Deliverable Report

Deliverable Title:

Report with the results obtained in the industry laboratory trials with the different alloys

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[1] PU = Public
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Summary

This document outlines the testing and analysis carried out on different alloys, including AlSi10MnMg, AlSi8MnMg, and AlMg3. For the AlSi10MnMg variants, 150 flat plates were produced and optimal HPDC parameters were determined resulting in high-quality parts casted with a melt with a density index of <3.5%. The majority of these parts will undergo T6-7 heat treatment (1h at 490ºC + 1h at 230ºC), while other heat treatments such as T4, T5, and other T6 will be performed on variants 2, 4, and 6.

For each of the 7 variants of AlSi8MnMg and AlMg3, different types of specimens were produced for tensile and impact testing. The effects of artificial ageing were studied by comparing the results of tensile tests conducted in September 2022 and March 2023. AlMg3 alloys showed no significant changes in YS and UTS, but ductility decreased. In contrast, AlSi8MnMg alloys demonstrated an increase in YS and a slight increase in UTS, with no change in ductility. Regarding T5 and T6 AlSi8MnMg alloys also responded well to both. AlMg3 alloy variants didn't show relevant responses to T5 and T6 heat treatments, being intrinsically not suitable to heat treatments.

Disclaimer

Abbreviations

Abbreviation / Acronyms	Description
HPDC	High Pressure Die Casting
YS	Yield Strength
UTS	Ultimate Tensile Strength

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1. Introduction and Background

In WP4 of SALEMA project, the pilots regarding HPDC will be implemented and the new HPDC alloys validated. It is a WP devoted to the assessment of the new alloys developed within the project, by manufacturing and characterizing the final properties of two HPDC demonstrators with important mechanical requirements produced in two pilot plants implemented in industrial sites.

In Task 4.2 SALEMA the alloys variants produced in Task 4.1 taking into account the research carried out in WP1 and PW2 are tested and characterized, in order to select those with better performance to be further studied and validated in the industrial demonstrators.

The tests carried out with HPDC machines to validate the performance of the different alloy variants are:

- Process variable optimization of 6 different variants of AlSi10MnMg alloy with higher level of some impurities than the standard alloy
- Production of 150 flat plates to assess properties of each of 3 different variants of AlSi10MnMg0.2 alloy with higher level of some impurities than the standard alloy
- Production of 150 flat plates to assess properties of each of 3 different variants of AlSi10MnMg0.3 alloy with higher level of some impurities than the standard alloy
- Production of testing samples of 4 different variants of a newly developed AlSi8MnMg alloy
- Production of testing samples of 3 different variants of a newly developed AlMg3 alloy

This task of WP4 will assess the performance of a wide range of alloy variants in order to select those with better performance for final validation under full industrial.

1.1. Objectives of task and deliverable

The main objective of this deliverable is to describe the casting trials conducted to select the alloy with better performance to be further studied and validated in the industrial demonstrators. All the tests carried out on the different alloy variants will allow obtaining knowledge about the alloys and their processing, which will enable the selection of those with better performance. This includes finding the optimal HPDC parameters and heat treatment conditions. Making it possible to achieve the demonstrators' requirements.

2. Process variable optimization

2.1. Experimental procedure

The characterization of the HPDC SALEMA alloys started by conducting a first set of trials with a double intention: 1) to determine the process parameters that result in the highest quality part and 2) to assess the process stability and the sensitivity of the alloy to changes in casting parameters.

In this first set of trials, several parameters were assessed, including melt temperature, melt treatment, 1st phase, 2nd phase, speed change position, and break position. The melt temperature refers to the temperature of the furnace, while the 1st and 2nd phases refer to the speed of the piston

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during two different instances of filling. The speed change position is the place where transition from the 1st phase to the 2nd phase occurs, while the break position refers to the position at which the piston brakes.

These parameters were tested in various combinations, and the resulting parts were evaluated through visual inspection on a 2-5 scale. For each combination, ten parts were casted and analyzed.

The melt temperatures tested were 720ºC and 740ºC. For the 1st phase, speeds of 0.35m/s, 0.40m/s, 0.45m/s, and 0.50m/s were selected, while for the 2nd phase, speeds of 1.2m/s, 1.5m/s, and 1.8m/s were chosen. The break positions selected were 390mm, 400mm, and 410mm, as these values were suggested by the high-pressure die casting machine software, considering the selected alloy. The parameter optimization was done by testing different values around the suggested values.

2.2. Quality assessment of the parts

To quantify the visual quality of the part, a scale from 2 to 5 was developed, where: 2 is for parts that contain cold joints or big solidification defects or on both sides; 3 for parts that show blisters; 4 for parts that display water marks or small superficial solidification defects and 5 for parts that don't show defects. Figure 1 illustrate the different part quality types.

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Figure 1 – Example of the different part quality levels established in visual inspection: Quality 5 (top-left), quality 4 (top-right), quality 3 (bottom-left) and quality 2 (bottom-right)

2.3. Results and information obtained

To determine the optimal value for each parameter, the data obtained from the tests was processed. For each parameter, a graph was created to analyze its influence on the occurrence of big defects, blisters, and high-quality parts (rated 4 and 5). The optimal values for each parameter were determined based on the parts with high quality (rated 4 and 5). The label BD indicates big defects.

For temperature there is a trend that shows a slightly better part quality mean for 720ºC when compared to 740ºC (Figure 2).

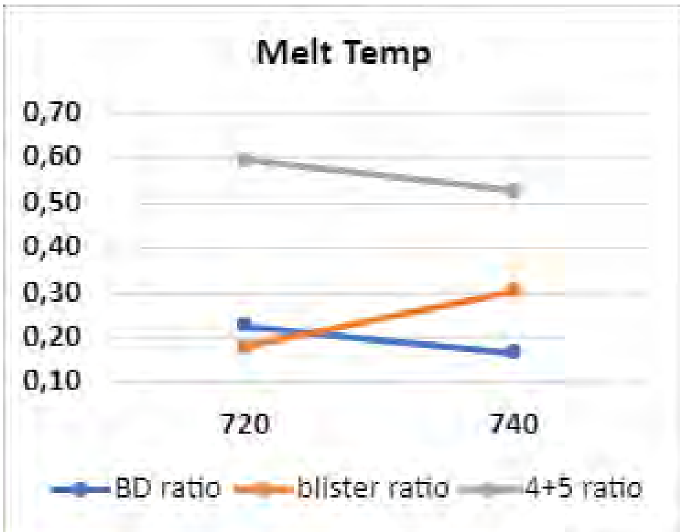

Figure 2 - Influence of melt temperature on part quality

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For the 1st phase speed is clear that with increasing speed the part quality diminishes (Figure 3). Making 0.4m/s the speed that produces parts with better quality.

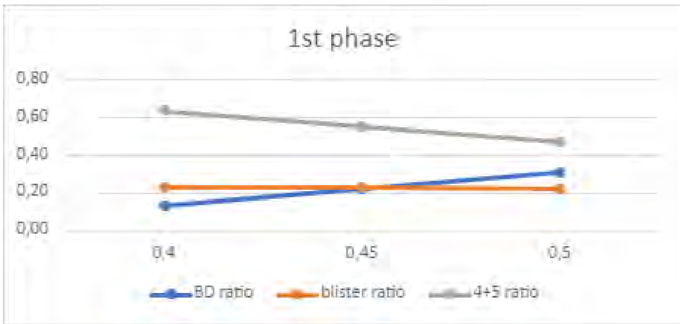

Figure 3 - Influence of 1st phase speed on part quality

For the 2nd phase speed there is an opposite trend when compared to the 1st phase speed (Figure 4). Increasing speed results in higher part quality, being 1.8 m/s the optimum value.

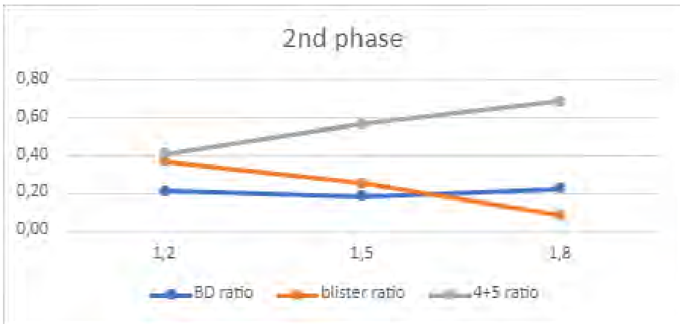

Figure 4 - Influence of 2nd phase speed on part quality

Regarding the speed change position, the ideal value is in the middle of the values tested (295mm) (**Error! Reference source not found.**).

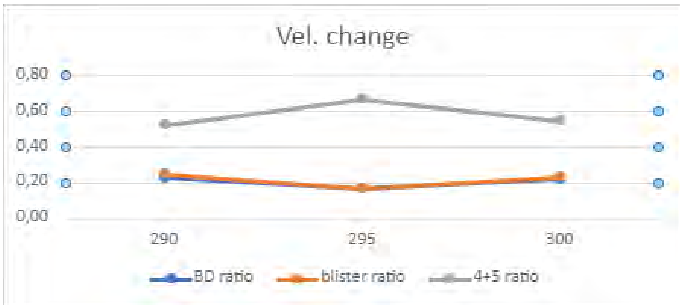

Figure 5 - Influence of speed change position on part quality

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The break position that showed a higher ratio of 4+5 was 410mm (Figure 6).

Figure 6 - Influence of break position on part quality

2.4. Conclusions

The study of different parameter combinations resulted in the identification of optimal values that formed the basis for all subsequent high-pressure die casting trials with different variants of AlSi10MnMg. The values defined for further use in the try outs were: temperature - 720ºC; 1st phase speed – 0.4 m/s; 2nd phase speed – 1.8 m/s; speed change position 295 mm; break position – 410 mm. Figure 7 illustrates the usage of these parameters during a cycle of the HPDC process.

Figure 7 - Injection curve parameters of Buhler software

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3. Production of the casting plates with the optimized process parameters

3.1. Experimental procedure

For each variant of the alloy AlSi10MnMg the target number of produced parts defined was 150. Ten additional parts were produced on each test, at the beginning to stabilize the die temperature and some related parameters such as clamping force. These ten extra parts were then sent to scrap. The furnace temperature was controlled every ten parts to make adjustments, if needed. The melt preparation included the addition of fluxes to promote the slag cleaning effect and 20 minutes of nitrogen degassing through graphite porous lance.

3.2. Production of the AlSi10MnMg0.3 and AlSi10MnMg0.2 alloy variants

To produce the AlSi10MnMg0.3 and AlSi10MnMg0.2 alloy, three different chemical compositions were utilized for each, denoted as Variant 1, 2, and 3 and Variant 4, 5 and 6, respectively. For further information regarding the chemical composition, please refer to Deliverable 4.3.

Table 1 summarizes the process parameters used to produce every Variant. The melting temperature was set to 720ºC but in reality, varied between 710-730ºC. After the trial, the parts were marked and visually inspected. The density index was also calculated for each variant.

Table 1 – Summary of relevant process parameters

config	Melt Temp	1st phase	2nd phase	Vel. change	Break Position	Numb parts
1.1	720	0,4	1,8	295	410	10
1.2	720	0,4	1,8	295	410	10
1.3	720	0,4	1,8	295	410	10
1.4	720	0,4	1,8	295	410	10
1.5	720	0,4	1,8	295	410	10
1.6	720	0,4	1,8	295	410	10
1.7	720	0,4	1,8	295	410	10
1.8	720	0,4	1,8	295	410	10
1.0	720	0,4	1,8	295	410	10
1.10	720	0,4	1,8	295	410	10
1.11	720	0,4	1,8	295	410	10
1.12	720	0,4	1,8	295	410	10
1.12	720	0,4	1,8	295	410	10
1.14	720	0,4	1,8	295	410	10
1.15	720	0,4	1,8	295	410	10

The results of the density index for each variant are presented in Table 2. Overall, the results are considered particularly good. For more detailed information on how to calculate the density index, refer to Deliverable 3.5.

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Table 2 - Density index results

Alloy	Density index (%)
Variant 1	2,00
Variant 2	3,51
Variant 3	2,62
Variant 4	3,30
Variant 5	3,30
Variant 6	1,63

Overall, the trials were successful for each variant. However, some process-related stoppages occurred due to occasional die sticking and part extraction failure. These stoppages resulted in a decrease in die temperature, leading to lower quality parts. Nonetheless, such events occurred sporadically and only impacted one or two consecutive parts at a time. However, such stoppages will be visible in the statistical analysis of part quality for each variant. This is because, in general, when the process runs without any issues, the parts have a high level of quality (grade 5).

3.3. Inventory of the plates produced

The quality report for each variant is presented in Table 3. Most of the produced parts exhibit the highest level of quality, followed by a small number of parts with minor surface defects, and a very small number of parts with low quality.

Table 3 - Quality report

Variant	1	2	3	4	5	6
Count (5)	124	132	87	147	133	135
Count (4)	25	16	22	2	8	15
Count (2-3)	1	2	0	1	1	0

3.4. Heat treatment of the plates

Several heat treatments will be performed on the produced parts, with the majority of the parts undergoing the considered as optimal T6-T7 heat treatment from the results obtained in Task 1.5 for 1h at 490ºC + 1h at 230ºC. Table 4 summarizes the optimal heat treatment parameters and posterior mechanical testing. This optimal heat treatment will be performed in all six variants. Other heat treatments such as T4, T5 and other T6 will be performed too. More detail about the treatments is presented in Table 5-7.

Table 4 - T6/7 number of parts for each variant and posterior mechanical testing

Heat treated (T6-T7) 1 h at 490ºC + 1 h at 230ºC						
Variant	**1**	**2**	**3**	**4**	**5**	**6**
CRF corrosion	15	15	15	15	15	15
CRF welding	10	10	10	10	10	10
Tensile tests + micro	4	4	4	4	4	4
Tensile tests 90º	-	4	-	-	4	-
Fatigue	21	-	21	-	-	21

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TEF	10	-	10	-	-	10
Bake Paint	4	-	-	-	-	4
FORD 3-Point bending	5	5	5	5	5	5
FORD Riveting	8	-	8	-	-	8
FORD tensile at different strain rates	10	10	-	10	10	10
TOTAL Heat treatment (T6)	105	58	88	53	58	105

In addition to the optimal full T6-T7 heat treatment, four other variations with small differences in either the solution treatment or the artificial ageing will be tested (Table 5).

Table 5 - Other T6/T7 heat treatments

Conditions (T6/T7)	**Variant 2**	**Variant 4**	**Variant 5**
1 h at 490ºC + 4 h at 190ºC	4	4	4
1 h at 490ºC + 2 h at 210ºC	4	4	4
1 h at 490ºC + 2 h at 230ºC	4	4	4
4 h at 490ºC + 1 h at 230ºC	4	4	4

The mechanical properties obtained under this full heat treatment will also be compared with two different T4 heat treatments (Table 6),

Table 6 - T4 heat treatment

Conditions (T4)	**Variant 2**	**Variant 4**	**Variant 5**
1 h at 490ºC + natural ageing	4	4	4
4 h at 490ºC + natural ageing	4	4	4

And also, six T5 heat treatments will be evaluated for three of the variants. In some of the treating conditions, ten additional parts will be treated for each of some of the variants to conduct also preliminary welding tests in addition to the tensile tests that will be done after each of the different heat treatments (Table 7).

Table 7 - T5 heat treatment

Conditions (T5)	**Variant 2**	**Variant 4**	**Variant 5**
2 h at 190ºC	4	4	14
4 h at 190ºC	14	4	4
1 h at 210ºC	4	14	4

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2 h at 210ºC	4	14	4
30 min at 230ºC	4	14	4
1 h at 230ºC	4	14	4

3.5. Conclusions

Flat plates of good quality have been produced for AlSi10MnMg alloy variants following the previously optimized process parameters. The number of testing parts produced is large enough to:

- Determine all the alloy properties defined in WP1 and WP2 as requirements for the different demonstrators
- Assess the performance of alternative heat treatments in order to tune them according to the requirements of the different demonstrators

4. Production of testing samples with AlSi8MnMg and AlMg3 alloy variants

4.1. Experimental procedure

The production of testing samples with AlSi8MnMg and AlMg3 alloy variants has been performed in the frame of WP2. For clarity, strategy of alloy variants selection, processing parameters and results achieved in the as cast conditions, fully described in Deliverables D2.3 and D2.4, are shortly summarized below.

The alloys considered as potentially interesting for HPDC in terms of minimal use of CRM such as Si and Mg are:

- **Three Al-2Mg-type alloys, whose target compositions are reported in Table 8,**
- **Four AlSi8MnMg0.3-type alloys, whose target compositions are reported in Table 9.**

Table 8 - Target compositions for Al-2Mg-type alloys

Type	Alloy #	% Si	% Fe	% Cu	% Mn	% Mn	% Cr	% Ni	% Zn	% Pb	% Sn	% Ti	% Sr	% Co
Al-Mg2	1	0,2-0,3	0,15	0,05	0,9-1,2	2,1-2,3	0,03	0,03	0,08	0,03	0,03	0,1	--	0,3-0.4
Al-Mg2	2	0,2-0,3	0,15	0,05	0,8-1,1	2,6-2,8	0,03	0,03	0,08	0,03	0,03	0,1	--	0,3-0.4
Al-Mg2	3	0,3-0,5	0,15	0,05	0,8-1,1	2,6-2,8	0,03	0,03	0,08	0,03	0,03	0,1	--	0,3-0.4

Table 9 - Target compositions for AlSi8MnMg0.3-type alloys

Type	Alloy #	% Si	% Fe	% Cu	% Mn	% Mg	% Cr	% Ni	% Zn	% Pb	% Sn	% Ti	% Sr
AlSi8MnMg0.3	4	8.5-9.0	0,20	0,2-0,3	0,6-0,7	0,15-0,25	0,03	0,03	0,07	0,03	0,03	0,05-0,15	0,01-0,018
AlSi8MnMg0.3	5	8.5-9.0	0,20	0,2-0,3	0,6-0,7	0,25-0,35	0,03	0,03	0,07	0,03	0,03	0,05-0,15	0,01-0,018
AlSi8MnMg0.3	6	7.5-8.0	0,20	0,03	0,6-0,7	0,15-0,25	0,03	0,03	0,07	0,03	0,03	0,05-0,15	0,01-0,018
AlSi8MnMg0.3	7	7.5-8.0	0,20	0,03	0,6-0,7	0,25-0,35	0,03	0,03	0,07	0,03	0,03	0,05-0,15	0,01-0,018

Role and expected effects of alloying elements are schematically shown below

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- **Si:** improve fluidity in alloys 4 and 5; minimized in alloy 6 and 7 to achieve a compromise between fluidity and low CRM amount; values in alloys 1, 2 and 3 are those compatibles with managing of available scraps (which are usually Si-rich);
- **Cu:** increase in mechanical properties in alloys 4 and 5;
- **Mn:** increase in mechanical properties in alloys 1, 2 and 3; minimize embrittling effects of Fe-based intermetallics and minimize die soldering tendency (all alloys);
- **Mg**: increase mechanical behavior in alloys 2 and 3 (with respect to 1) and in alloys 5 and 7 (with respect to 4 and 6);
- **Co:** refinement and improvement of mechanical behavior in alloys 1, 2 and 3;
- **Sr:** modification of eutectic Silicon in alloys 4, 5, 6 and 7.

The mechanical potential of high pressure die cast Al-based alloys has been evaluated by the reference die designed, built and tested in the frame of NADIA Project (New Automotive components Designed for and manufactured by Intelligent processing of light Alloys, EU IPs-SMEs, Contract n. 026563-2, 2006-2010). Such die is included in the CEN/TR 16748 Standard “Aluminium and aluminium alloys - Mechanical potential of Al-Si alloys for high pressure, low pressure and gravity die casting” [1-3]. Figure 8 shows the configuration of this reference die. Castings produced allow to easily take specimens for mechanical testing and for other characterizations. The reference die has been used for High Pressure Diecasting of SALEMA alloys: 25 castings for each of the 7 SALEMA alloys have been produced, under constant processing parameters.

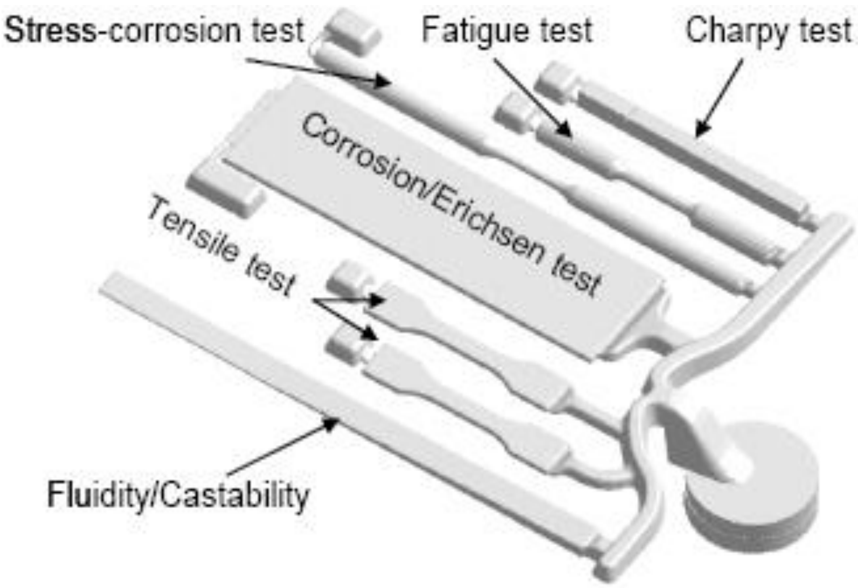

Figure 8 - HPDC Reference casting according to CEN/TR 16748 Standard and specimens achievable

4.2. Production of the AlSi8MnMg alloy variants

From HPDC tests, 25 castings have been produced, with the specific composition collected in Table 10:

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Table 10 - Chemical analysis [wt%] of HPDC SALEMA Al-Mg3

		Al	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ni	Ti	Pb	Sn	Sr	V	Na	Bi	Co
Alloy 1	Lega 1	Bal	0,335	0,18	0,0104	1,14	2,42	0,0219	0,008	0,0069	0,0119	0,0072	0,0062	<0,0001	0,0192	0,0003	<0,0015	0,374
Alloy 2	Lega 2	Bal	0,286	0,189	0,0103	0,935	2,94	0,0165	0,0079	0,0063	0,0171	0,0098	0,0058	<0,0001	0,0218	0,0007	0,0021	0,398
Alloy 3	Lega 3	Bal	0,617	0,181	0,0113	0,918	3,07	0,0258	0,0081	0,0076	0,0185	0,0066	0,0071	<0,0001	0,0223	0,0004	<0,0015	0,347

4.3. Production of the AlMg3 alloy variants

From HPDC tests, 25 castings have been produced, with the specific composition collected in Table 11:

Table 11 - Chemical analysis [wt%] on HPDC SALEMA Al-Si8-Mn-Mg0.3 alloys

		Al	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ni	Ti	Pb	Sn	Sr	V	Na	Bi	Co
Alloy 4	Lega 4	Bal	9,98	0,181	0,274	0,701	0,22	0,0206	0,0157	0,0112	0,1	0,0059	0,0033	0,010	0,01	<0,0001	<0,0015	0,0028
Alloy 5	Lega 5	Bal	9,42	0,169	0,258	0,661	0,328	0,0203	0,016	0,0104	0,106	0,0057	0,0031	0,0094	0,0118	<0,0001	<0,0015	0,002
Alloy 6	Lega 6	Bal	8,63	0,175	0,017	0,677	0,204	0,0192	0,0162	0,0033	0,105	0,0056	0,0036	0,0119	0,0134	0,0001	<0,0015	<0,001
Alloy 7	Lega 7	Bal	8,55	0,171	0,0163	0,679	0,336	0,0199	0,0159	0,0033	0,106	0,0056	0,0035	0,0112	0,0148	<0,0001	<0,0015	<0,001

4.4. Inventory of the plates produced

For each of the 7 variants selected, there have been produced the following specimens (see Figure 8):

- 50 flat specimens for tensile test;
- 25 round specimens for tensile test;
- 25 long round specimens for tensile test;
- 25 notched specimens for impact test;
- 25 un-notched specimens for impact tests;
- 25 plates, for corrosion tests as well as for setting up heat treatment parameters.

4.5. Heat treatment of the plates

Heat treatment tests have been performed by following this strategy:

- Check of the (eventual) effect of natural ageing, by comparing results of tensile tests performed in September 2022 and then in March 2023
- Evaluation of ageing curves achieved by performing T5 and T6 treatments, under different processing parameters, on specimens taken from HPDC cast plates, and selection of more efficient T5 and T6 conditions

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- Performing selected T5 and T6 treatments on tensile test and impact test specimens, with evaluation of corresponding behavior of the alloys.

4.5.1 Effect of natural ageing

Investigations have been performed on flat specimens (Figure 9), just after HPDC casting (September 2022) and after 6 month (March 2023). Results, in terms of YS, UTS and elongation are collected in Figure 10-12.

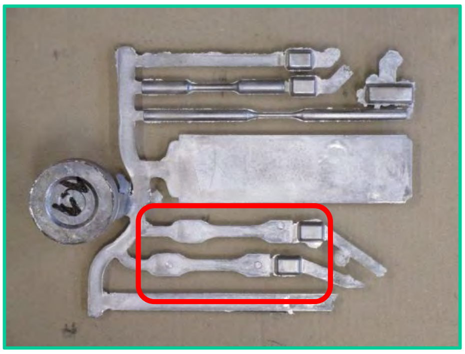

Figure 9 - Specimens for testing natural ageing effect on mechanical behavior

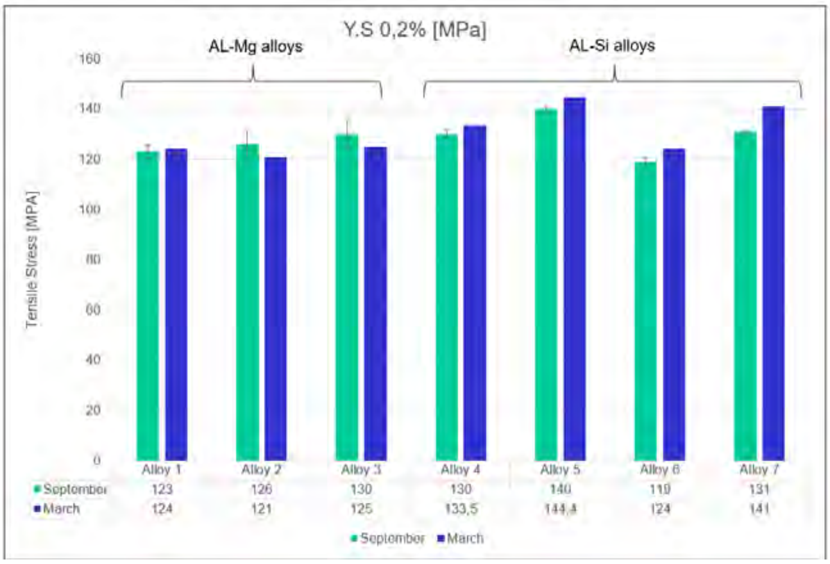

Figure 10 - Effect of natural ageing on the 7 alloy variants in terms of YS (MPa)

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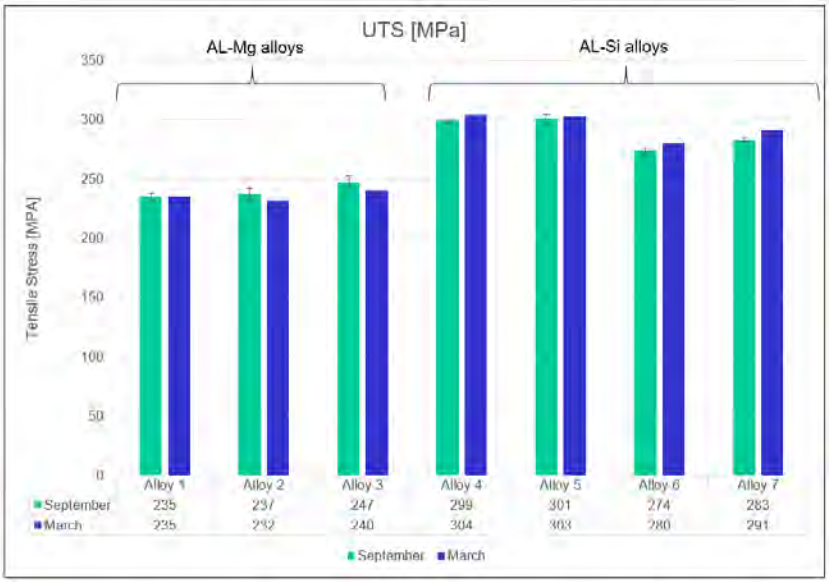

Figure 11 - Effect of natural ageing on the 7 alloy variants in terms of UTS (MPa)

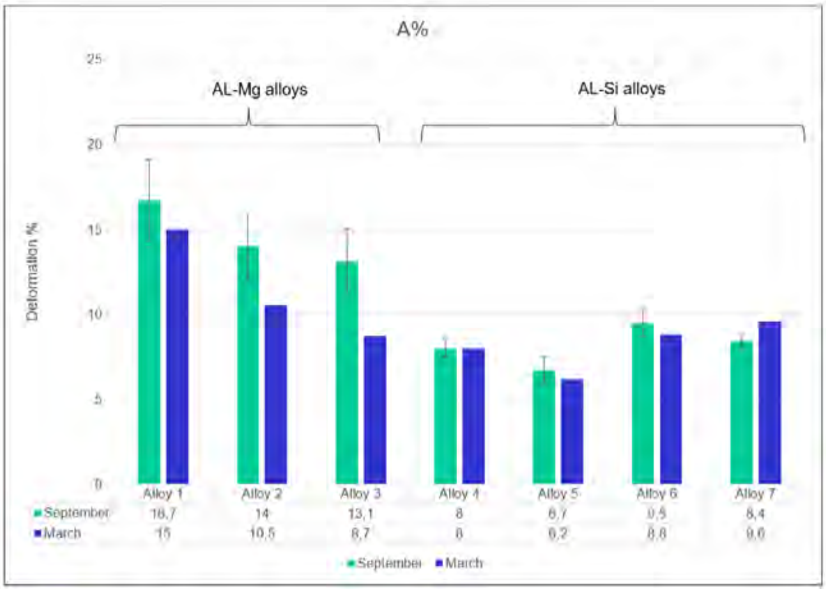

Figure 12 - Effect of natural ageing on the 7 alloy variants in terms of elongation (%)

AlMg3 alloys do not show relevant changes in YS and UTS, while ductility decreases with natural ageing.

AlSi8MnMg alloys typically show an increase in YS and, in a smaller extent in UTS; ductility seems not significantly affected by natural ageing.

4.5.2 Set up of T5 and T6 treatments

Investigations have been performed on small specimens taken from the cast plates (Figure 13).

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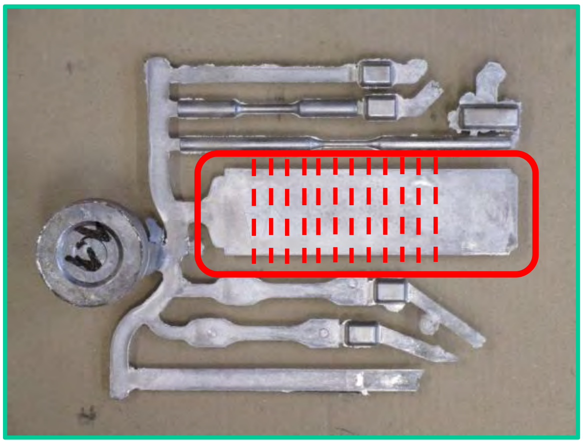

Figure 13 - Specimens for setting up T5 and T6 treatments on the alloy variants+

Various T5 and T6 conditions have been performed on the specimens referred to alloy variants #3, #5 and #7. Figure 14 – 16 show the T5 ageing curves respectively for alloy variants #3, #5 and #7.

Temp → / Time ↓	190°C	210°C	230°C
0	67.5	67.5	67.5
0.5	67.1	66.9	69.5
1	67.9	66.4	68.2
2	68.37	67.07	68.2
4	67.5	66.03	69.3
8	70.7	72	69.3

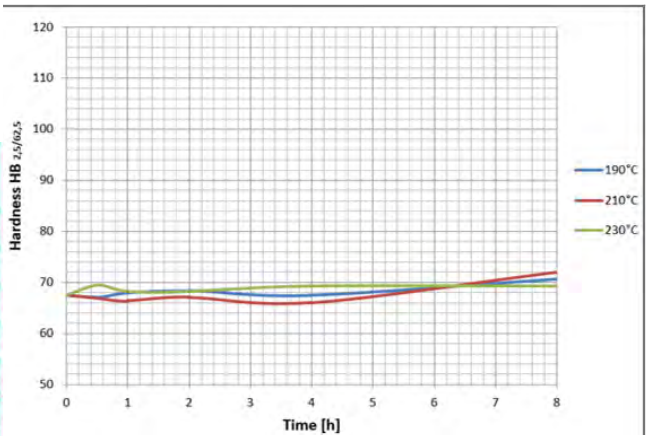

Figure 14 - T5 ageing parameters, Vickers hardness values and ageing curves for alloy variant #3

Temp → / Time ↓	190°C	210°C	230°C	245°C
0	88.7	88.7	88.7	88.7
0.25			101	98
0.5	93.5	100.3	100	98
0.75				96.1
1	94.3	100.1	100	95
2	98.73	102	98.35	
4	101.6	101.2	97.2	
8	103.3	100.3	91.6	

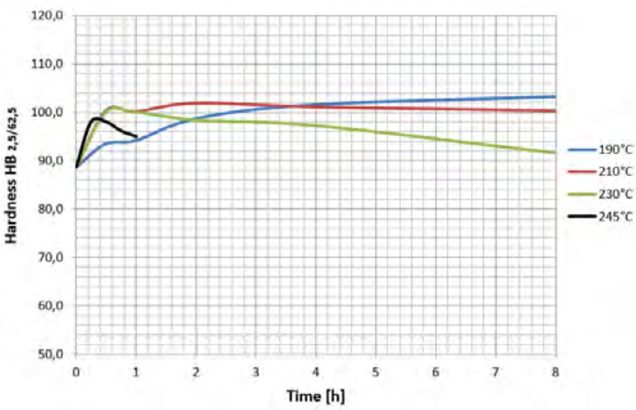

Figure 15 - T5 ageing parameters, Vickers hardness values and ageing curves for alloy variant #5

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Temp→ Time ↓	190°C	210°C	230°C	245°C
0	80.7	80.7	80.7	80.7
0.25			92	90.5
0.5	90.0	90.7	92.1	90.1
0.75				88.1
1	90.7	92.1	91.4	87.2
2	94.27	94	91.07	
4	97.23	93.17	86.2	
8	96.5	92.5	85	

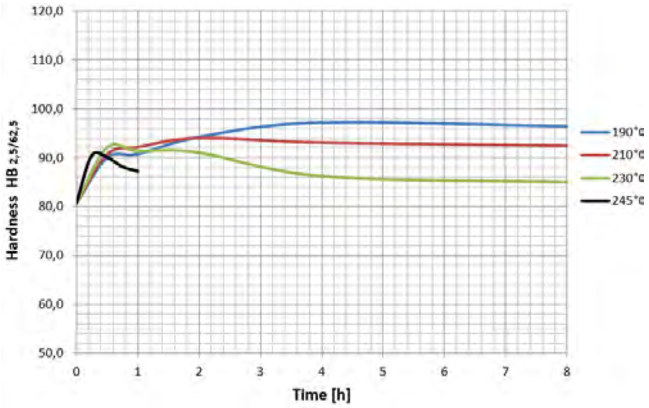
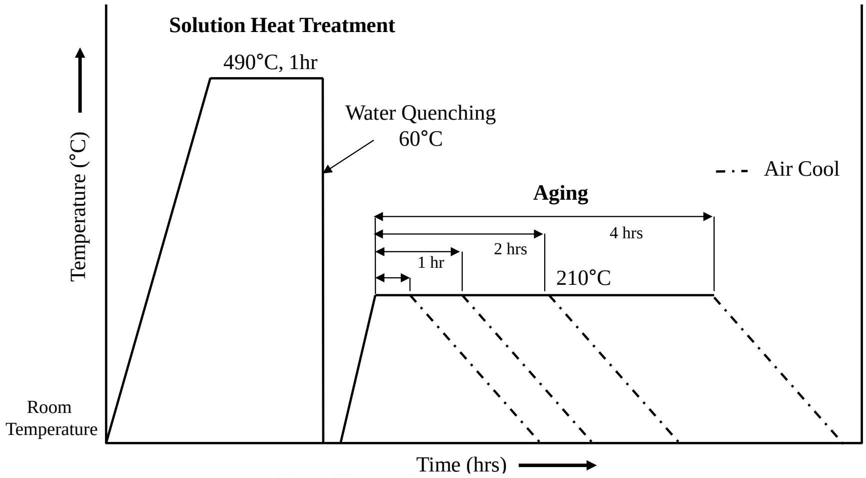


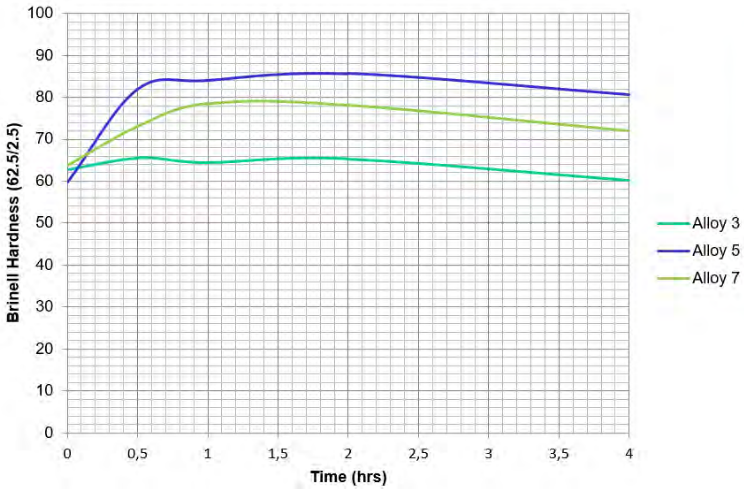
Figure 16 - T5 ageing parameters, Vickers hardness values and ageing curves for alloy variant #7

As expected, T5 does not affect mechanical behavior of Al-Mg3, being this family of alloys non heat treatable; on the other side, significant results, with hardness respectively going from 88.7 to 102-103 HB and from 80.7 to 96-97 HB for alloy variants #5 and #7.

T6 treatments have been organized in different rounds, described as follows.

<u>Round #1, alloy variants #3, #5, #7 (Figure 17):</u>





	Alloy 3	Alloy 5	Alloy 7
0 (After Quenching)	62.8	59.7	63.8
0.5	65.55	81.87	72.95
1	64.47	84	78.47
2	65.33	85.6	78.18
4	60.1	80.7	71.95

Average hardness values

Figure 17 - Round #1: T6 ageing parameters) and T6 ageing curves, with related HB hardness values

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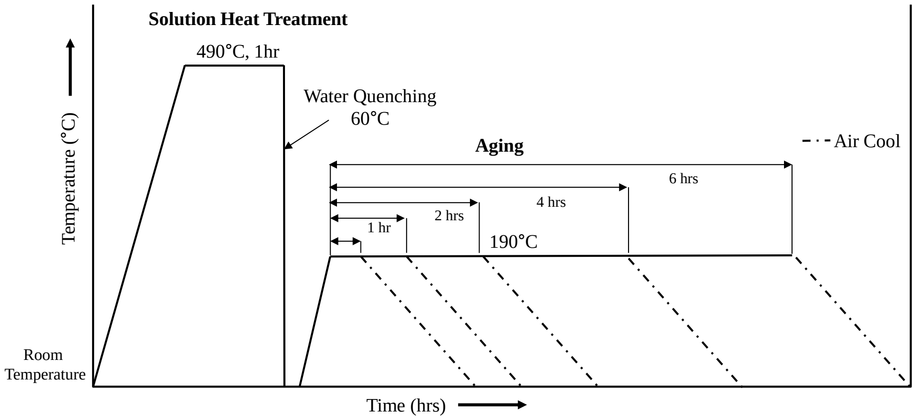
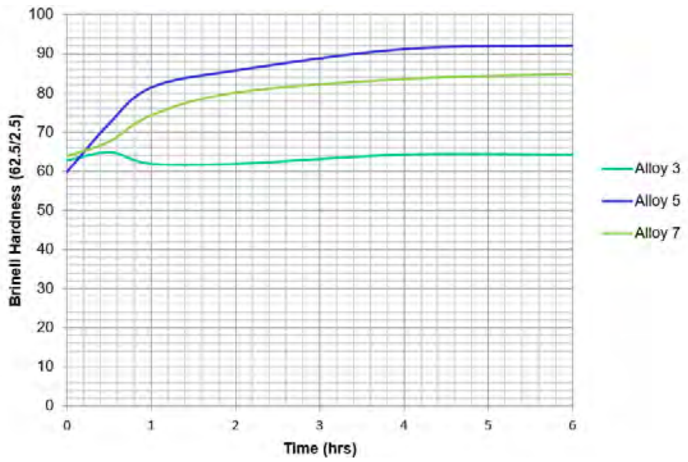
Round #2, alloy variants #3, #5, #7 (Figure 18):



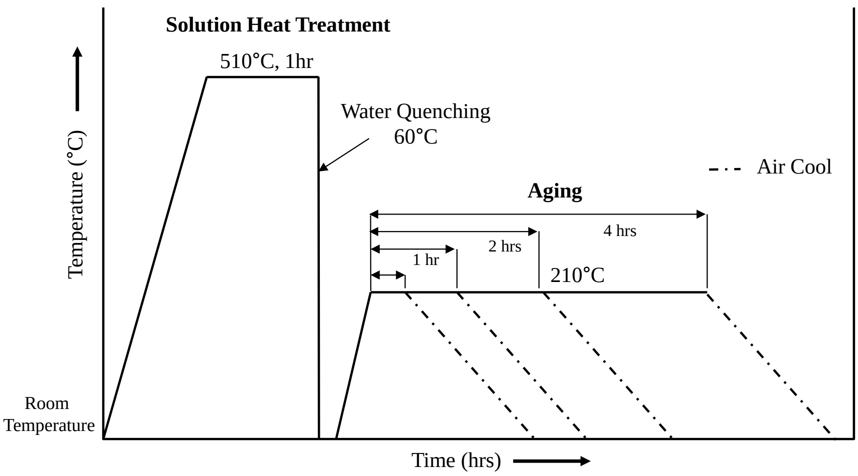


	Alloy 3	Alloy 5	Alloy 7
0 (After Quenching)	62.8	59.7	63.8
0.5	64.9	72.2	67.5
1	62	81.47	74.23
2	62	85.67	80.17
4	64.27	91.13	83.63
6	64.27	92	84.9

Average hardness values

Figure 18 - Round #2: T6 ageing parameters and T6 ageing curves, with related HB hardness values

Round #3, alloy variants #3, #5 (Figure 19):



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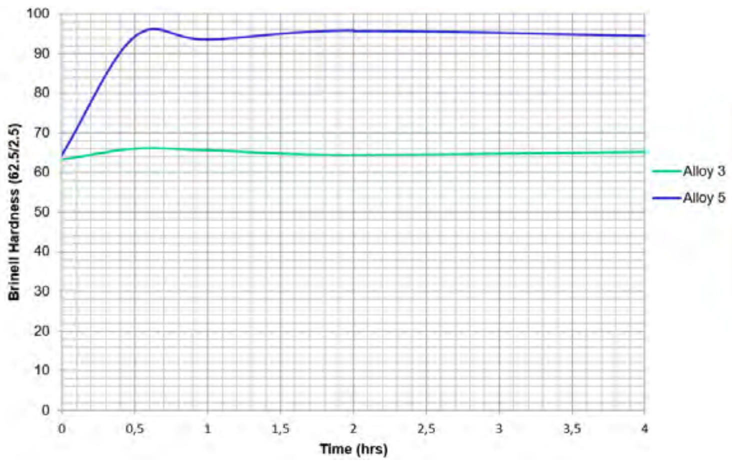
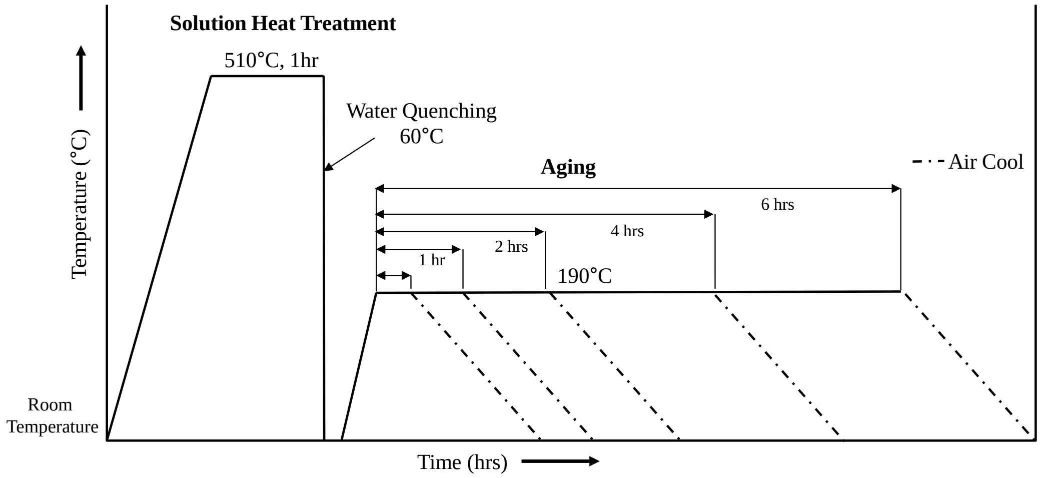


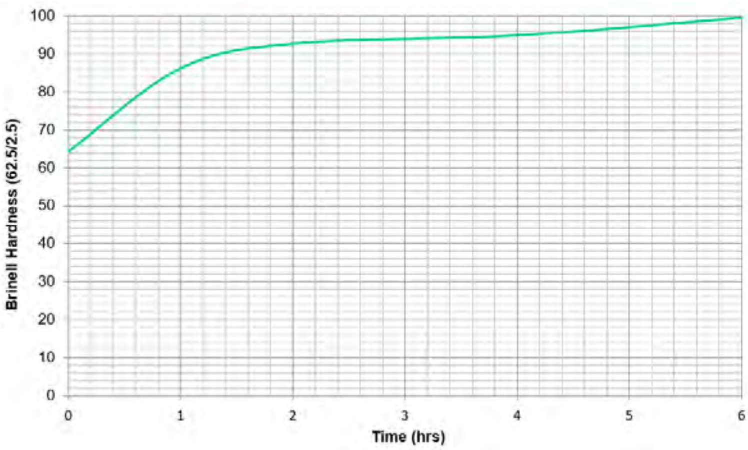
	Alloy 3	Alloy 5
0 (After Quenched)	63.3	64.5
0.5	65.98	94.3
1	65.6	93.5
2	64.47	95.8
4	65.3	94.6

Average hardness values

Figure 19 - Round #3: T6 ageing parameters and T6 ageing curves, with related HB hardness values

Round #4, alloy variant #5 (Figure 20):





0 (After quenching)	64.5
1	86.17
2	92.8
4	95
6	99.6

Average hardness values- Alloy 5

Figure 20 - Round #4: T6 ageing parameters and T6 ageing curves, with related HB hardness values

Rounds #5, alloy variant #5 (short solutioning at 530°C or 510°C: 10 or 30 min) (Figure 21)

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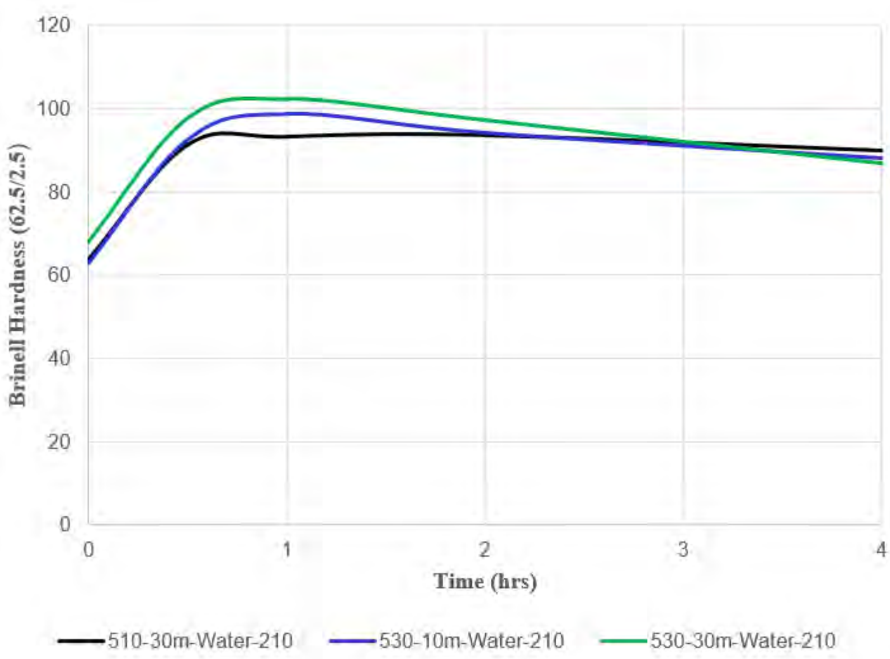
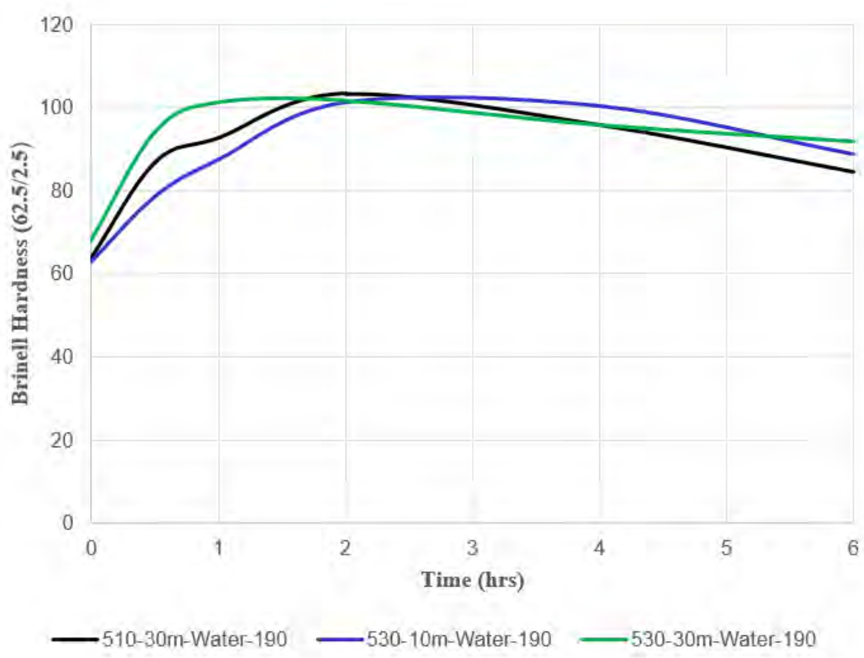


a)



b)

Figure 21 - Rounds #5: T6 ageing curves, for the 6 combinations of T6 parameters adopted

From the investigations carried out, some sets of parameters have been individuated for final T5 and T6 treatments on AlSi8MnMg alloys (Table 12).

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Table 12 - Selection of parameters for final T5 (a) and T6 (b) treatments

T5	
Aging Temprature (C°)	**Time (h)**
190	2
190	4
210	1
210	2
230	0.5
230	1

T6			
Solubilization Temp. (C°)	**Quenching**	**Aging Temperature (C°)**	**Time (h)**
490-1h	Water	190	4
	Water	210	2
	Water	230	0.5
	Air	210	2
510-1h	Water	190	4
	Water	210	2
	Water	230	0.5
	Air	210	2
510-30 min	Water	190	2
	Water	210	1

4.5.3 Optimized T5 and T6 treatments

T5 and T6 treatments have been performed under the conditions reported in Tables above, using flat and round tensile test specimens. Table 13-12 collect the results, referred to alloys #4, #5, #6 and #7.

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Table 13 - Mechanical behavior of alloy #4 variant, under different T5 and T6 treatment

Alloy #4 (Al-Si9-Mn0.7-Mg0.2-Cu0.2-Fe0.15)			
Flat Specimens Thickness=3mm Width=10mm L =35mm	**Y.S 0.2% (MPA)**	**UTS (MPA)**	**Et %**
As Cast Specimens - Average	130	299	10
Std. Dev.	1.1	3.8	0.8

T5- Heat Treatment			
	Y.S 0.2% (MPA)	**UTS (MPA)**	**Et %**
190°C-2hr Specimens - Average	196	314	5.7
Std. Dev.	5.69	1.53	1.28
190°C-4h Specimens - Average	199	315	5.9
Std. Dev.	3.79	4.36	0.84
210°C-1h Specimens - Average	196	313	5.8
Std. Dev.	5	3.79	0.34
210°C-2h Specimens - Average	199	315	5.7
Std. Dev.	4	3.21	0.64
230°C-0.5h Specimens - Average	191	307	6.5
Std. Dev.	5	2.31	1.12
230°C-1h Specimens - Average	192	308	6.9
Std. Dev.	3.21	3.06	0.62

T6- Heat Treatment			
	Y.S 0.2% (MPA)	**UTS (MPA)**	**Et %**
490-1h-W-190-4h Specimens - Average	152	226	11.5
Std. Dev.	2	7.23	1.32
490-1h-W-210-2h Specimens - Average	129	215	14.2
Std. Dev.	2.08	1	0.82
490-1h-W-230-0.5hSpecimens - Average	121	212	15.1
Std. Dev.	3.06	2.08	0.35
510-1h-W-190-4h Specimens - Average	150	226	10.7
Std. Dev.	3.51	5.51	2.34
510-1h-W-210-2h Specimens - Average	135	219	11.3
Std. Dev.	3.06	3.46	1.25
510-1h-W-230-0.5h Specimens - Average	125	212	14.9
Std. Dev.	2.08	2.52	1.68
510-0.5h-W-190-2h Specimens - Average	178	258	10.4
Std. Dev.	2.52	3.21	1.68
510-0.5h-W-210-1h Specimens - Average	159	238	11
Std. Dev.	3.51	3.06	0.47

[illegible] Specimens - Average	[illegible]	[illegible]	[illegible]
Std. Dev.	7.23	6.81	0.7
230°C-1h Specimens - Average	209	322	4.9
Std. Dev.	7.81	11.27	0.4

Et %
9.7
0.81
8.9
1.65
11
1.4
7.9
0.23

[illegible] Specimens - Average	[illegible]	[illegible]	8
Std. Dev.	5	4.04	0.47
510-1h-W-230-0.5h Specimens - Average	196	257	9.1
Std. Dev.	3.51	2.89	0.55
510-0.5h-W-190-2h Specimens - Average	247	313	7

Table 14 - Mechanical behavior of alloy #5 variant, under different T5 and T6 treatments

Std. Dev.	3.46	4.58	0.99

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Table 15 - Mechanical behavior of alloy #6 variant, under different T5 and T6 treatments

Alloy #6 (Al-Si7.5-Mn0.7-Mg0.2-Cu0.02-Fe0.2)			
Flat Specimens Thickness=3mm Width=10mm L=35mm	Y.S 0.2% (MPA)	UTS (MPA)	Et %
As Cast Specimens - Average	119.6	274	11.5
Std. Dev.	1.1	3.8	0.8

T5- Heat Treatment	Y.S 0.2% (MPA)	UTS (MPA)	Et %
190°C-2hr Specimens - Average	175	287	7.34
Std. Dev.	2	2.08	0.69
190°C-4h Specimens - Average	179	289	6.84
Std. Dev.	1.15	2.08	1.48
210°C-1h Specimens - Average	179	285	6.78
Std. Dev.	3.21	2.08	0.61
210°C-2h Specimens - Average	177	278	7.3
Std. Dev.	6.11	4.73	1.82
230°C-0.5h Specimens - Average	170	279	7.1
Std. Dev.	4.93	5.77	0.88
230°C-1h Specimens - Average	171	274	7.6
Std. Dev.	2.52	3.06	0.5

T6- Heat Treatment	Y.S 0.2% (MPA)	UTS (MPA)	Et %
490-1h-W-190-4h Specimens - Average	121	197	16.2
Std. Dev.	2.08	2.65	0.66
490-1h-W-210-2h Specimens - Average	127	198	15.1
Std. Dev.	3	2.31	1
490-1h-W-230-0.5hSpecimens - Average	119	196	17.9
Std. Dev.	3.06	2.52	0.97
510-1h-W-190-4h Specimens - Average	143	214	13.8
Std. Dev.	5.29	4.16	0.93
510-1h-W-210-2h Specimens - Average	138	202	15.24
Std. Dev.	3.61	5.51	0.77
510-1h-W-230-0.5h Specimens - Average	124	197	14.4
Std. Dev.	4.73	3.61	3.21
510-0.5h-W-190-2h Specimens - Average	158	232	12.85
Std. Dev.	5.51	4.51	1.48
510-0.5h-W-210-1h Specimens - Average	141	214	13.32
Std. Dev.	3.79	3	0.61

Table 16 - Mechanical behavior of alloy #7 variant, under different T5 and T6 treatments

Alloy #7 (Al-Si8-Mn0.7-Mg0.3-Cu0.02-Fe0.2)			
Flat Specimens Thickness=3mm Width=10mm L=35mm	Y.S 0.2% (MPA)	UTS (MPA)	Et %
As Cast Specimens - Average	131	282	9.8
Std. Dev.	1.1	3.8	0.8

T5- Heat Treatment	Y.S 0.2% (MPA)	UTS (MPA)	Et %
190°C-2hr Specimens - Average	201	307	5.9
Std. Dev.	3.06	4.04	0.55
190°C-4h Specimens - Average	205	306	6.5
Std. Dev.	3.06	4.73	0.61
210°C-1h Specimens - Average	198	300	5.2
Std. Dev.	2.89	2.52	0.66
210°C-2h Specimens - Average	198	294	6.6
Std. Dev.	4.16	4.58	1.19
230°C-0.5h Specimens - Average	195	292	5.8
Std. Dev.	3.61	3.51	0.85
230°C-1h Specimens - Average	193	286	6.2
Std. Dev.	5.29	2.08	0.96

T6- Heat Treatment	Y.S 0.2% (MPA)	UTS (MPA)	Et %
490-1h-W-190-4h Specimens - Average	216	269	8.9
Std. Dev.	3.21	3.51	1.12
490-1h-W-210-2h Specimens - Average	198	250	8.9
Std. Dev.	3	5.03	0.23
490-1h-W-230-0.5hSpecimens - Average	166	225	12.6
Std. Dev.	3.61	2.65	2.05
510-1h-W-190-4h Specimens - Average	213	260	9.1
Std. Dev.	2.65	3	1.48
510-1h-W-210-2h Specimens - Average	178	229	10.8
Std. Dev.	3.21	2.89	0.69
510-1h-W-230-0.5h Specimens - Average	153	201	11.4
Std. Dev.	5.57	7.77	2.22
510-0.5h-W-190-2h Specimens - Average	228	279	8.7
Std. Dev.	2.52	4.51	2.3
510-0.5h-W-210-1h Specimens - Average	205	254	10.9
Std. Dev	3.21	5.69	2.15

4.6. Conclusions

The main conclusions achieved with regards of the variants investigated and their responses to heat treatment are the following:

- AlMg3 alloy variants do not show relevant changes due to natural ageing in YS and UTS, while ductility decreases with natural ageing;
- AlMg3 alloy variants do not show relevant responses to T5 and T6 heat treatments, being intrinsically not suitable to heat treatments;
- AlSi8MnMg alloy variants, after 6 months of natural ageing, typically show an increase in YS and, in a smaller extent in UTS; ductility seems not significantly affected by natural ageing

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- AlSi8MnMg alloy variants show good response to T5 treatments:
  - Variant #4: YS around 195-200 MPa, UTS around 310-315 MPa, elongation around 6-7%
  - Variant #5: YS around 210 MPa, UTS around 325 MPa, elongation around 5%
  - Variant #6: YS around 170-180 MPa, UTS around 280-290 MPa, elongation around 7%
  - Variant #7: YS around 190-200 MPa, UTS around 290-300 MPa, elongation around 5-6%
- AlSi8MnMg alloy variants show good response to T6 treatments:
  - Variant #4: YS around 120-170 MPa, UTS around 220-260 MPa, elongation around 10-15%
  - Variant #5: YS around 225-235 MPa, UTS around 290-300 MPa, elongation around 8-10%
  - Variant #6: YS around 120-160 MPa, UTS around 200-230 MPa, elongation around 13-18%
  - Variant #7: YS around 170-230 MPa, UTS around 230-270 MPa, elongation around 9-12%

Proper combinations of time & temperature parameters, with reference to AlSi8MnMg variants, on the basis of the experiments performed, may lead to the achievement of final properties responding to demonstrators' requirements.

5. Conclusions and Outlook

The present document sets the basis for the selection of the alloy variants with better performance and the better fit with the project requirements.

- For AlSi10MnMg alloy variants:
  - The impact of variation on HPDC process parameters on part quality has been assessed, determining the optimal casting conditions as well as the alloy sensitivity to fluctuations in processing environment
  - Flat plates parts with optimal apparent quality have been produced and selected for the subsequent heat treatment
- For AlSi8MnMg alloy variants:
  - Testing specimens have been produced by HPDC and their mechanical properties have been determined shortly after casting as well as after natural ageing.
  - Hardness curves have been assessed for several heat treatment conditions
- For AlMg3 alloy variants:
  - Testing specimens have been produced by HPDC and their mechanical properties have been determined shortly after casting as well as after natural ageing.
  - Hardness curves have been assessed for several heat treatment conditions

6. Next steps

In the following months the properties defined in WP1 and 2 should be assessed in order to determine if the requirements defined for each demonstrator are met. Those results will be the base of Deliverable 4.5. In order to achieve this objective, the following steps should be reached:

- Casting of Eurecat flat plates with AlSi8MnMg and AlMg3 alloy variants
- Characterization of essential properties to select the best variants of AlSi10MnMg alloy
- Characterization of the rest of the properties with the flat plates for all SALEMA HPDC alloy

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