Texture Evolution During Creep Deformation in Pure Magnesium and Mg-Mn Alloys

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In the last decade, an increasing demand for lightweight materials occurred in order to decrease the oil consumption and enhance vehicle performance in automotive industry. Being the lightest structural metal, magnesium offers an attractive solution. The heaviest component of a vehicle is the powertrain (engine block and transmission) where weight reduction offers the maximum benefits. The powertrain service conditions necessitate materials that can resist up to 50-100MPa at 150-200°C. Most Mg alloys undergo creep deformation under these conditions [1]. Consequently, if magnesium is to be used for such applications, its resistance to creep needs to be improved. This requires a comprehensive understanding of deformation behavior of magnesium and its alloys [2]. Since many components are put in service in as-cast condition, the effect of as-cast structure, in term of crystallographic orientation, on creep behavior was investigated. This is especially important if the creep stress is above the yield strength of the alloy.

The materials used in this study are pure Mg and an Mg-1.5%Mn alloy. Mg-Mn is a peritectic system with intra-granular second phase (α-Mn) particles. The pure Mg is considered as a reference material and the Mg-Mn alloy has been studied to determine how the presence of a second metallic phase will alters the creep behavior. The alloys were prepared in the Light Metals Research laboratory at McGill University.

The creep deformation was studied under compressive loading to simulate the compressive stresses applied by bolts and nuts at joints in the service. In the initial phase of the research, the compression creep tests were conducted at McGill and at Westmoreland Labs on the cylindrical samples at temperatures 100 - 175°C under constant loads of 15 MPa and 50 MPa.

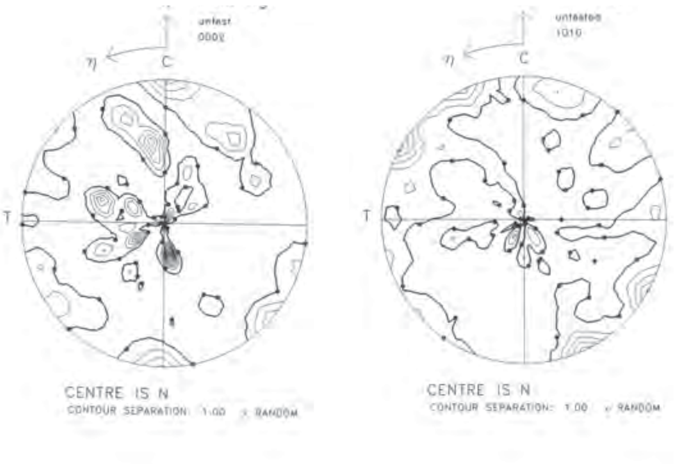

Fig 1. (left) Basal (00.2) and (right) Prismatic (10.0) pole figures for the as-cast (untested) pure Mg samples

Texture analysis by neutron diffraction was performed, at the Canadian Neutron Beam Center (CNBC), on both tested and as-cast (untested) samples under different loads and temperatures. Texture experiments were conducted using E3 - Triple axis spectrometer that receives neutrons from the National Research Universal (NRU) reactor.

The 00.2 and 10.0 pole figures of the as-cast pure Mg are seen Fig.1 where N is the compression axis (CA) and T and C are radial axes of the cylinder. Intensity of preferred orientation is represented by contour lines, each contour line separation has a specific intensity value (1.0 in Figure 1). The intensity was, therefore, calculated as:

I (intensity) = S (Specific value for contour separation) x N (Number of contour lines)

It can be seen from Fig.1a that for pure Mg the point of maximal intensity lies where basal pole is around 20° away from CA, which is also consistent with the 10.0 pole figure (Fig. 1b). The maximal intensity in the 00.2 pole figure is 12.5 times the random intensity. As a large number of grains have a preferred orientation as indicated in Fig.1, it can be assumed that a strong directional solidification leads to such an orientation of the hcp crystals that the basal planes become parallel to the direction of solidification (Fig. 2).

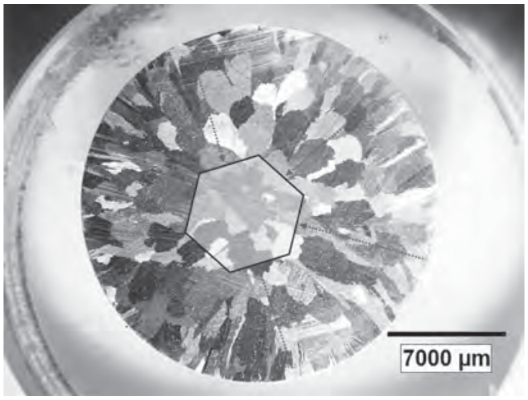

Fig 2. Schematic representation of grain growth from prismatic planes in pure Mg.

Similar preferred orientation still exists when the 15MPa -100°C - 150 hours tested pure Mg sample (Fig.3a) is compared with as-cast (untested) pure Mg. A slight decrease in intensity of texture seems to have occurred as seen in the 10.0 pole figures; however the change is not significant.

The 15MPa – 175°C – 150 hours sample (Fig. 3b) also shows similar preferred orientation in general, however, the maximum intensity of texture dropped significantly from 12.5

times random to around 5 times random when compared to the15MPa-100°C-150 hours sample and the as-cast untested sample. This might be due to dissolution of existing strong texture resulting from directional solidification (presence of columnar grains) by creep deformation at 175°C. The increase in temperature seems to facilitate the slight rotation of basal poles away from existing preferred orientation. This might be the reason for decrease in maximum intensity of texture.

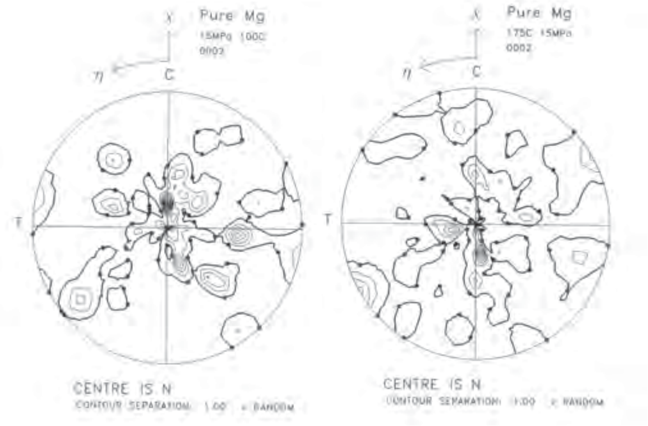

Fig 3. Basal-plane pole figures (00.2) for pure Mg after creep testing: (left) 15MPa 100°C 150hrs. and (right) 15MPa 175°C 150hrs.

An increase in the creep load from 15MPa to 50MPa resulted in enhanced rotation of the basal poles towards CA. The pole figures received for the 50MPa-150°C-5 hours sample (Fig. 4) indicate that basal poles become aligned with CA. Interestingly, Sato et al. reported rotation of the basal poles to becomes perpendicular to stress axis (tensile) for pure Mg [3].

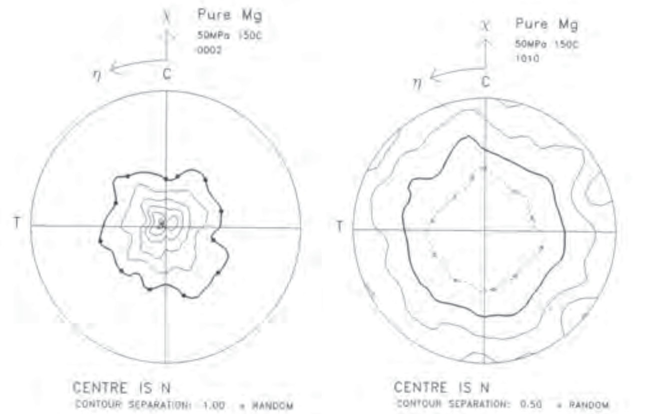

Fig 4. Pole figures for creep-tested pure Mg sample (50MPa 150°C 5hrs.): (left) (00.2) reflection and (right) (10.0) reflection.

The effect of Mn addition on crystallographic texture evolution was investigated under similar creep conditions. Pole figures for the as-cast Mg-1.5%Mn material (see Fig. 5) exhibit similar, but weaker, preferred orientation than pure Mg where basal poles have preferred orientation either at an angle of ≤30° away from CA or perpendicular to the CA (Fig. 1 a.). It can be seen that, compared to as-cast pure Mg samples, the addition of 1.5%Mn resulted in a more random as-cast texture.

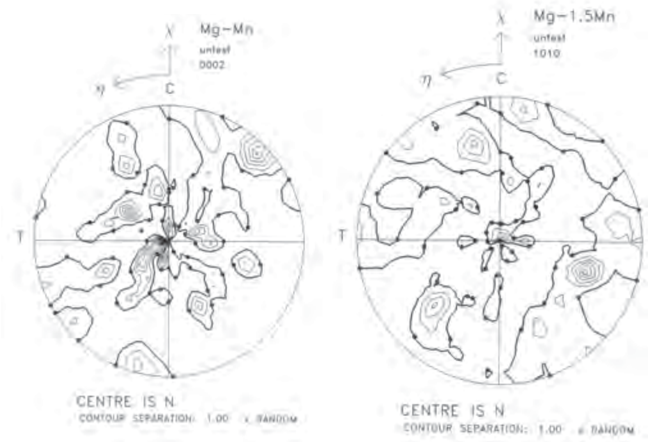

Fig 5. Pole figures for as-cast (untested) Mg-1.5%Mn alloy: (left) Basal reflection (00.2) and (right) prismatic reflection (10.0).

Additionally, creep tested Mg-1.5%Mn alloy exhibits no obvious change when the test conditions change from 15MPa-100°C-150 hours to 15MPa -175°C-150 hours (Fig. 6).
In other words, the decrease in maximum texture intensity observed for pure Mg was not observed in the Mg-1.5%Mn alloy tested under the identical conditions.

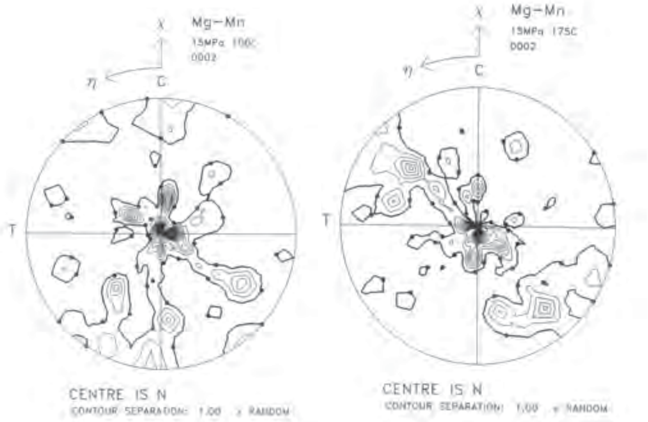

Fig 6. Basal pole figures (00.2) of Mg-1.5Mn after creep testing: (left) 15MPa 100°C 150hrs. and (right) 15MPa 175°C 150hrs.

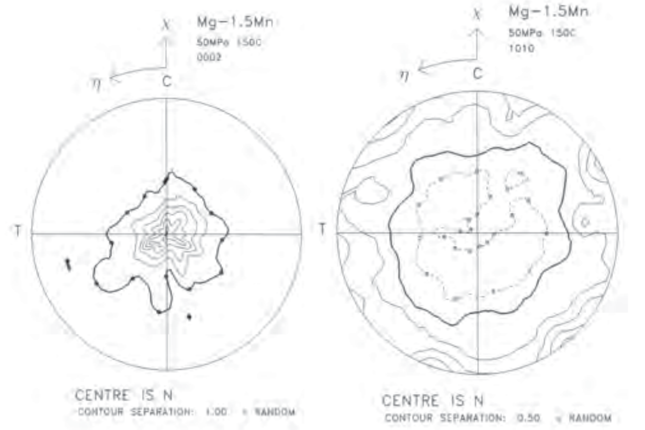

Fig 7. Basal (00.2) and Prismatic (10.0) pole figures of creep tested Mg-1.5Mn (50MPa 150°C 10hrs.)

Almost complete inhibition of rotation of the basal poles during the high-temperature creep testing (from 100oC to 175oC) indicates that α-Mn precipitates are effective in resisting the deformation (creep). On the other hand, rotation of the basal poles to become parallel to CA is obvious for the 50MPa-150°C sample (Fig.7). Similar rotation was earlier observed in pure Mg under similar conditions (Fig, 4). Apparently, at 50MPa stress Mn addition could not effectively reduce the magnitude of texture evolution, as the α-Mn precipitates were no longer efficient in resisting creep deformation.

Maximum texture intensity observed in various studied specimens is summarized in Table 1.

Conclusions

Texture studies on as-cast pure Mg indicated that preferred orientation of basal planes of the hcp crystals is almost parallel to the growth direction of columnar grains. Similar observations were also made for Mg-1.5%Mn as-cast alloy, though points of high intensity were also observed at ~90° from the compression axis.

Maximum intensity of texture in pure Mg dropped significantly after the compressive creep testing (15MPa, 175°C for 150hrs.).

No significant change in maximum intensity of texture was observed in 15MPa samples at different temperatures, indicating that α-Mn precipitates resisted enhanced creep deformation and, correspondingly, the texture evolution.

Higher-load creep tests (stress is above the yield strength - 50MPa, 150°C) resulted in rotation of the c-axis to become parallel to CA for the both materials tested.

Table 1. Summary of Results

Sample	Testing Conditions	Preferred texture orientation	
		Angle between the hcp c-axis and CA	Maximum Intensity
Pure Mg	Untested (As-cast)	~20°	12.5
Pure Mg	15MPa-100°C-150hrs.	~20°	12.5
Pure Mg	15MPa-100°C-150hrs.	≤20°	5
Pure Mg	15MPa-100°C-150hrs.	~20°	5
Pure Mg	50MPa-150°C-5hrs.	0	5
Mg-1.5%Mn	Untested (As-cast)	≤30° and ~90°	~13
Mg-1.5%Mn	15MPa-100°C-150hrs.	≤30° and ~80-90°	~13
Mg-1.5%Mn	15MPa-100°C-150hrs.	≤30° and ~70-80°	~10
Mg-1.5%Mn	15MPa-100°C-150hrs.	≤30° and ~90°	~12
Mg-1.5%Mn	15MPa-100°C-150hrs.	0	6

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