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Ageing Properties of Zinc Alloys

F. Goodwin
International Zinc Association

W. Leis & L. Kallien
Aalen University of Applied Sciences

ABSTRACT

Natural ageing of zinc diecasting alloys results in changes in their mechanical properties. However, artificial ageing treatments can stabilize these properties. The relationship between casting wall thickness, alloy copper content and resulting properties has been statistically analyzed for different ageing treatments and related to microstructural changes.

INTRODUCTION

The mechanical properties of zinc alloys can change over time because of ageing effects. Zinc alloys age at room temperature because of their low melting point that permits a relatively high amount of diffusion at room temperature. Natural ageing is typically managed by using a relatively short artificial ageing heat treatment.

EXPERIMENTAL PROCEDURE

To investigate ageing effects, 50 x 150 mm die cast coupons of zinc alloys 2,3 and 5 with compositions confirming to EN12844 were cast with thicknesses of 0.8, 1.5 and 3 mm using a Frech Type DAW 80 hot chamber die casting machine. Die temperature and injection velocity were also varied at three levels. Die temperatures were 120, 160 and 200°C. Details of injection velocity and corresponding fill times for each of the three thicknesses are shown in Table 1.

Table 1. Injection velocities at the gate to the die cavity VG and fill times for the test specimens

	filling time in ms		
thickness in mm	V_G = 25 m/s	V_G = 40 m/s	V_G = 55 m/s
0,8	5,9	3,7	2,7

1,5	11,1	6,9	5,0
3,0	22,1	13,7	10,1

After casting, all samples were stored at -20°C until individual samples were removed for testing. Tensile test specimens were machined according to DIN 50125. The influence of the natural ageing was measured after 3 and 6 weeks, 3 and 6 months and after 1 year. After 2 years a final measurement will be made. Artificial ageing was carried out by heat treating samples for 24h at 65°C, 85°C and 105°C. Tensile yield and ultimate tensile strengths, elongation and Young's modulus were evaluated at 23°C (room temperature or RT), -35°C and +85°C as these are the temperatures of concern for automotive applications. Additionally, secondary creep rates were evaluated at RT and 85°C, and fatigue, density and hardness properties at RT. Only the ultimate tensile strength and elongation results will be discussed in this paper.

To minimize the number of tests, a designed experiment was developed using Design-Expert7 by Stat-Ease. This specified 27 conditions including 3 levels of wall thickness, injection velocity and die temperature, together with the 3 temperatures of tensile testing, to represent all effects using statistical analysis. Five replicates were tested for each tensile condition.

The tensile strength results were quite stable, with all standard deviations in the range of 5%. Because of porosity, elongations varied between 2 and 12%. The statistical analysis revealed a linear effect of the casting production variables on tensile strength. Tensile properties were most sensitive to changes in wall thickness, with the highest strengths found with the thinnest sections, followed by die temperature, where the lowest die temperature gave the highest strengths, and then injection velocity, where the highest injection velocities gave moderately higher strengths.

The effect of test temperature and wall thickness on the tensile strength of Alloy 5 for five times of natural ageing, together with as-cast values is shown in Figure 1.

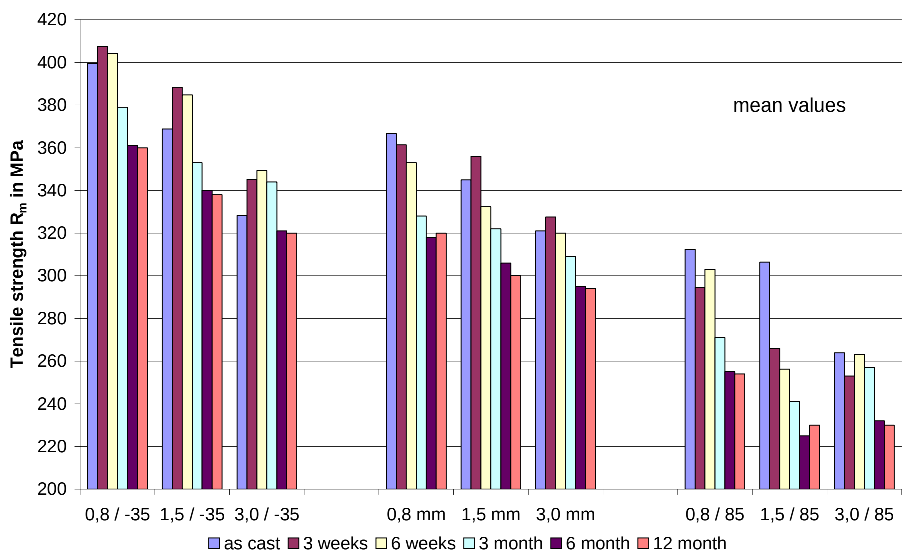

Figure 1. Tensile strengths of Alloy 5 grouped by test temperature (-35, 23 and 85°C), by wall thickness, and for different natural ageing times.

When the RT tensile strength results for the Alloy 5 RT samples aged up to 1 year are plotted, a continuous decrease in tensile strength for the 0.8 and 1.5 mm thick samples is seen, as shown in Figure 2. For the 3.0 mm thickness, tensile strength initially increased and then decreased in a manner similar to the thinner sections.

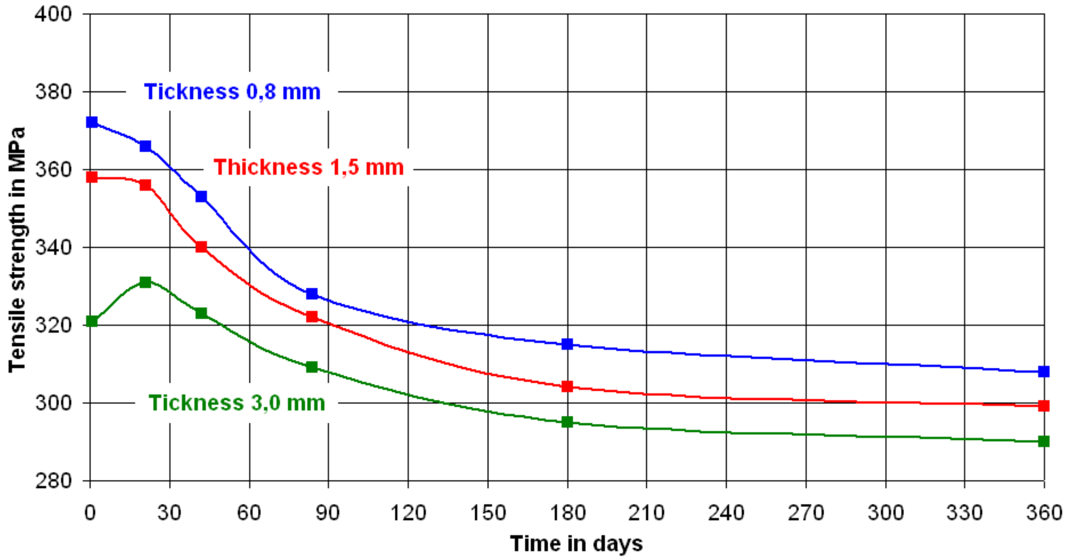

Figure 2. Effect of RT ageing on RT ultimate tensile strength of Alloy 5 as a function of ageing time and wall thickness

The results of artificial ageing for 1 hour at 65,85 or 105°C for 3 the three testing temperatures of -35, 23 and 85°C and three wall thicknesses is shown in Figure 3. Again, a continuous decrease in strength can be seen with increased ageing temperature and wall thickness, except for the 3 mm specimen between the as-cast and 65°C/1h aged condition, similar to the earliest stage of natural ageing of this alloy with 3 mm thickness.

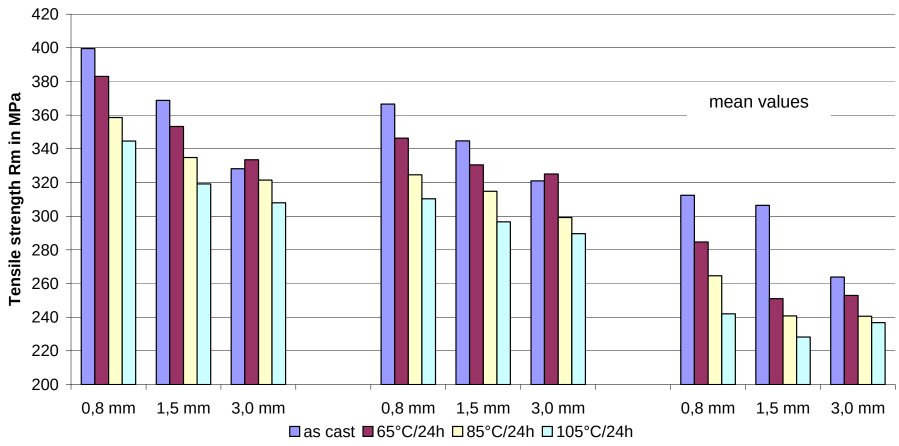

Figure 3. Alloy 5 tensile strength results, grouped by test temperature (-35, 23 and 85°C), by wall thickness, and for different 1 hour artificial ageing treatments at 65, 85 or 105°C.

When the RT test values of the artificially aged specimens of Figure 3 are plotted onto the results of Figure 2, the equivalent natural ageing times required to give the artificial ageing results are obtained, Figure 4. These are not constant with wall thickness, especially at the higher artificial ageing temperatures, indicating a microstructural effect on the ageing process.

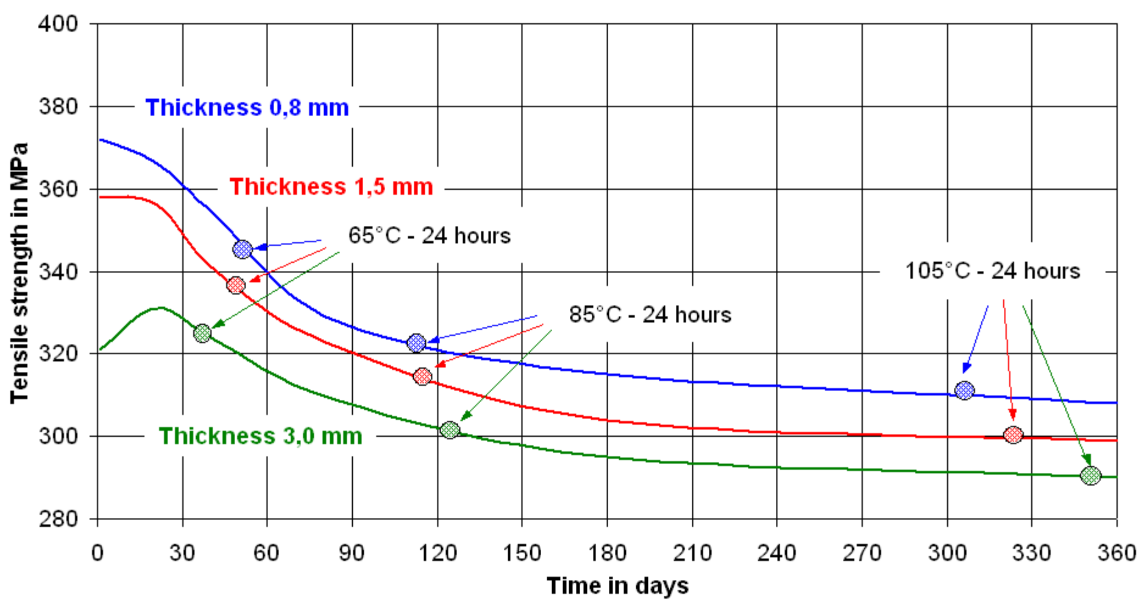

Figure 4. Results of artificial ageing of Alloy 5 for 24 hours at 65, 85 and 105 °C with 3 casting thicknesses plotted together with natural aging results of Figure 7

Natural aged tensile strengths for Alloys 3 and 2 at tested at RT out to 2 months are shown in Figure 5 and 6 respectively, together with as-cast values for specimens tested at -35 and 85°C. Results for longer ageing times will be reported in the future. The results are consistent with the Alloy 5 data reported above.

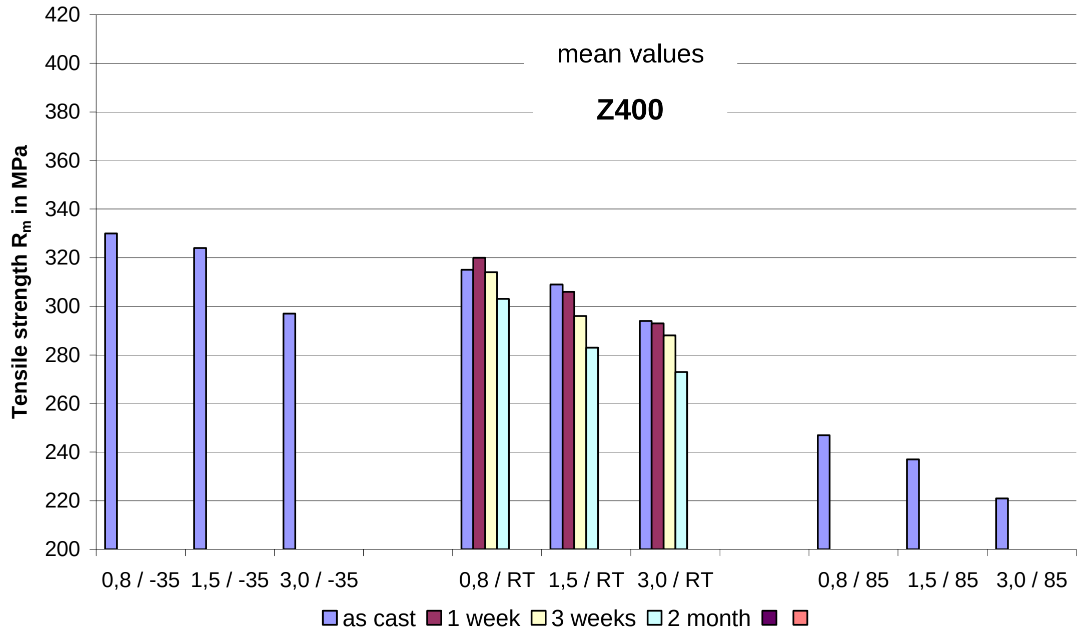

Figure 5. Tensile strengths of Alloy 3 grouped by test temperature (-35, 23 and 85°C), by wall thickness, and for different natural ageing times. Only as-cast results are available for the -35and 85°C test temperatures.

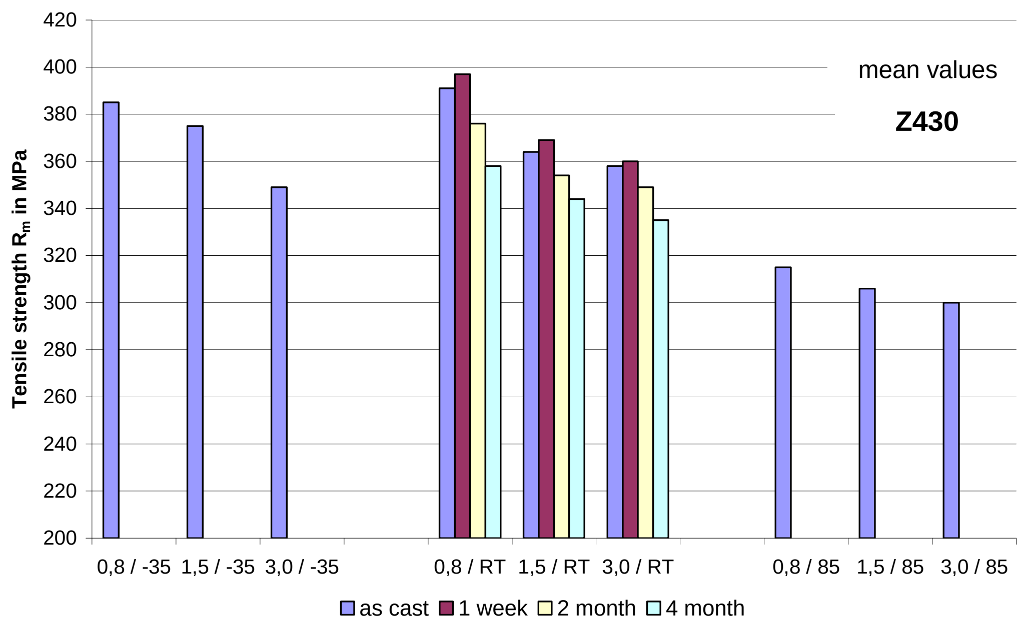

Figure 6. Tensile strengths of Alloy 2 grouped by test temperature (-35, 23 and 85°C), by wall thickness, and for different natural ageing times. Only as-cast results are available for the -35and 85°C test temperatures.

Figures 7 and 8 shows the effect of artificial ageing for 1 hour at 65,85 or 105°C for the three testing temperatures of -35, 23 and 85°C and three wall thicknesses for Alloys 3 and 2, respectively. A continuous decrease in strength can be seen with increased ageing temperature and wall thickness in all cases

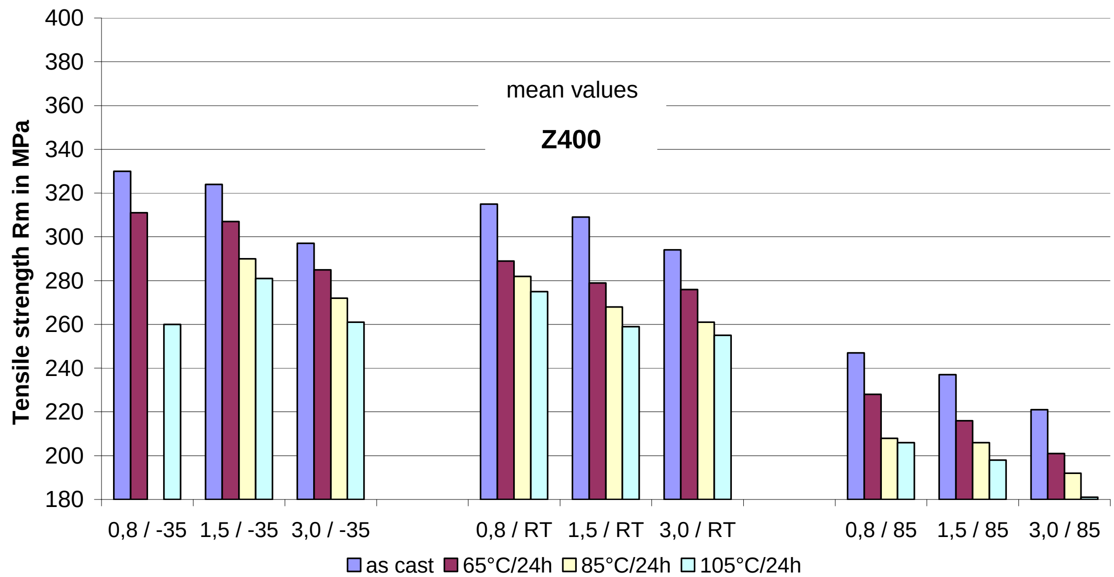

Figure 7. Alloy 3 tensile strength results, grouped by test temperature (-35, 23 and 85°C), by wall thickness, and for different 1 h artificial ageing treatments at 65, 85 or 105°C.

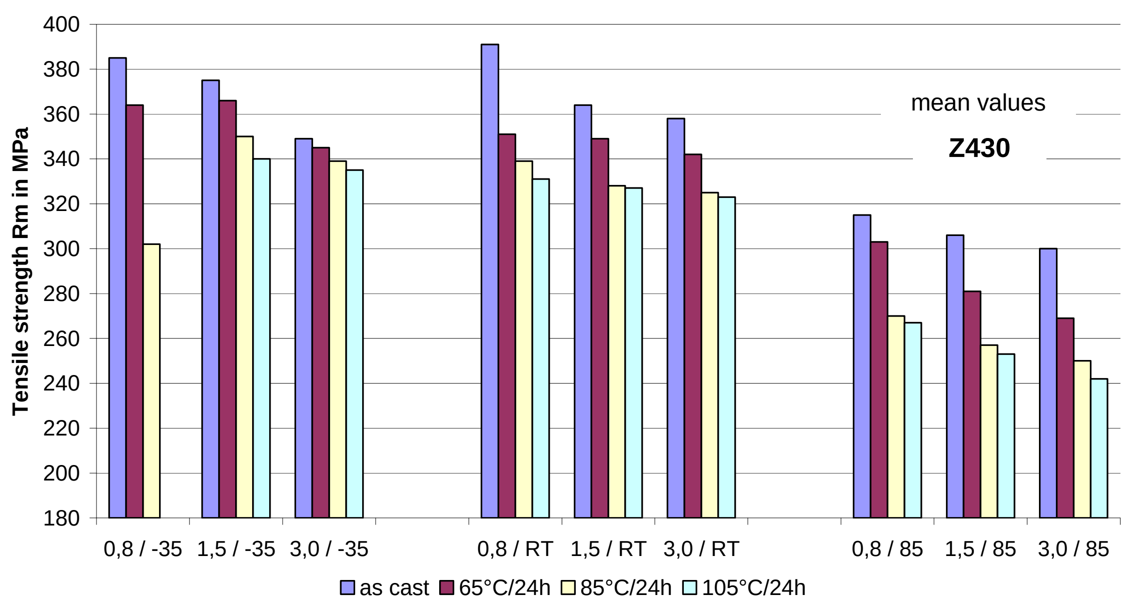

Figure 8. Alloy 2 tensile strength results, grouped by test temperature (-35, 23 and 85°C), by wall thickness, and for different 1 h artificial ageing treatments at 65, 85 or 105°C.

The tensile strengths of Alloys 5,3 and 2 samples with 1.5 m wall thicknesses to natural and artificial ageing are co-plotted in Figure 9. The relative values of strength agree with the published literature[1].

Unlike the correlations of Figure 4, the artificial ageing results are observed to fall into vertical patterns. Therefore, for all three alloys with a 1.5 mm section thickness, a 24 h age at 65°C is equivalent to about 40 days of natural ageing, 24 h at 85°C to about 100 days of natural ageing, and 24 h at 105°C to about 350 days.

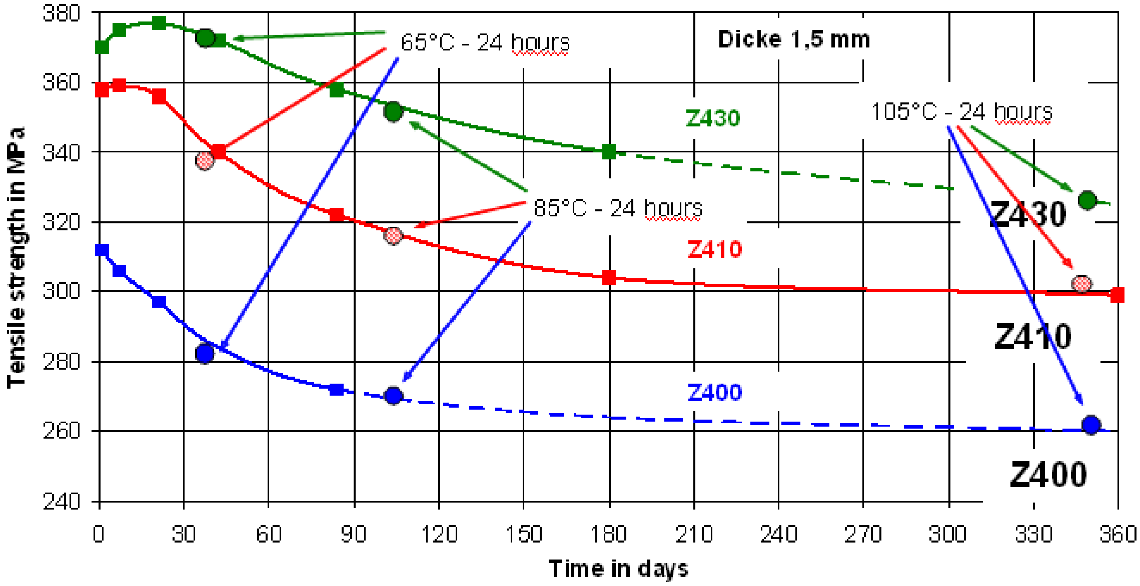

Figure 9. Results of artificial ageing of 1.5 mm samples of Alloys 5,3 and 2 for 24 h at 65, 85 and 105 °C plotted together with natural aging results. Dotted lines indicate expected behavior from work to date.

However, the rate of change of tensile strength with ageing treatments differs among the alloys. For example, after artificial ageing of at 105°C for 24 h Alloy 3 shows 83%, Alloy 5 shows 84% and Alloy 2 88% of the as-cast tensile strength. For Alloy 5, natural ageing is substantially completed after 1 year. It is expected that Alloy 3 will also show completion of natural ageing in 1 year, while Alloy 2 will require a longer time to complete natural ageing. Although the strength levels change with wall thickness, the shapes of the ageing curves are the same so that, within the range of thicknesses studied, the rates of natural ageing are the same.

For completeness, values of tensile elongation at fracture for all 3 wall thicknesses are shown in Table 2. The elongation data show a wide band of values. The data measured at -35°C (~1 to 2%) are lowest, the highest data are at +85°C (~20% to 25%). As expected, Alloy 3 shows the highest RT elongation, consistent with the tensile strength results reported above.

Table 2. Results of tensile elongation at fracture for all wall thicknesses for each alloy.

	Elongation at fracture, %		
Test temperature	-35°C	+23°C	+85°C
Alloy 5			
as cast	1.5 ± 0,4	2.7 ± 1,0	22.7 ± 8,6
1 year natural ageing	2.0 ± 0,5	5.5 ± 1,7	22.6 ± 6,8
Alloy 3			
as cast	2.0 ± 1,0	5.0 ± 3.0	20 ± 8
2 months natural ageing		9.0 ± 5.0	
artificial ageing 105°C/24h	2.0 ± 1.0	10 ± 5	25 ± 5
Alloy 2			
as cast	1.1 ± 0.5	3.0 ± 1.0	15 ± 8
4 months natural ageing		5.0 ± 1.5	
artificial ageing 105°C/24h	1.7 ± 0,9	4.6 ± 1.5	24 ± 8

CONCLUSIONS

1. The effect of pressure diecasting process variables and ageing on tensile properties of Alloys 2,3 and 5 have been determined for test temperatures of -35, 23 and 85°C. Casting thicknesses in the range of 0.8-3 mm significantly influenced results, while die temperature and injection velocity did not.
2. Ageing at room temperature (natural ageing) gave decreased tensile strengths and increased elongations as expected. For Alloys 2,3 and 5 at the 1.5 mm section thickness, a 24 h age at 65°C was found to be equivalent to about 40 days of natural ageing, 24 h at 85°C to about 100 days of natural ageing, and 24 h at 105°C to about 350 days. Natural ageing of Alloy 5 was determined to essentially complete after 1 year.

REFERENCES

1. "Zinc and Zinc Alloy Castings," ASM Handbook, Vol. 15, 10th Ed., pp. 1095-1099, 2008, ASM, Materials Park, OH