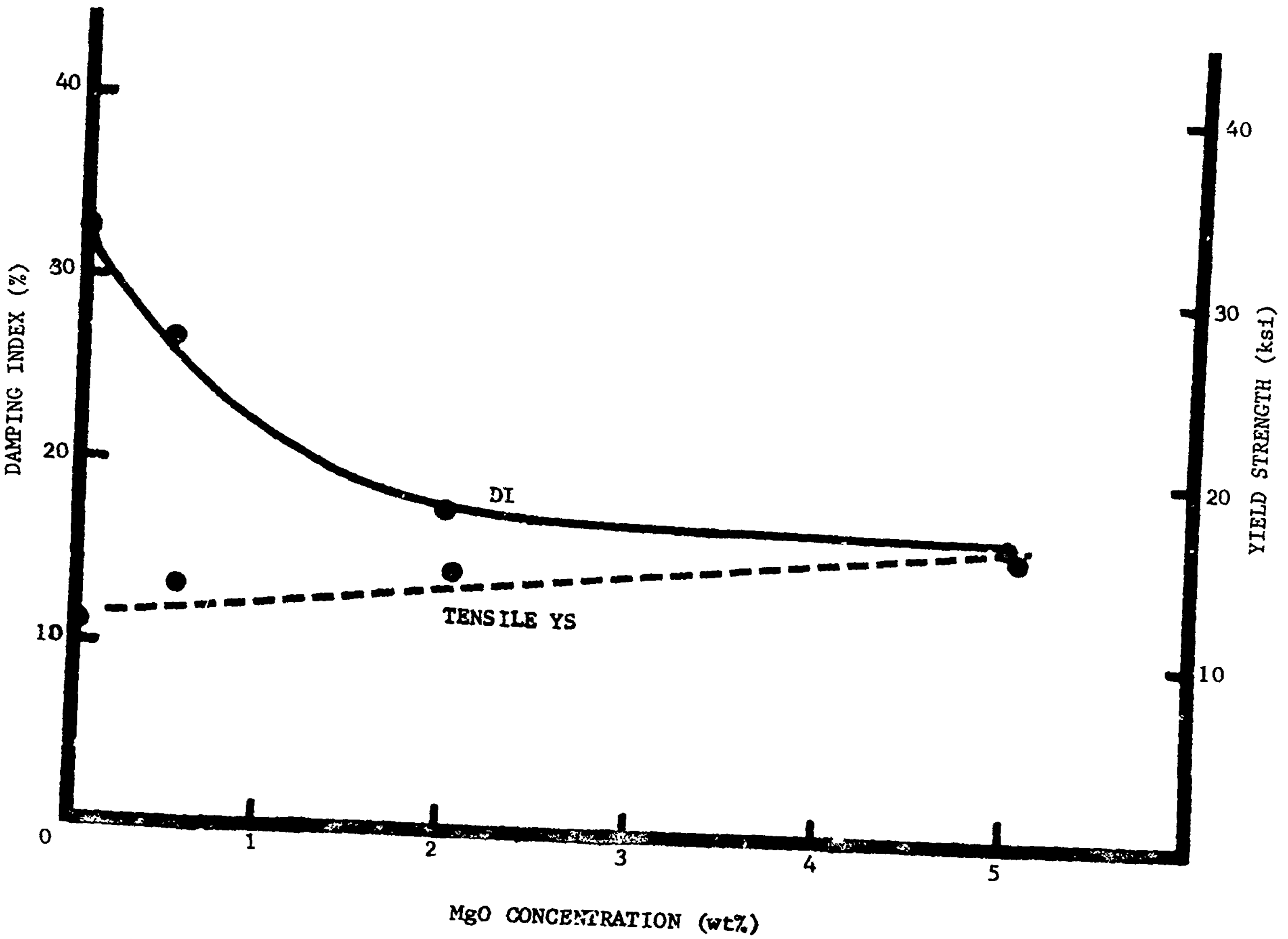

Figure 6. Damping Index and Yield Strength of Annealed Mg-1%Mn-MgO Alloys as a Function of MgO Content.

decreases and the yield strength slightly increases with increasing MgO concentration. Thus, it appears that the addition of dispersant such as MgO has a detrimental effect on the damping capacity while only slightly increasing the strength of the material.

Strength as a Function of DI and SDC

Since the objective of this work was to develop magnesium alloys with both high strength and high damping capacity, the DI and the SDC at 2.5 ksi was examined as a function of the tensile yield strength (Figures 7 and 8). It can be seen that there is an inverse relationship between damping capacity and yield strength. This inverse relationship can be explained on the basis of a dislocation mechanism for damping, since it has been reported that the major mechanism responsible for damping in most metals and alloys at the stress levels and frequencies of vibrations used in this investigation is the dissipation of energy by the motion of dislocations.[15,16] That is, the easier it is for dislocations to move, the greater is the damping capacity of the material, whereas the more difficult it is for dislocations to move, the greater the strength of the material.

It can be seen, however, from Figures 7 and 8 that at strength levels of 11 to 14 ksi there is a steep descent of the curve resulting in several alloys having similar yield strengths (11 to 14 ksi) and widely different damping capacities (DI or SDC of the order of 10 to 50%). It appears that the dislocation mechanism does not provide an adequate explanation for this behavior. It has been suggested that in certain high damping capacity cast magnesium alloys, elastic deformation twinning and untwinning occurs during damping.[17,18] This process, therefore, also provides a mechanism for the dissipation of energy. Thus, those annealed magnesium alloys that twin easily should have a good damping capacity. Although the twinning frequency was not quantitatively deter-

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[15] L.I. Rokhlin and V.V. Sheridin, the Damping Capacity of Magnesium Alloys. Translated from Metallovedenie i Termicheskaya Obrabotka Metallov, No. 8 (August 1969) pp 54-56.

[16] C.F. Burdett and T.J. Queen, The Role of Dislocations in Damping, Met. Rev 143 (Part I) (1970) pp 47.

[17] M.E. Drits, L.I. Rokhlin and V.V. Sheridin, Magnesium Alloys with High Damping Capacity. Translated from Metallovedenie i Termicheskaya Obrabotka Metallov 19, No. 11 (Nov 1970) pp 48-51.

[18] E. Plenard and A. Mena, Influence de Sollicitations Preables sur la Capacite d'Amortissement d'un Alliage Mg-Zr Presentant un Phenomene de Maclage, C.R. Acad. Sc. Paris, t. 262 (27 Juin 1966) Series C pp 1848-1851.

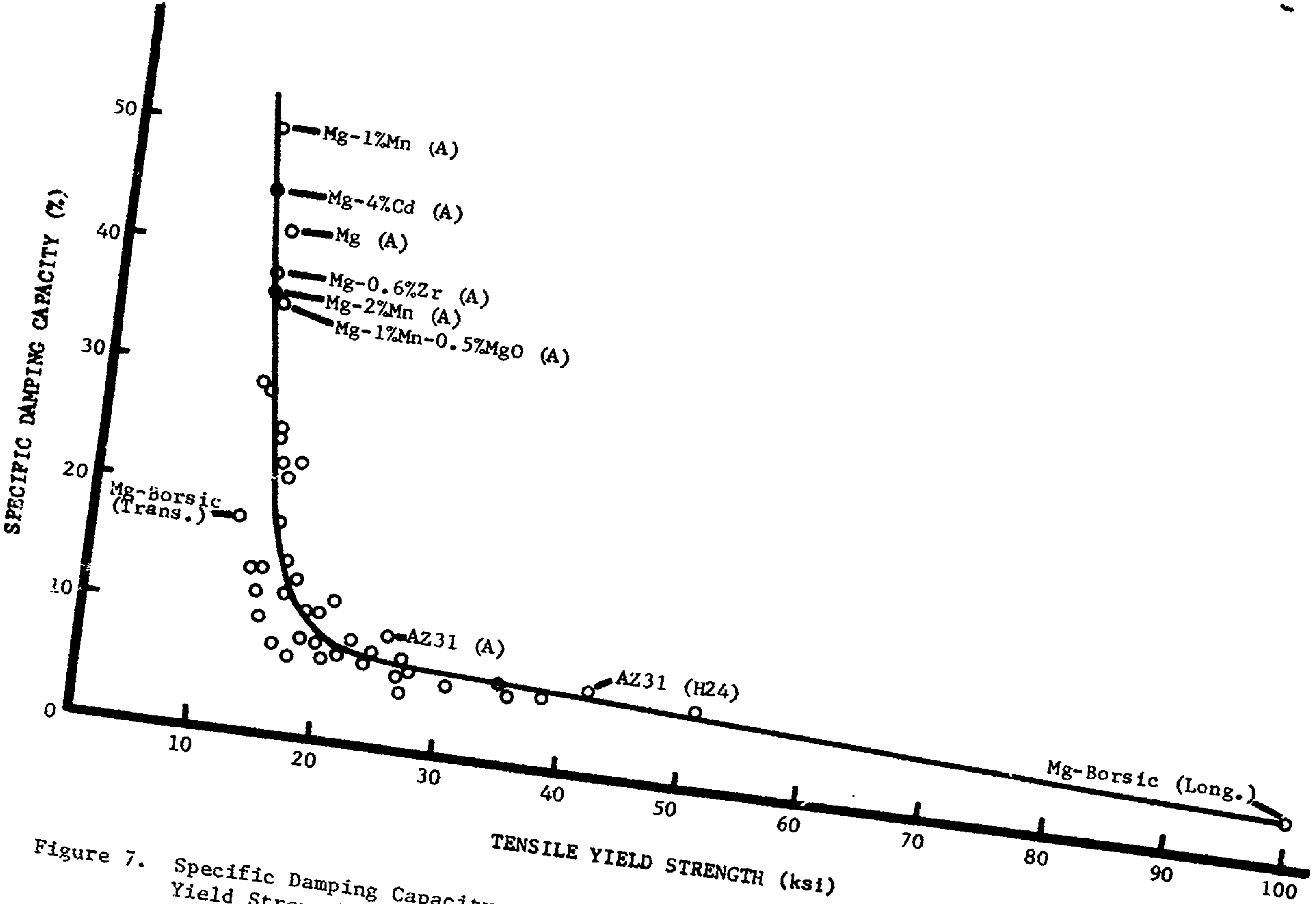

Figure 7. Specific Damping Capacity at 2.5 ksi of Magnesium Alloys as a Function of Yield Strength. Several of the Higher Damping Alloys, as well as AZ31, and the Mg-Borsic Composites are Designated. (A) Denotes Annealed.

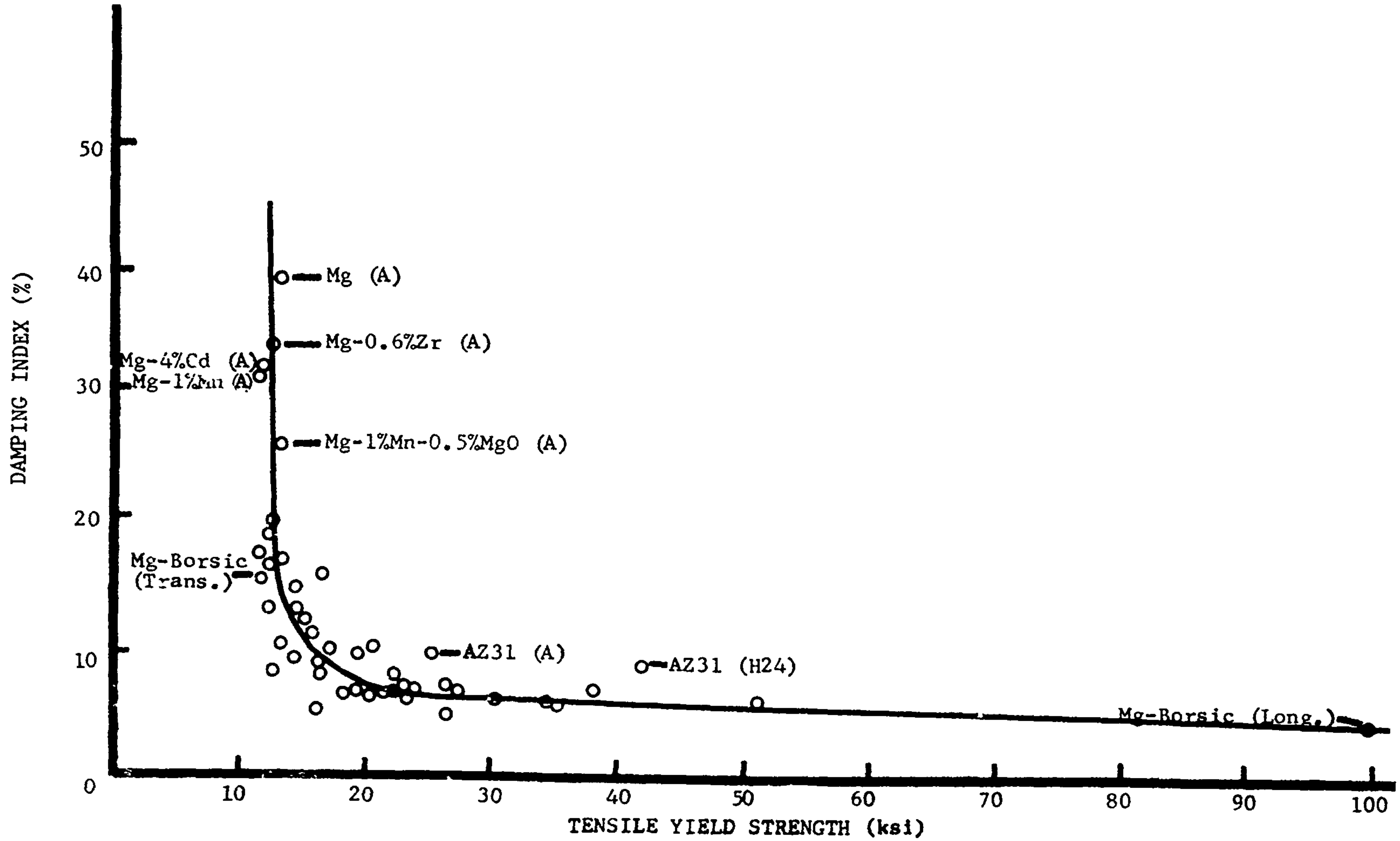

Figure 8. Damping Index of Magnesium Alloys as a Function of Yield Strength. Several of the Higher Damping Alloys, as well as A731, and the Mg-Borsic Composites are Designated. (A) Denotes Annealed.

mined in this work, some measure of the ease of twinning could be obtained from optical metallography. Specifically, the appearance of polishing twins were used as an index of the ease of twinning. It was found that the microstructures of the Mg, and the Mg-1%Mn, Mg-4%Cd and Mg-0.6%Zr alloys, in the annealed condition, contained heavily twinned areas (Figure 9). In fact, all of the alloys that were on the steep part of the curves (Figures 7 and 8) showed evidence of twinning whereas the other alloys on the knee and flat part of the curves did not. Also, in those alloys that had high damping capacities, a "tin cry" was produced during testing. This "tin cry" has been associated with twinning.[19] Thus it can be concluded that in the better damping capacity magnesium alloys, there are two mechanisms operating, dislocation damping and twinning damping.

The effect of grain size on the damping capacity and strength of a high damping alloy (Mg-1%Mn) and a low damping alloy (Mg-1%Mn-0.5%Al-0.2%Zn) was also investigated. The results are shown in Figure 10. The grain sizes of the Mg-1%Mn alloy were varied by the application of different isochronal (1 hr) annealing treatments in the temperature range from room temperature (as-fabricated) to 800°F. It can be seen that from room temperature (RT) to 500°F, recovery occurs allowing increased dislocation mobility with an accompanying increase in DI and decrease in strength. Above 500°F, recrystallization occurs with further effects on DI and strength. Specifically, with increasing annealing temperatures, the grain size and the DI increase while the strength decreases. A possible explanation for this behavior is that with increasing recrystallized grain size, there is less surface area of grain boundaries present. Thus, the grain boundaries offer less resistance to dislocation motion resulting in increased damping and decreased strength.

The grain size appears to have less of an effect on strength and especially on DI in the low damping Mg-1%Mn-0.5%Al-0.2%Zn alloy than in the high damping Mg-1%Mn alloy. The reason for this may be that in addition to the effect of grain size that occurs in both alloys, in the Mg-1%Mn alloy, elastic twinning and untwinning also occurs leading to the larger DI. This is supported by the observation that in the Mg-1%Mn alloy, those annealing treatments which gave the largest DI also produced the greatest degree of twinning (Figure 10). A final point is that all the values of strength and DI presented in Figure 10 obey the inverse relation between strength and damping capacity shown in Figures 7 and 8.

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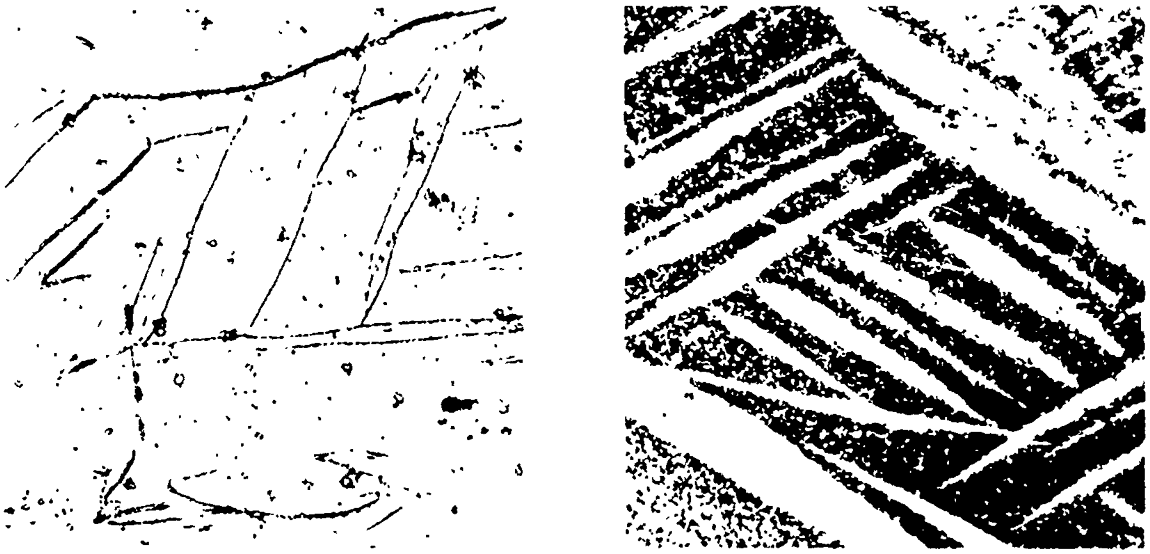
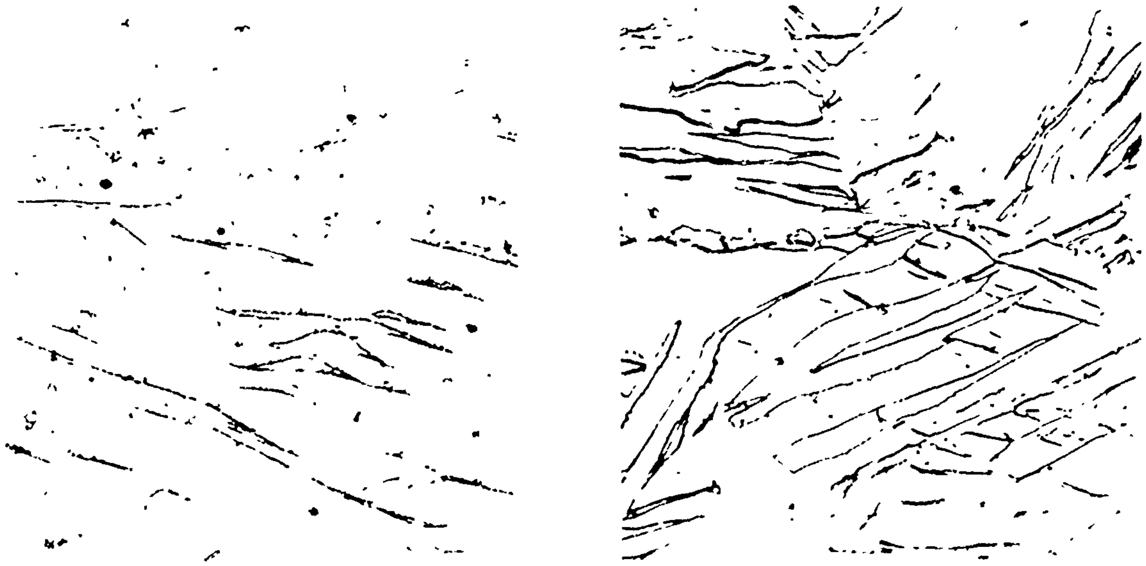
[19] G. E. Dieter Jr., Mechanical Metallurgy, McGraw-Hill (1961) p 106.



Mg

Mg-4%Cd



Mg-1%Mn

Mg-0.6%Zr

Figure 9. Microstructures of Annealed Wrought Mg and Its Alloys Showing the Presence of Twins. Nital Etch. 500X.

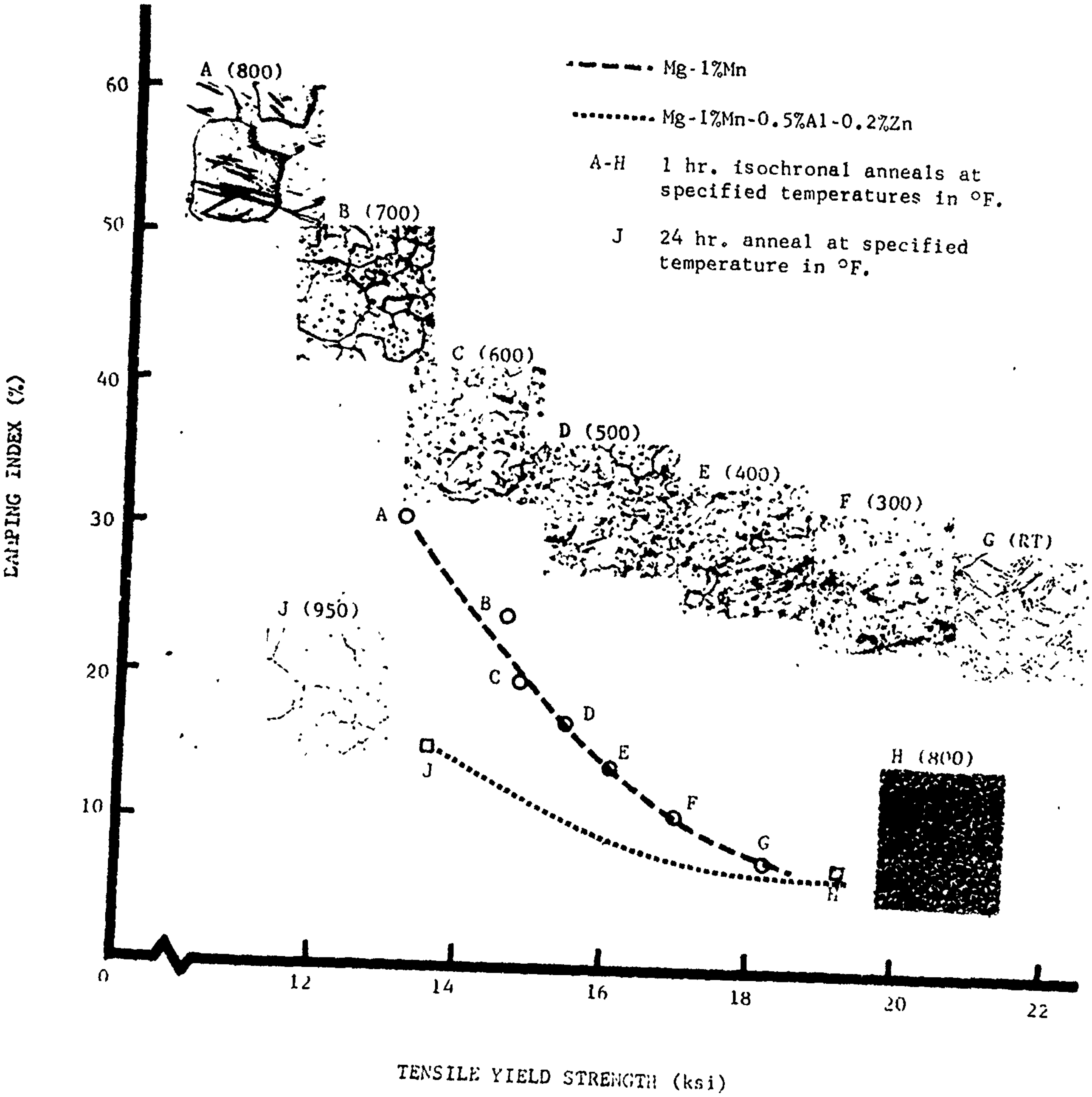


Figure 10. Damping Index, Yield Strength, and Microstructures of Mg-1%Mn and Mg-1%Mn-0.2%Zn Alloys as a Function of Various Annealing Treatments. Nital Etch. 100X.

CONCLUSIONS

1. An inverse relationship exists between the damping index or specific damping capacity and the yield strength of wrought magnesium alloys.

2. The wrought magnesium alloys that had the highest damping capacity are annealed Mg-1%Mn, Mg-4%Cd and Mg-0.6%Zr. Although their damping indices are significantly higher than those of AZ31, their strengths are about 10 ksi lower than that of AZ31.

3. The principal reason for alloys of similar yield strength having various damping indices is related to the relative amount of twinning and untwinning that occurs. Therefore, the relative ease with which twinning occurs in annealed wrought magnesium and annealed Mg-1%Mn, Mg-4%Cd and Mg-0.6%Zr alloys explains their good damping capacities.

4. The strength-damping capacity relationship in Mg-borsic composites is a function of fiber orientation. The addition of a dispersion of MgO to an annealed Mg-1%Mn alloy decreases the damping capacity of the alloy while only slightly increasing its yield strength.

5. The specific damping capacity of wrought magnesium alloys increases with bending stress; the increase is especially significant in those annealed alloys which have a high damping capacity.

6. The specific damping capacity of wrought magnesium alloys at a given stress is equal to or greater for the alloy in the annealed condition than in the as-fabricated condition.

7. The damping index of wrought magnesium alloys increases as the solute concentration decreases; this increase is more pronounced in the annealed alloys.

8. Increasing the grain size of wrought magnesium alloys decreases their strength and increases their damping capacity.

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