

On Precipitation Phenomena in Magnesium-Zinc Alloys

By

Yotaro MURAKAMI*, Osamu KAWANO* and Hideaki TAMURA*

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The ageing characteristics of magnesium-zinc alloys in the composition range from 3.2 to 19.0 wt.% zinc were studied at temperatures from 70° to 200°C mainly with X-ray diffraction methods and electron-microscopic observations with thin foils.

The G.P. zones were confirmed to exist on the $\{10\bar{1}1\}$ matrix planes. The transition phase on the $\{10\bar{1}0\}$ matrix planes is MgZn' indistinguishable from the hexagonal Laves phase MgZn_2 . The effects of plastic deformation were examined with direct observations by thin foils. The formation of G.P. zones on the $\{10\bar{1}1\}$ matrix plane was hindered by cold working after water quenching, while the rates of precipitation of the transition phase β' and equilibrium phase β were accelerated.

I. Introduction

Work on precipitation phenomena has been rather limited to solid solutions of cubic structures. Little attention was paid to hexagonal close-packed structures. In order to understand more fully the precipitation phenomena in solid solutions of hexagonal close-packed crystals, Mg-Zn alloys that show the most potent precipitation hardening effects among the magnesium-based binary systems were investigated as to their ageing characteristics at various temperatures after suitable solution-treatment, especially as to whether G.P. zones occur before the appearance of a transition phase and as to the structure of such transition phases. Recently, Clark and Rhines¹⁾ determined the phase equilibria of the Mg-Zn system as shown in Fig. 1. From this diagram, it may be seen that the β phase with a composition corresponding approximately to MgZn is in equilibrium with the magnesium solid solution. The studies by Sturkey and Clark²⁾ of the alloys in the composition range from 4 to 8% zinc have clarified the structure and orientation of the precipitates in this system. They have found the cause of hardening by a general continuous precipitation³⁾ and have confirmed that the initial precipitate is not the equilibrium phase MgZn , but rather a transition phase MgZn' , and that the structure of this precipitate is the same as that of the Laves phase MgZn_2 .⁴⁾ The diffraction technique showed that the precipitate

* Department of Metallurgy

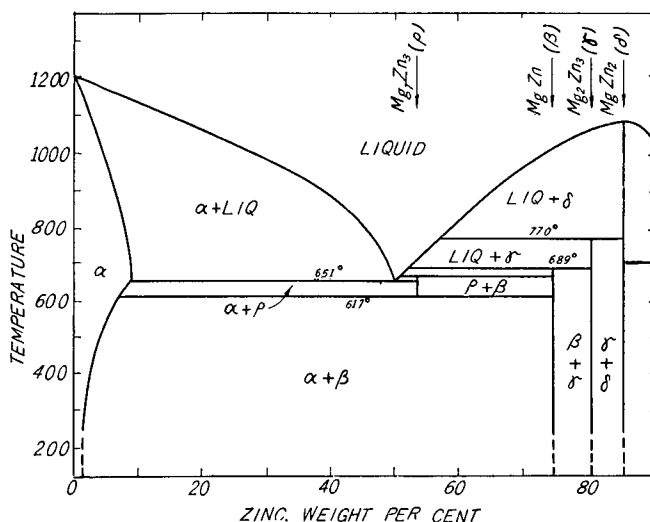


Fig. 1 The phase equilibria of the magnesium-zinc system (after Clark and Rhines)¹⁾.

is present in arrays of rods which are perpendicular to the basal planes of the solid solution. However, they did not extensively study whether or not G.P. zones occur before the appearance of the β' regions as in Al-Cu alloys. Therefore, it is the purpose of this research to offer experimental evidence to indicate whether the G.P. zones occur during low temperature ageing and to clarify the precipitation process during ageing in magnesium-rich magnesium-zinc alloys by means of the X-ray Laue method, Norelco geiger counter X-ray diffractometer, and measurements of micro-hardness. The actual changes produced by ageing and the effect of cold working on precipitation were also investigated by examining thin foils of these alloys with an electron-microscope.

II. Experimental Procedure

The magnesium-zinc alloys in these experiments were melted by using 99.99% magnesium in a graphite crucible lined with magnesia under blowing of argon gas in order to prevent oxidation and burning. After the alloying elements were added, they were cast into a chill mould.

The composition of the alloys and the solution treatment temperatures are shown in Table 1.

Table 1. Composition of the Mg-Zn alloys and the solution treatment temperatures.

Zinc wt. pct.	Solution treatment temperatures (°C)
3.2	330
5.6	330
12.4	310
19.0	310

The ingots were solution-treated for 24 hr at 310° or 330°C and cut into 1~2 mm in thickness for X-ray diffraction technique and measurements of micro-hardness and 0.7~1.2 mm in thickness for electron-micrographs. The large-grain specimens for the Laue method were prepared by the strain-anneal method.

Micro-Vickers hardness measurement :

The micro-vickers hardness was measured on the section of the sheet specimens by using a "Durimet" micro-vickers hardness tester under a load of 100 g. The hardness number was taken as the average of four fairly equal values.

X-ray Laue method :

The Laue method is generally recommended for a rapid survey of the ageing process. The large-grain specimens of Mg-5.6% Zn alloys were examined mainly with the [0001], [10 $\bar{1}$ 0] and [$\bar{1}$ 2 $\bar{1}$ 0] axes of the matrix parallel to the X-ray beam. Further, a series of Laue photographs was taken while rotating the crystals about a certain axis in order to observe scattering patterns. Satisfactory photographs were obtained by copper radiation with exposures of 30 min at 60 mA, 35 KVP using a collimeter 5.5 cm in length and 0.5 mm bore with a specimen to film distance of 3.5 cm.

Electron-micrographs :

The thin foil specimens were prepared by controlled electro-polishing and chemical polishing using the solution containing 33% HNO₃ and 67% ethyl alcohol. A small section was cut with scissors from the thinnest parts of the foil and mounted in a microscope specimen holder between two meshes bored at their centers. Examination was carried out in a Shimazu-SM-D4 type electron microscope operating at 75 KV.

Norelco geiger counter X-ray diffraction method :

The powder of Mg-Zn alloys was aged isothermally under an atmosphere of argon gas. The structure of precipitates, the eutectoid decomposition products and changes of lattice parameter were examined by Norelco geiger counter diffractometer.

III. Experimental Results

1. Hardness

Specimens of Mg-Zn alloys were solution-treated for 24 hr at 310° or 330°C in argon and then quenched into ice-water. The 3.2 and 5.6% zinc alloys were shown to consist entirely of magnesium solid solution, but the 12.4 and 19.0% zinc alloys contained globular precipitates corresponding to Mg₂Zn₃ along the grain boundaries. These solution-treated alloys were then aged at 70°, 100°, 150° and 200°C respectively.

Hardness measurements were made immediately after ageing with a micro-vickers hardness tester. The results are shown in Fig. 2. It is clear that the micro-hardness changes in isothermal ageing of Mg-Zn alloys at 70° and 100°C, differ from those at 150° and 200°C. From these hardness changes, G.P. zones may be supposed to exist in the isothermal ageing of Mg-Zn alloys at low temperatures.

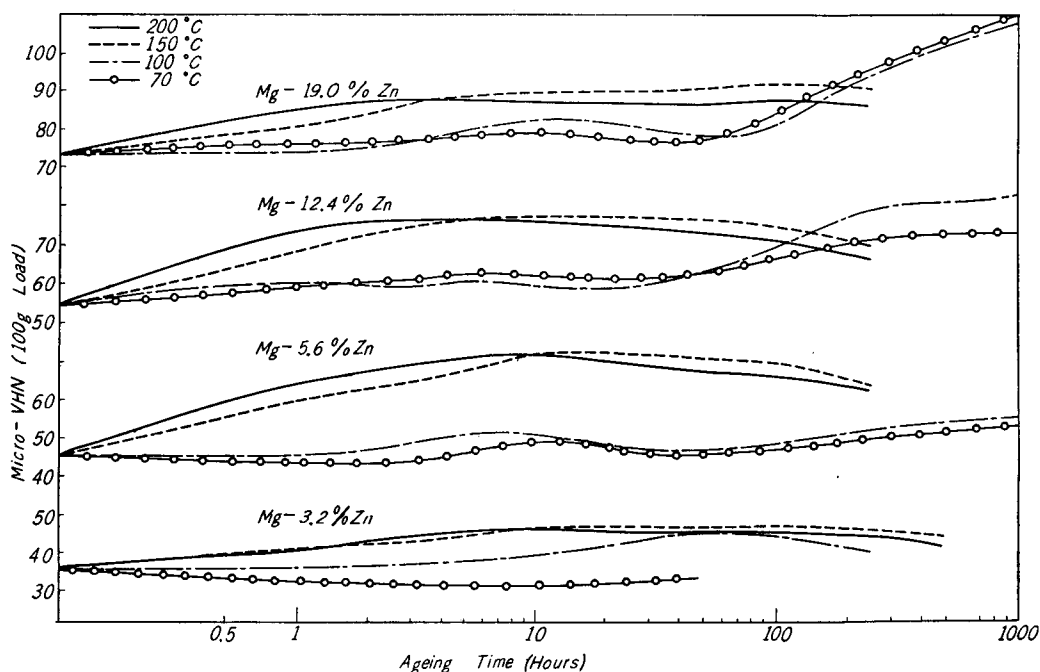


Fig. 2 Hardness changes of Mg-Zn alloys as a function of aging temperature.

2. Light-microscopic examinations

Photo. 1 to photo. 6 give the structural changes in isothermal ageing of the 5.6, 12.4 and 19.0% zinc alloys at 70° and 150°C. After 2 days ageing at 70°C, precipitates were observed in Mg-5.6% Zn alloys within the grains and along grain boundaries as shown in photo 1. As ageing proceeded, the grain boundaries were delineated by a clear area and a fine agglomerated precipitate. At higher zinc concentrations as shown in photo 3 to photo 6, the eutectoid decomposition products were observed to remain after solution treatment. No discontinuous grain-boundary precipitate in the Geisler sense could be detected in any case.

3. Norelco geiger counter X-ray diffractometer.

Fig. 3 shows the distribution condition of X-ray powder patterns in relation to lattice spacing "d". The longitudinal lines correspond to the diffraction lines

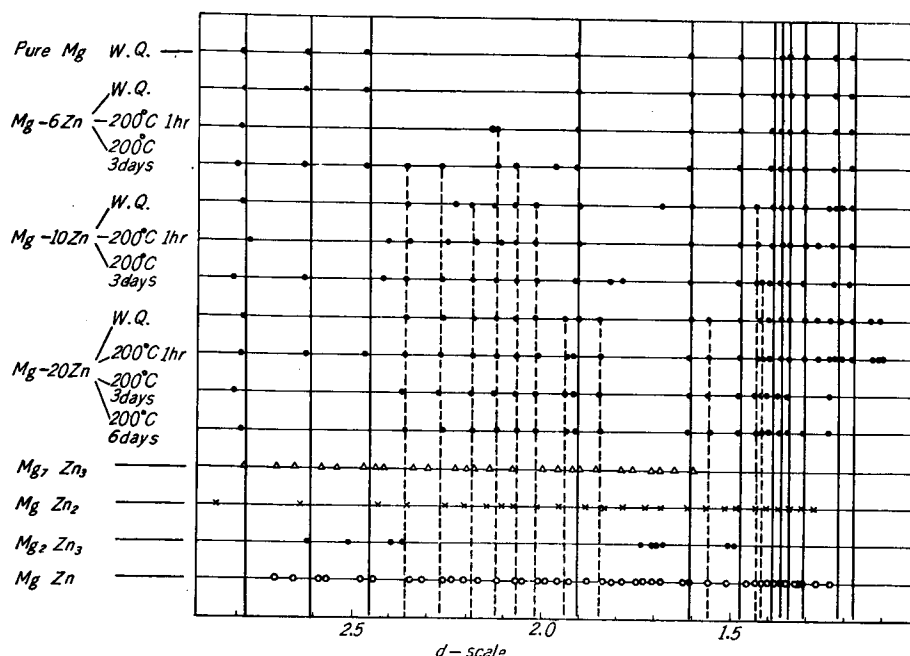
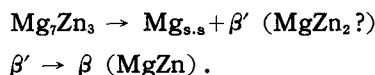


Fig. 3 The phase sequence of X-ray powder pattern in relation to "d".

of pure magnesium being based upon ASTM card. As for the eutectoid decomposition products, the diffraction line of Mg_7Zn_3 is faintly observed in the pattern from the 12.4 or 19.0% zinc alloys immediately after water quenching. In this condition, the diffraction lines of MgZn and MgZn_2 become visible in addition to these lines. This is in accordance with the results of the studies by Sturkey and Clark²⁾ who showed that the reaction proceeds in two steps which correspond to



As to the precipitates, the diffraction lines of MgZn or MgZn_2 are distinctly observed in the pattern from Mg-5.6% Zn specimens aged for 3 days at 200°C. According to studies by Sturkey and Clark, the initial precipitate is not the equilibrium phase MgZn , but rather a transition phase MgZn' , as rod-like ordered regions perpendicular to the principal slip plane of the magnesium matrix. By the time maximum hardness has been attained, these rod-like regions have begun to develop some of the three-dimensional structure characteristics of a transition phase indistinguishable from MgZn_2 , although the equilibrium phase should have a different structure and composition near MgZn .

4. Laue methods.

Streaks were observed on the Laue patterns of Mg-5.6% Zn single crystal aged for 21 days at 70°C as shown in photos 7 to 9, although these additional streaks were not observed in the specimens aged for 2 to 8 days at the same annealing temperature. In order to obtain further X-ray evidence, a series of Laue photographs was taken while rotating the crystals about some axes. Photos 10 to 12 show some of the examples. The streaks on the Laue photographs were plotted on the stereographic projection as shown in Fig. 4. It seems to be clear that these streaks are due to plate-like G.P. zones on $\{10\bar{1}1\}_{\text{Mg}}$ matrix.

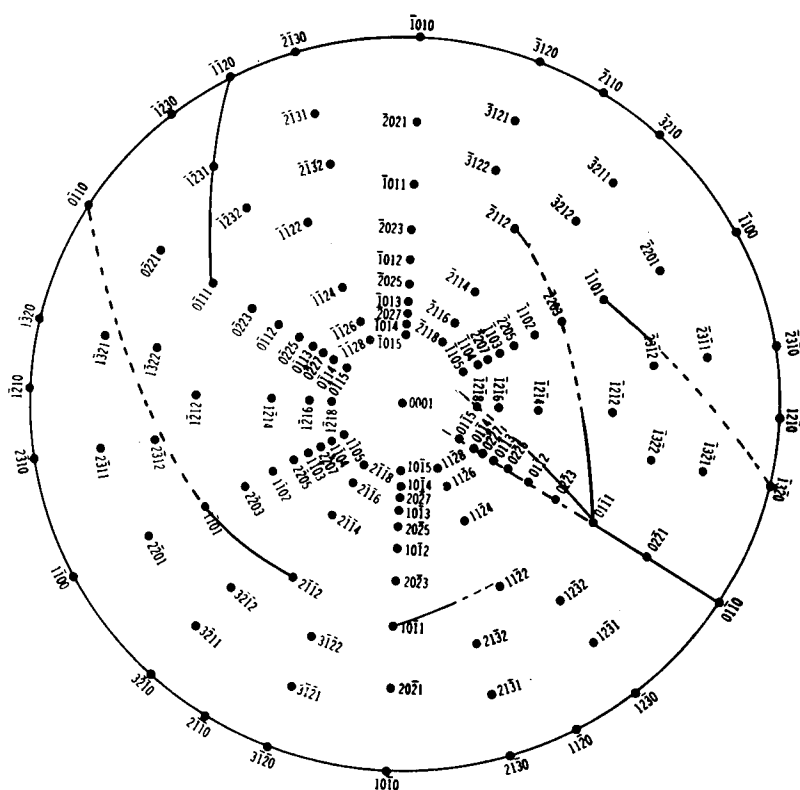


Fig. 4 Stereographic projection of Laue photographs of the specimens aged for 21 days at 70°C.

When ageing at 150°C, streaks different from those aged at 70°C are observed to occur on the Laue patterns. Photos 13 to 15 show the Laue photographs of Mg-5.6% Zn alloys taken by beams perpendicular to (0001) , $(10\bar{1}0)$ and $(12\bar{1}0)$ respectively. Furthermore, these streaks were examined in detail by rotating the crystals about some axes.

Some examples are shown in photos 16 to 18. For example, in photo 15, the incident X-ray beam was perpendicular to $\{1\bar{2}10\}$ plane of the matrix, and in photo 18 the crystal was inclined at 17° around $[10\bar{1}0]$ axis. These results were analysed stereographically as shown in Fig. 5. It was confirmed from these analyses that these streaks were due to a plate-like magnesium-zinc transition phase β' on $\{10\bar{1}0\}_{\text{Mg}}$ matrix.

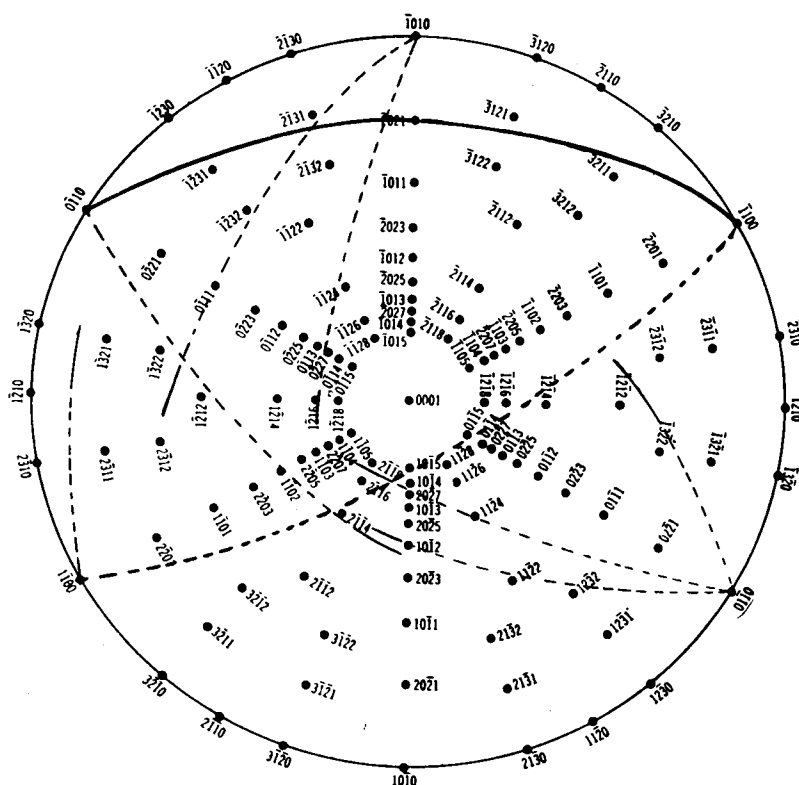


Fig. 5 Stereographic projection of Laue photographs of the specimens aged for 58 hr at 150°C .

5. Electron-microscopic studies.

Photos 19 and 20 show annealing twin bands in the electron micrographs of thin foils of Mg-5.6% Zn water-quenched from 330°C . In this photograph, dislocation lines along the twin bands are most likely observed.

In isothermal ageing for 6 hr at 70°C , electron micrographs in undeformed Mg-5.6% Zn alloy showed the small circular faint spots due to G.P. zones and the helical dislocations as in Al-Cu alloys⁵, but in 20% rolled materials these spots were not found, as shown in photos 21 and 22. As ageing progressed, many large circular black spots due to G.P. zones were observed within the grains or

along the grain boundary in undeformed alloys as shown in photo 23. Photo 24 illustrates a few small circular black spots due to G.P. zones in Mg-5.6% Zn alloys rolled by 20% and then aged for 2 days at 70°C.

The effect of plastic deformation on the Mg-5.6% Zn alloys at a lower ageing temperature such as 70°C could be clearly recognized by a comparison of the transmission electron-micrographs of the undeformed and deformed specimens as shown in photos 21 to 24. It is probable that the formation of G.P. zones in Mg-5.6% Zn alloys is hindered by the cold rolling after quenching.

Photos 25 to 32 are the electron-micrographs of the thin foils prepared from Mg-5.6% Zn alloys aged for various periods at 150°C in the undeformed and 20 or 40% rolled conditions. Although every photograph showed both β' and β precipitates, it seems to be certain that plastic deformation after water quenching increases the size and the number of precipitates. After 30 min ageing at 150°C, the compression bands⁶⁾ by a complex double-twinning mechanism (a $\{10\bar{1}1\}$ twin forms first and the twinned material twins again on a $\{10\bar{1}2\}$ plane) were found clearly in the 20% rolled specimens. In addition to this, the large circular black spots due to β or β' precipitates were observed on the twin bands as shown in photo 26. In undeformed specimens aged for 1 day at 150°C as shown in photo 29, β' precipitates were found along the grain boundaries or within the grains. This phenomenon is clearly in accordance with the results of the X-ray studies. The formation of β' or β precipitates may be accelerated in deformed specimen as shown in photo 30. Photos 31 and 32 are the electron-micrographs of thin foils of both undeformed and 40% rolled Mg-5.6% Zn alloys aged for 13 days at 150°C. In photo 31, the β' as plate-like ordered regions perpendicular to the principal slip plane of the magnesium matrix are clearly observed. In photo 32, the β' and β precipitates were found to occur in the shape of large circular black spots. Photos 33 to 38 show the structures of the undeformed and 20 or 40% rolled Mg-5.6% Zn alloys aged for various hours at 200°C. As shown in photos 33 and 34, plastic deformation increased the size and the number of the precipitates. This was similar to that in ageing at 150°C. After ageing at 200°C for 3 hr, the electron-micrograph of undeformed Mg-5.6% Zn alloy showed β' precipitates in the shape of long and thin rods. In this condition, the crystal was near its maximum hardness as shown in Fig. 2. As ageing progressed, these rod-like precipitates began to grow to globular precipitates as shown in photo 37. Photo 38 illustrates numerous globular precipitates in 40% rolled alloy aged for 4 days at 200°C. It may be concluded that at higher ageing temperatures such as 150° and 200°C the formation of β' or β precipitates in Mg-5.6% Zn alloys is accelerated by deformation. Photos 39 to 46 are electron-micrographs of thin foils of

Mg-3.2% Zn alloys. Photo 39 shows a structure of an undeformed specimen after being aged for 40 days at room temperature. Dislocation lines were observed to pile up parallel to the grain boundaries.

Photo 40 shows the situation when the whole area of the specimen was recrystallized in 60% rolled materials aged at 70°C for 5 days, and the precipitates are shown to be along the sub-boundaries.

Photo 41 illustrates the precipitates along grain boundaries in undeformed specimens aged for 3 days at 100°C. In specimens aged for 40 days at 100°C, the piled-up dislocations and precipitates are found, and the precipitates have no relationship with the dislocation lines.

After ageing for 3 hr at 150°C, the small circular faint spots, indicated by arrows in Photo 43, were found to be along the grain boundary. They seemed to correspond to β' precipitates.

Photos 44 and 45 are the electron-micrographs in 30% rolled specimens aged for 1 hr or 1 day at 200°C. Photo 44 shows that the precipitates occur not only along the grain boundaries but also within the grains. As ageing progressed, the precipitates spread widely as shown in photo 45.

IV. Discussion

Laue patterns after ageing for 21 days at 70°C were found to be accompanied with streaks, although these streaks could not be observed after ageing for 2 to 8 days at 70°C. According to the stereographic projection, these streaks are due to the plate-like G.P. zones on $\{10\bar{1}1\}_{\text{Mg}}$ matrix.

Guinier⁷⁾ studied the shape of G.P. zones in various alloys by the X-ray small angle scattering technique and concluded that in cases where the size difference between solute and solvent atoms is more than 10%, the G.P. zones are plate-like, and where it is less than 10%, the shape is spherical. In the present studies, the atomic size of zinc is about 14% smaller than that of magnesium, so the G.P. zones were assumed to be plate-like.

After ageing at 150°C, different streaks were observed in the Laue patterns of specimens aged for 21 days at 70°C. These streaks were shown to be due to plate-like β' precipitates on $\{10\bar{1}0\}_{\text{Mg}}$ matrix by stereographic analysis and to be associated with the general precipitation of a magnesium-zinc transition phase β' as rod-like ordered regions perpendicular to the principal slip plane of the magnesium matrix.

By structural analysis using a Norelco geiger X-ray diffractometer, it was confirmed that the initial precipitate is not the equilibrium phase MgZn, but rather a transition phase MgZn'. The structure of this precipitate was the same

as that of Laves phase MgZn_2 . The eutectoid decomposition product was Mg_7Zn_3 and underwent a transition to MgZn_2 and MgZn .

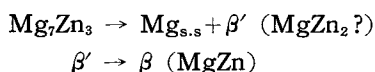
From electron microscopic studies with thin foils, it seems that in deformed Mg-Zn alloys the formation of G.P. zones are hindered, although the rate of precipitation of intermediate β' phase and equilibrium β phase are accelerated similarly in Al-4% Cu alloys.^{8,9)}

Furthermore, new grains were observed similar to those in Al-Zn-Mg alloys¹⁰⁾ immediately after cold rolling in large amounts. When the matrix was recrystallized, the precipitates were found to grow.

V. Conclusion

The precipitation phenomena during ageing of Mg-Zn alloys were studied mainly with X-ray Laue method, Norelco geiger counter diffraction method and electron microscopic observations with thin foils. It may be concluded:

- (1) The ageing process at lower temperatures such as 70° or 100°C is quite different from that at higher temperatures such as 150° or 200°C.
- (2) In the Laue patterns, the streaks due to plate-like G.P. zones on $\{10\bar{1}1\}_{\text{Mg}}$ matrix were observed in the specimens aged at 70°C. On the other hand, the streaks due to plate-like β' precipitates on $\{10\bar{1}0\}_{\text{Mg}}$ matrix were found clearly in the ageing at 150°C.
- (3) As ageing progressed at higher ageing temperatures, transition phases β' in the shape of long, thin rods grew up to plate-like or globular precipitates. Furthermore, at higher ageing temperatures the precipitate was not the equilibrium phase MgZn , but rather a transition phase MgZn' ($\text{MgZn}_2?$). The reaction of the eutectoid decomposition of Mg_7Zn_3 seemed to proceed in two steps:



These results may be in accordance with studies by Sturkey and Clark.

- (4) In Mg-Zn alloys the formation of G.P. zones on the $\{10\bar{1}1\}$ matrix plane was hindered by plastic deformation after water quenching, while the rate of precipitation of the transition phase β' and the equilibrium phase β was accelerated.

Acknowledgement

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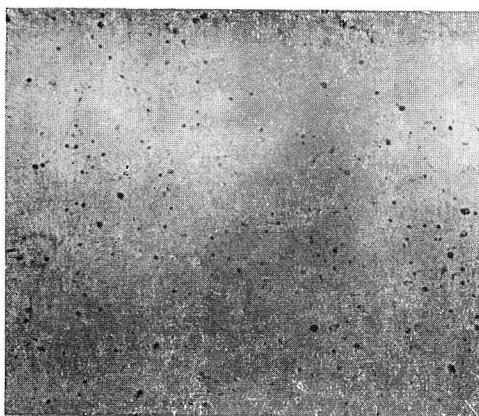


Photo. 1. Mg-5.6% Zn alloy, W.Q., aged for 2 days at 70°C. ($\times 1000$)

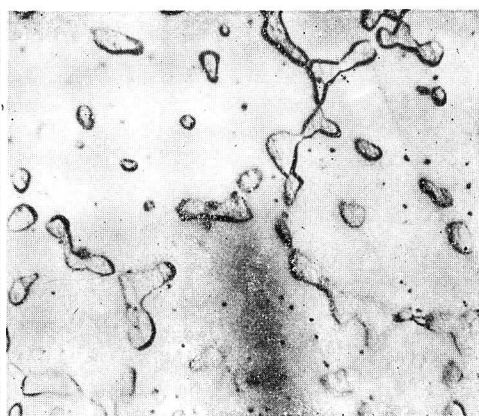


Photo. 4. Mg-19.0% Zn alloy, W.Q., aged for 6 hr at 70°C. ($\times 1000$)

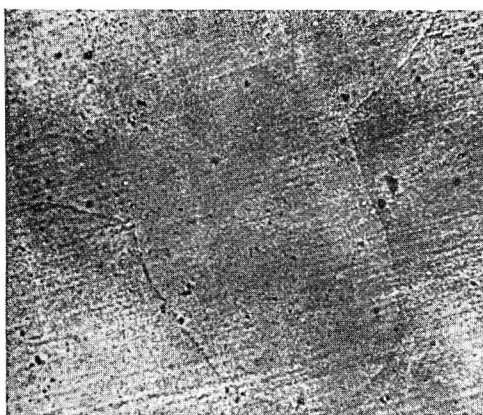


Photo. 2. Mg-5.6% Zn alloy, W.Q., aged for 10 days at 70°C. ($\times 1000$)

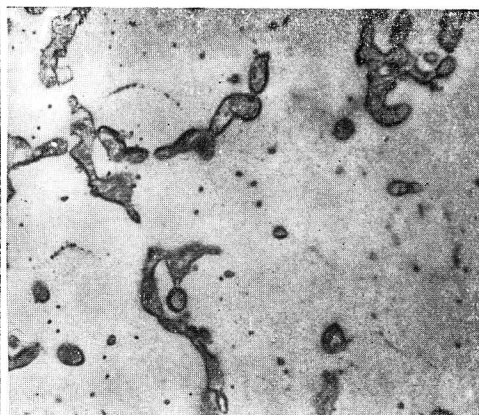


Photo. 5. Mg-19.0% Zn alloy, W.Q., aged for 2 days at 70°C. ($\times 1000$)



Photo. 3. Mg-12.4% Zn alloy, W.Q., aged for 4.5 hr at 150°C. ($\times 1000$)

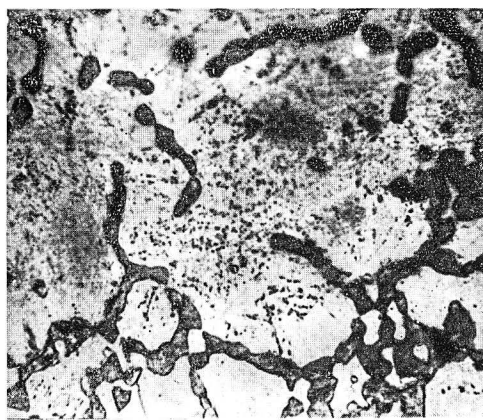


Photo. 6. Mg-19.0% Zn alloy, W.Q., aged for 4.5 hr at 150°C. ($\times 1000$)

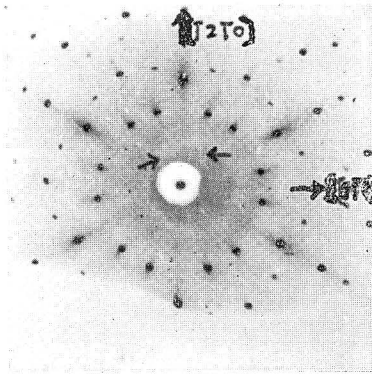


Photo. 7. Mg-5.6%Zn alloy, W.Q., aged for 21 days at 70°C.
Beam $\perp (0001)$

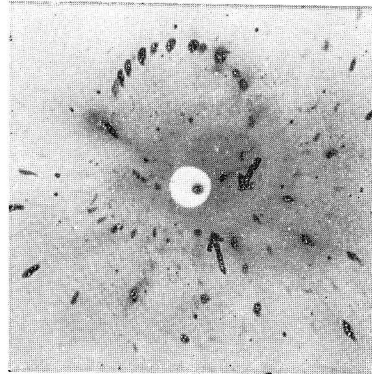


Photo. 10. Mg-5.6%Zn alloy, W.Q., aged for 21 days at 70°C. The crystal being rotated about $[10\bar{1}0]$, angle between incident beam and $[0001]$ axis: 15°

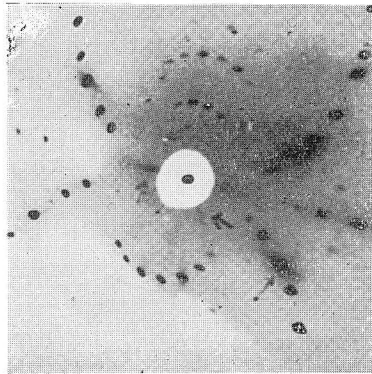


Photo. 8. Mg-5.6%Zn alloy, W.Q., aged for 21 days at 70°C.
Beam $\perp \{10\bar{1}0\}$

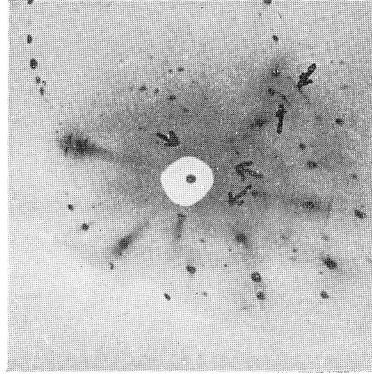


Photo. 11. Mg-5.6%Zn alloy, W.Q., aged for 21 days at 70°C. The crystal being rotated about $[10\bar{1}0]$, angle between incident beam and $[\bar{1}210]$ axis: 15°

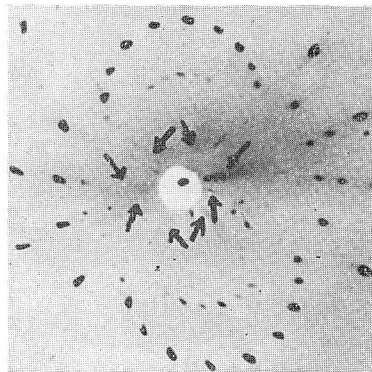


Photo. 9. Mg-5.6%Zn alloy, W.Q., aged for 21 days at 70°C.
Beam $\perp \{\bar{1}210\}$

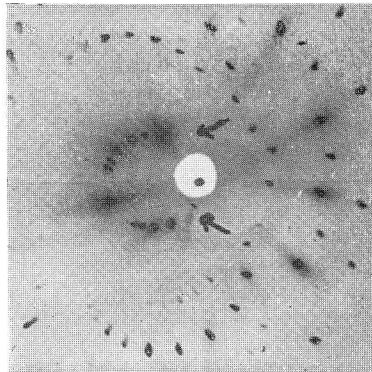


Photo. 12. Mg-5.6%Zn alloy, W.Q., aged for 21 days at 70°C. The crystal being rotated about $[\bar{1}210]$, angle between incident beam and $[10\bar{1}0]$ axis: 15°

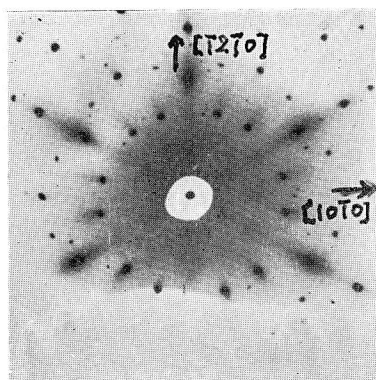


Photo. 13. Mg-5.6%Zn alloy, W.Q., aged for 58 hr at 150°C.
Beam $\perp (0001)$

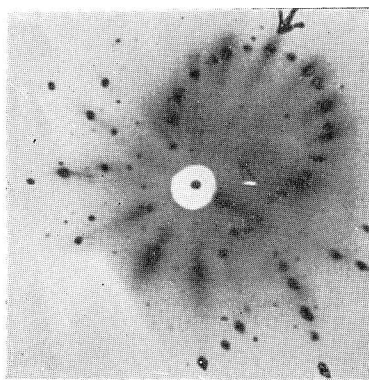


Photo. 16. Mg-5.6%Zn alloy, W.Q., aged for 58 hr at 150°C. The crystal being rotated about $[10\bar{1}0]$, angle between incident beam and $[0001]$ axis: 17°

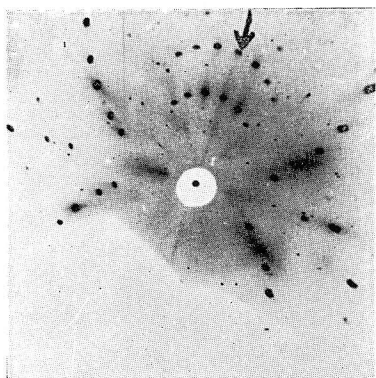


Photo. 14. Mg-5.6%Zn alloy, W.Q., aged for 58 hr at 150°C.
Beam $\perp \{10\bar{1}0\}$

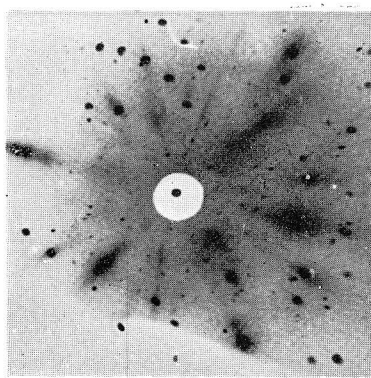


Photo. 17. Mg-5.6%Zn alloy, W.Q., aged for 58 hr at 150°C. The crystal being rotated about $[10\bar{1}0]$, angle between incident beam and $[\bar{1}210]$ axis: 17°

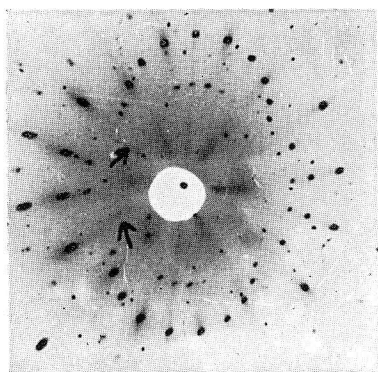


Photo. 15. Mg-5.6%Zn alloy, W.Q., aged for 58 hr at 150°C.
Beam $\perp \{\bar{1}2\bar{1}0\}$

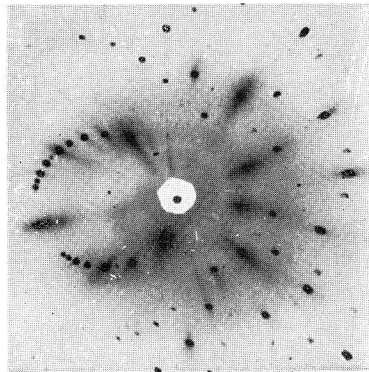


Photo. 18. Mg-5.6%Zn alloy, W.Q., aged for 58 hr at 150°C. The crystal being rotated about $[\bar{1}2\bar{1}0]$, angle between incident beam and $[10\bar{1}0]$ axis: 17°

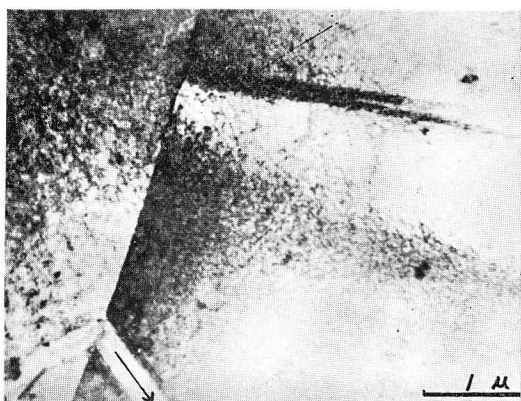


Photo. 19. Mg-5.6%Zn alloy, 330°C., W.Q.
($\times 18000$)

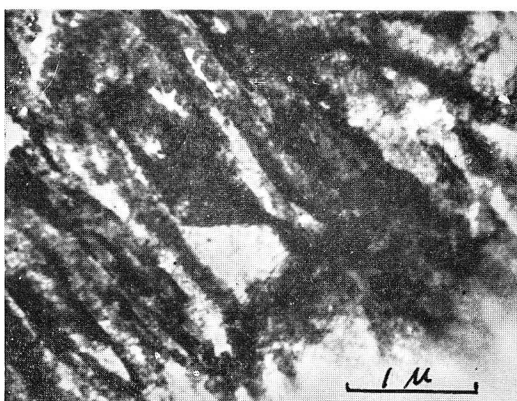


Photo. 22. Mg-5.6%Zn alloy, W.Q., 20% rolled,
aged for 6 hr at 70°C. ($\times 17000$)

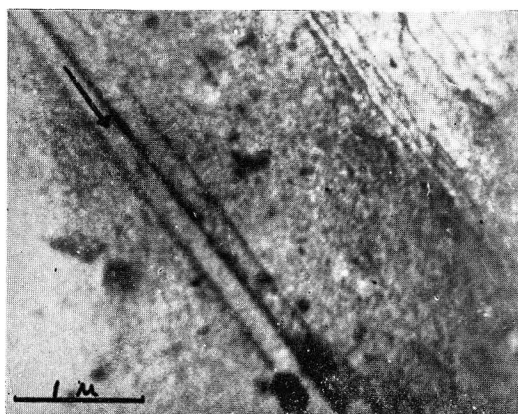


Photo. 20. Mg-5.6%Zn alloy, 330°C., W.Q.,
($\times 17000$)

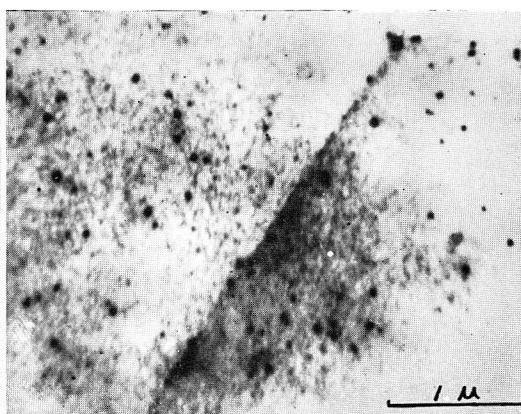


Photo. 23. Mg-5.6%Zn alloy, W.Q., aged for 2
days at 70°C. ($\times 18000$)

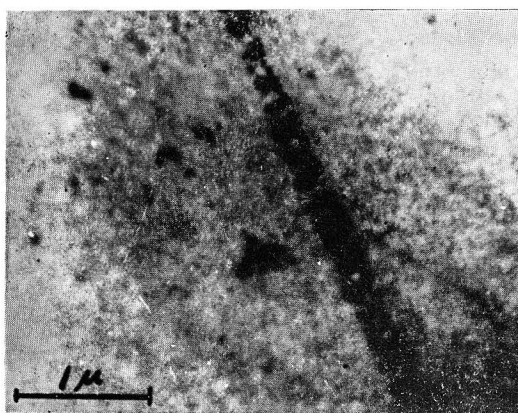


Photo. 21. Mg-5.6%Zn alloy, W.Q., aged for 6
hr at 70°C. ($\times 18000$)

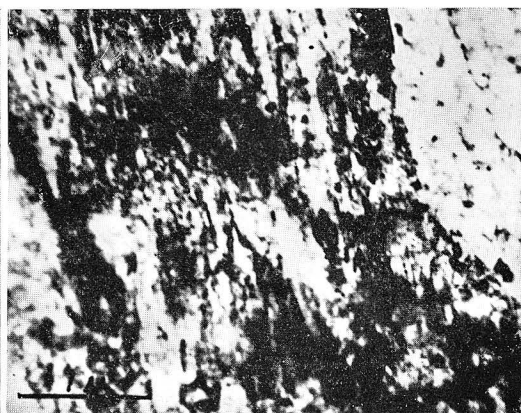


Photo. 24. Mg-5.6%Zn alloy, W.Q., 20% rolled,
aged for 2 days at 70°C. ($\times 18000$)

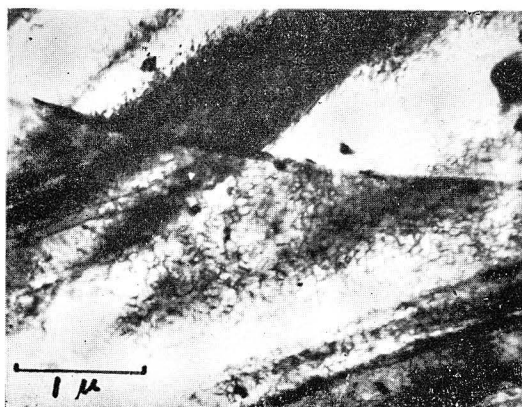


Photo. 25. Mg-5.6%Zn alloy, W.Q., aged for 30 min at 150°C. ($\times 17000$)

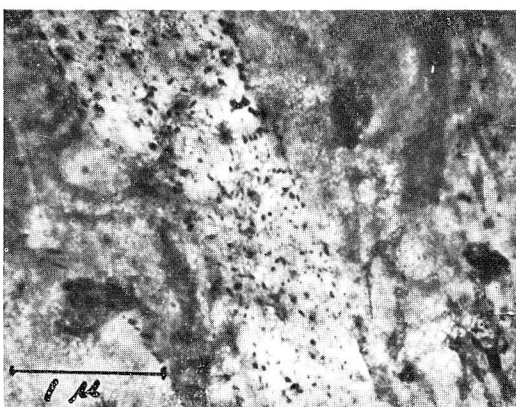


Photo. 28. Mg-5.6%Zn alloy, W.Q., 20% rolled, aged for 3 hr at 150°C. ($\times 20000$)

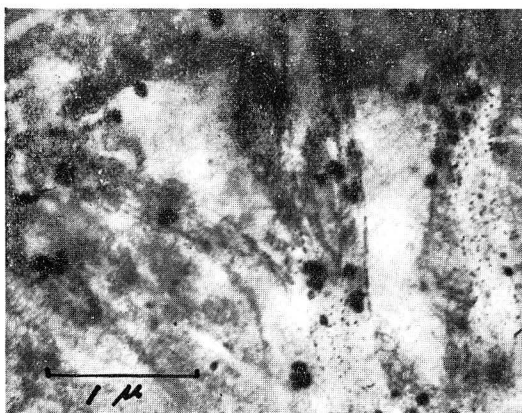


Photo. 26. Mg-5.6%Zn alloy, W.Q., 20% rolled, aged for 30 min at 150°C. ($\times 20000$)

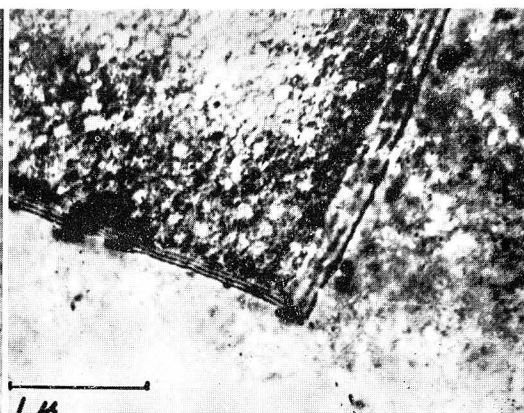


Photo. 29. Mg-5.6%Zn alloy, W.Q., aged for 1 day at 150°C. ($\times 18000$)

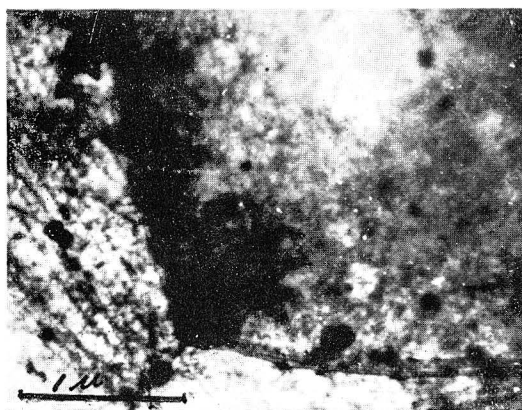


Photo. 27. Mg-5.6%Zn alloy, W.Q., aged for 3 hr at 150°C. ($\times 22000$)

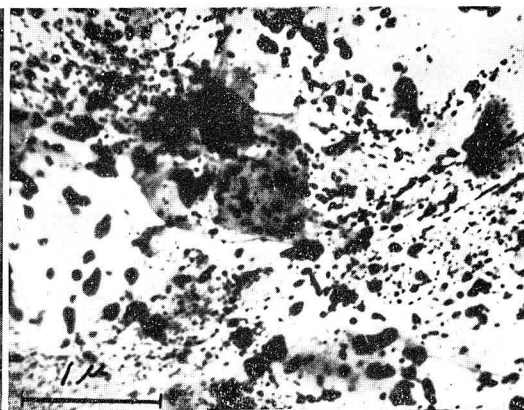


Photo. 30. Mg-5.6%Zn alloy, W.Q., 40% rolled, aged for 1 day at 150°C. ($\times 18000$)

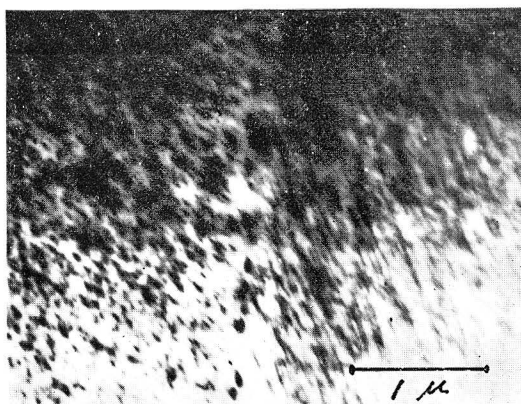


Photo. 31. Mg-5.6%Zn alloy, W.Q., aged for 13 days at 150°C. ($\times 18000$)

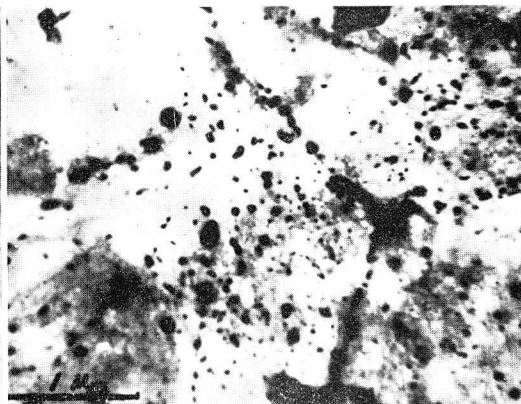


Photo. 34. Mg-5.6%Zn alloy, W.Q., 20% rolled, aged for 30 min at 200°C. ($\times 18000$)



Photo. 32. Mg-5.6%Zn alloy, W.Q., 40% rolled, aged for 13 days at 150°C. ($\times 20000$)

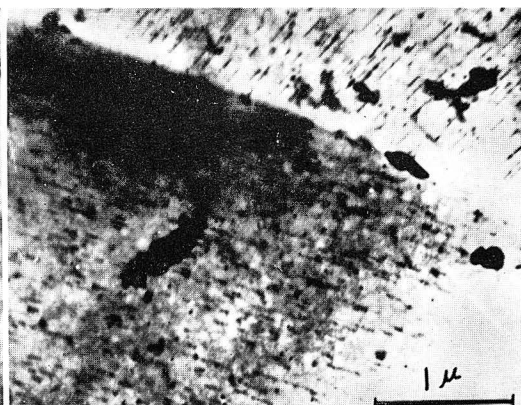


Photo. 35. Mg-5.6%Zn alloy, W.Q., aged for 3 hr at 200°C. ($\times 18000$)

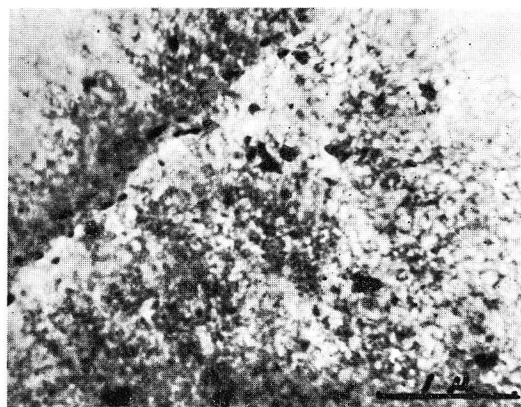


Photo. 33. Mg-5.6%Zn alloy, W.Q., aged for 30 min at 200°C. ($\times 18000$)

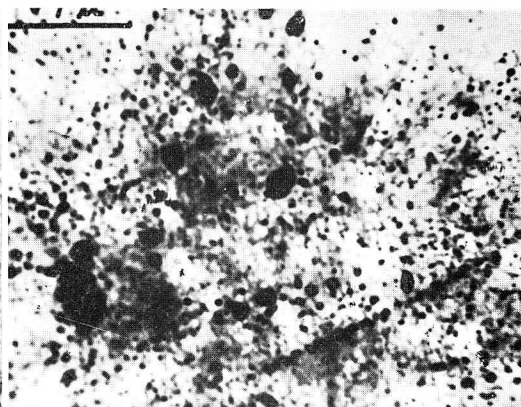


Photo. 36. Mg-5.6%Zn alloy, W.Q., 20% rolled, aged for 3 hr at 200°C. ($\times 18000$)

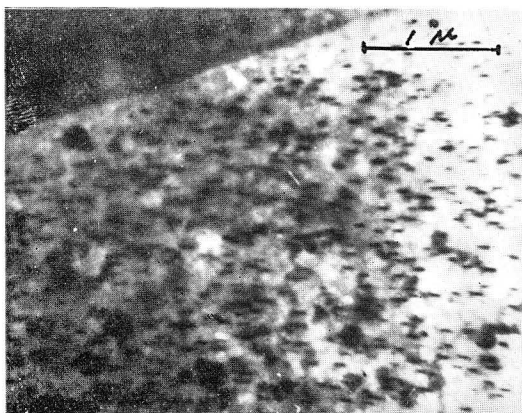


Photo. 37. Mg-5.6%Zn alloy, W.Q., aged for 4 days at 200°C. ($\times 18000$)

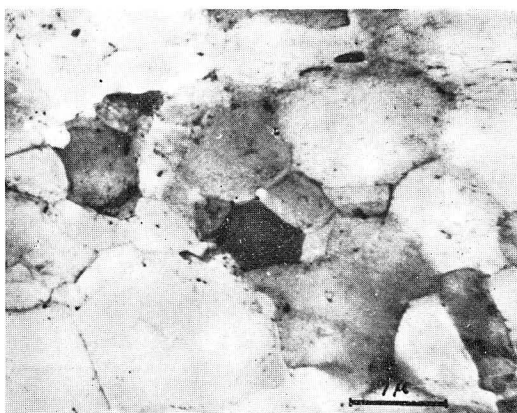


Photo. 40. Mg-3.2%Zn alloy, W.Q., 60% rolled, aged for 5 days at 70°C. ($\times 13000$)

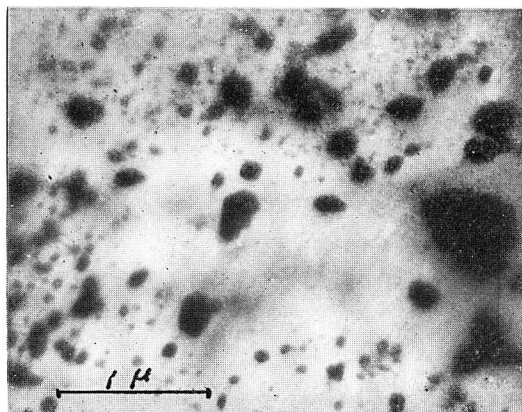


Photo. 38. Mg-5.6%Zn alloy, W.Q., 40% rolled, aged for 4 days at 200°C. ($\times 20000$)

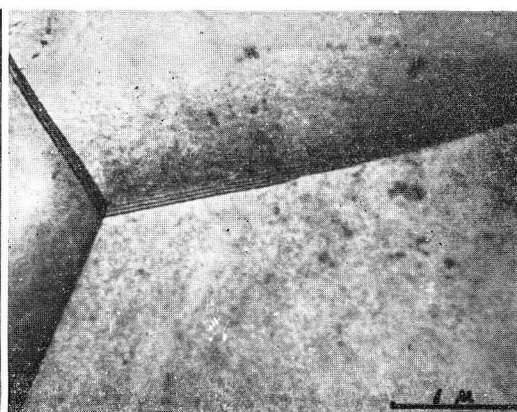


Photo. 41. Mg-3.2%Zn alloy, W.Q., aged for 3 days at 100°C. ($\times 18000$)

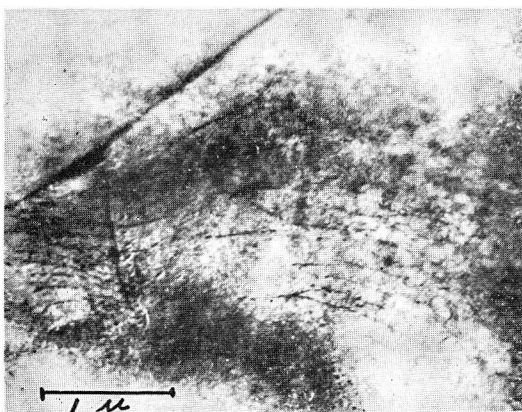


Photo. 39. Mg-3.2%Zn alloy, W.Q., aged for 40 days at room temp. ($\times 17000$)

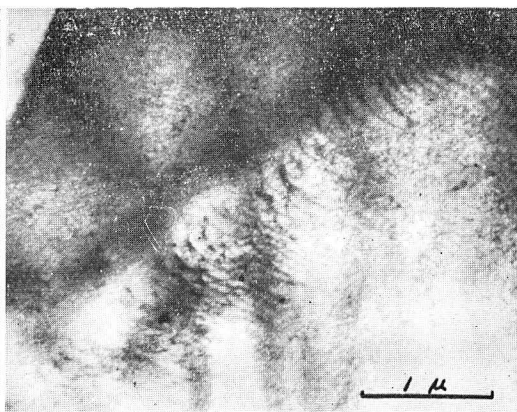


Photo. 42. Mg-3.2%Zn alloy, W.Q., aged for 40 days at 100°C. ($\times 17000$)

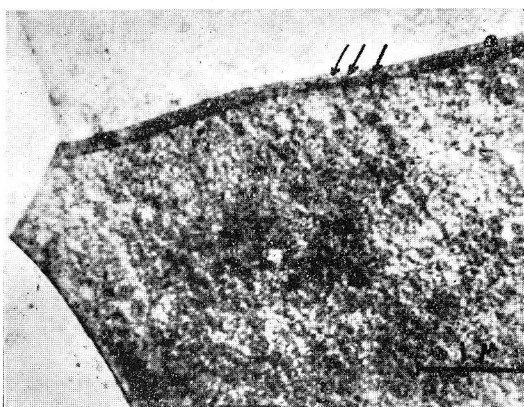


Photo. 43. Mg-3.2%Zn, W.Q., aged for 3 hr at 150°C. ($\times 17000$)

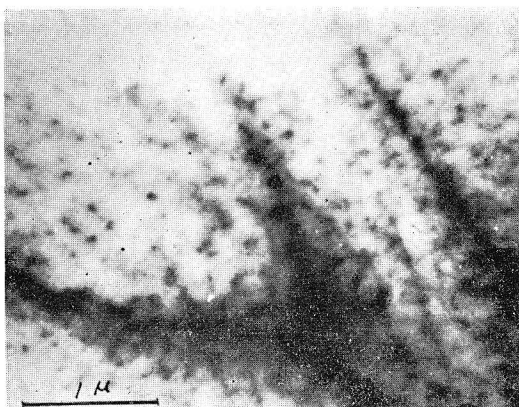


Photo. 44. Mg-3.2%Zn alloy, W.Q., 30% rolled, for 1 hr at 200°C. ($\times 18000$)



Photo. 45. Mg-3.2%Zn alloy, W.Q., 30% rolled, aged for 1 day at 200°C. ($\times 7000$)