Deliverable Report

Deliverable Title:

Design procedure and identification of new alloys with reduced CRM content,

to be produced and analysed in the subsequent stages of the project

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[1] PU = Public
PP = Restricted to other programme participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)

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V	Date	Author (Affiliation)	Actions& Approvals
V1.0	28.04.2022	Franco Bonollo (UNIPD)	Drafting and circulation
V1.0	28.04.2022	Manel da Silva and Hannah Arpke	Technical and formal review
V2.0	29.04.2022	Franco Bonollo (UNIPD)	Review of draft and addition of details
V3.0	29.04.2022	Franco Bonollo (UNIPD)	Final draft and addition of details

Summary

After the identification of the base-systems for the development of SALEMA alloys, i.e.:

- AlSi10MnMg, AlMg and Al4MgFe systems for HPDC Demonstrators,
- 5000 and 6000 series for Wrought (Extrusion, Stamping) Demonstrators,

criteria and tools developed and presented in Deliverable D2.2 have been applied for individuating the specific alloys to be used in experimental campaigns.
Alloy design and selection process has been performed separately for HPDC and wrought alloys.
For HPDC alloys selection, starting from the abovementioned systems, has been based on evaluation of Criticality Index as well as on estimation of castability, achieved combining fluidity, solidification shrinkage, sludge formation, die soldering and hot tearing models. Additional considerations have been developed considering the general role of key-alloying elements on mechanical behaviour, in view of achievement of requirements for SALEMA Demonstrators. This selection process has led to a ranking among different systems and sub-systems, and among specific alloys. Such ranking will be the base for performing of experimental HPDC campaigns.
For wrought alloys selection, performed in 5000 and 6000 "areas", Criticality Index has been calculated for the typical range of compositions, and models describing hot workability have been applied to evaluate alloys processability. Also in this case, additional considerations have been developed considering the general role of key-alloying elements on mechanical behaviour, particularly when associated to key processes such as cold working (5000 alloys) and precipitation hardening treatment (6000 alloys). Issues concerning the so-called material process maps have been developed, to understand the potential of alloys in view of achievement of requirements for SALEMA Demonstrators. This selection process has led to a ranking among 5000 and 6000 alloys, on which experimental campaigns of extrusion and stamping will be based.

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Abbreviations

Abbreviation / Acronyms	Description
A	Elongation at break
ARL	Abundance Risk Level
CI	Criticality Index
CI_{CRM}	Criticality Index for Critical Raw Material
CRM	Critical Raw Materials
DSI	Die Soldering Index
ECR	Environmental Country Risk
EI	Economic Importance
EIn	Extraction Index
HPDC	High Pressure Die Casting
Mk	Parameter for Molecular Orbital Calculation
NEI	Normalized Economic Importance
NSR	Normalized Supply Risk
RDI	Recycling Drawback Index
RM	Raw Material
SF	Sludge Factor
SGR	Sourcing and Geopolitical Risk
SR	Supply Risk
TA	Temperature of ageing
tA	time of ageing
TFR	Terminal Freezing Range
UTS or Rm	Ultimate Tensile Strength
Xi	Molar fraction
YS or ReH	Yield Strength
WP	Work Package

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1. Strategy for design and identification of new alloys with reduced CRM

1.1. Outcome from Tasks 2.1 and 2.2, and approach of Deliverable D2.3

Deliverable D2.1 individuated the specifications required by the low CRM aluminium alloys to be developed in the frame of SALEMA activities, referred to the following base-systems:

- AlSi10MnMg, AlMg and Al4MgFe systems for HPDC Demonstrators
- 5000 and 6000 series for Wrought (Extrusion, Stamping) Demonstrators.

The strategy and the criteria to be developed and implemented to minimise CRM content must be focussed, obviously, on the main alloying elements amounts, Mg and Si, whose reduction needs to be compensated by elements and/or treatments offering good technological and mechanical performance.

In Deliverable D2.2, for each group of alloys targeted (for HPDC, for extrusion and for rolling & stamping) the theoretical models more suitable for describing the key-characteristics required have been reviewed and investigated. Based on such models, included those implemented in Thermocalc software [1], state-of-the-art or properly developed tools have been identified for the evaluation of the characteristics mentioned above, as summarised in Table 1.

Conceptual area	Characteristic of phenomenon to be modelled	Category of model
CRM content	Criticality Index	Properly developed
Castability	Fluidity (as the inverse of viscosity)	Thermo-Calc Software
	Solidification shrinkage	+ elaboration
	Slag/dross formation tendency	+ elaboration
	Die soldering tendency	+ elaboration
	Hot tearing tendency	+ elaboration
Hot working attitude, extrudability	Solid solution element at processing temperature	Properly developed
Mechanical compensation of Si and Mg decrease in alloys	Alternative elements for solid solution strengthening	+ elaboration
	Grain refinement	Properly developed
	Improving of heat treatment	Properly developed
	Improving work hardening	Properly developed

Table 1 – Categories of the models adopted in this Deliverable

Key features, approaches and strategies of these models and tools are detailed below, with reference to the main conceptual areas identified: Criticality, Castability, Hot Working Attitude and Extrudability, Mechanical compensation of Si and Mg decrease in alloys.

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CRITICALITY

Evaluation of Criticality Index

Excel database containing information about alloy designation, condition, and chemical composition; elements that are critical, based on European Commission resolution, and the corresponding value of the overall criticality index are collected. The CI_A assessment for a specific alloy can be achieved simply by inserting its composition, in such excel file.

CASTABILITY

Viscosity

Viscosity (and, consequently, fluidity) of alloys depending on composition, are evaluated by Themo-Calc modelling; results can be extracted with reference to the relevant HPDC processing temperature range, i.e. considering 700, 680 and 650°C.

Solidification Shrinkage

Expected solidification shrinkage can be calculated by

- Determination of Liquidus and Solidus temperatures, under equilibrium conditions, of the alloy (by Thermo-Calc),
- Determination of the corresponding values of the volume of a known amount of the alloy (by Thermo-Calc),
- Calculation of the volume change (in %) in the liquidus-solidus transition (i.e. the solidification shrinkage)

Slag/dross formation tendency

Slag/dross formation tendency can be estimated by

- Evaluating, by means of Thermo-Calc simulations, the amount and temperature of formation of α-$Al_{15}(Fe,Mn,Cr)_3Si_2$-type phase
- Evaluating SF, Sludge Forming Temperature and Sludge fraction by equations (8), (9) and (10)

Results deriving these criteria must be compared, in order to have a balanced view of alloy behaviour.

Die Soldering tendency

Evaluation and ranking of the die-soldering tendency can be performed by

- Evaluating, for the range of compositions where it is possible the DSI,
- Evaluating, for all systems, the values of EIn, by equation (11)
- Evaluating, by means of Thermo-Calc software, on a selected (from the two previous stage) group of alloys, the Critical Temperature for die-soldering

Hot Tearing tendency

Evaluation and ranking of hot tearing tendency can be performed by

- Calculation of TFR by the software Thermo-Calc (existing phases and their fraction at the different temperatures estimated for non-equilibrium using Gulliver-Scheil approach [17])
- Defining hot tearing tendency as directly proportional to the amplitude of TFR.

HOT WORKING ATTITUDE AND EXTRUDABILITY

Hot Workability

Evaluation and ranking of attitude to hot workability can be estimated by simplified models based on solid solution strengthening as a function of alloys composition, considering that, at processing temperature, all alloying elements are expected to be in solid solution

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MECHANICAL COMPENSATION OF Si AND Mg DECREASE IN ALLOYS

SOLID SOLUTION STRENGTHENING

$\Delta\sigma_{SS}$ for each candidate alloy can be estimated by

- Evaluation of expected content of solid solution elements, by means of Themo-Calc software or by existing equilibrium diagrams,
- Applying equations [Y] and/or [Y], with implemented amount of solute elements and coefficients reported in Table 9.

GRAIN REFINEMENT

For taking into account grain refinement effects on alloys mechanical performance (also in terms of mechanical compensation of Si and Mg decrease), the strategy is:

- possible use of Ti as micro-alloying element,
- estimation of typical grain size ranges associated to reasonable processing (casting, extrusion, rolling & stamping) conditions,
- evaluation of related effects on mechanical behaviour by means of equation (13).

PRECIPITATION HARDENING

Process maps can be elaborated for some selected alloys systems and used to define the best processing conditions (to be tested in experimental campaigns) to achieve, by proper tuning, the requirements individuated for SALEMA Demonstrators.

IMPROVING WORK HARDENING

Process maps can be elaborated for some selected alloys systems and used to define, by proper tuning, the best processing conditions (to be tested in experimental campaigns) to achieve the requirements individuated for SALEMA Demonstrators.

Deliverable D2.3 presents the results achieved by applying such models and tools to a wide set of compositions, to select the specific systems offering the (theoretical) best compromise among processing properties, expected performance and low criticality characteristics. On these specific systems, experimental campaigns will be performed in next stages of SALEMA Project, to verify “in field” the best solutions, to be finally implemented in industrial production.

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2. New casting alloys with reduced CRM content

2.1. Systems investigated and design of variants

Deliverable D2.1 individuated the specifications required by the low CRM aluminium alloys to be developed in the frame of SALEMA activities; for what concerns HPDC processes and related Demonstrators, the following base-systems have been individuated:

- AlMg,
- AlMg4Fe,
- AlSi10MnMg.

AlMg is a system in which Si amount is close to zero (0.2% max) and Mg amount is kept as low as possible (from 2.1 to 2.7%); possible reinforcing actions are associated to selected amounts of Mn, Zn and Co; for the purpose of analysed done in this Deliverable, these alloys are identified as **set 1**.

AlMg4Fe is a system in which Si amount is close to zero (0.2% max), Mg amount is kept as low as possible (from 3.8 to 4.1%), and Fe may be useful for potential strengthening actions; possible reinforcing actions are associated to selected amounts of Cu, Mn, Zn and Ti; for the purpose of analysed done in this Deliverable, these alloys are identified as **set 2**.

AlSi10MnMg is a well-known system, in which three sub-systems can be individuated

- AlSi10MnMg0.3, with good fluidity and possible reinforcing actions associated to selected amounts of Cu, Mn, Zn and Ti (Table 2, **sets 3, 4 and 5**),
- AlSi10MnMg0.2, with good fluidity, minimisation of Mg and possible reinforcing actions associated to selected amounts of Cu, Mg, Zn and Ti (Table 3, **sets 6, 7 and 8**),
- AlSi8MnMg0.3, with sufficient castability, due to minimisation of Si, and possible reinforcing actions associated to selected amounts of Cu, Mg, Zn and Ti (Table 4, **sets 9, 10 and 11**).

Table 5 and Table 6 collects, respectively, the full lists of alloys of potential interest in **AlMg** and **AlMg4Fe** systems. From the composition ranges individuated in Tables 2-4, full lists of alloys of potential interest and investigated in the **AlSi10MnMg** system are reported in Tables 7-16.
On the variants designed in the frame of those systems, criteria and tools to individuate optimal alloys have been applied.

AlSi10MnMg0.3		*Si*	*Fe*	*Cu*	*Mn*	*Mg*	*Cr*	*Ni*	*Zn*	*Pb*	*Sn*	*Ti*
Set	3	9-11,5	0-0,2	0-0,03	0,45-0,65	0,25-0,35	0-0,03	0-0,03	0-0,07	0-0,03	0-0,03	0,05-0,15
Set	4	9-11,5	0-0,2	0,05-0,1	0,45-0,65	0,25-0,35	0-0,03	0-0,03	0-0,07	0-0,03	0-0,03	0,05-0,15
Set	5	9-11,5	0-0,2	0,05-0,1	0,45-0,65	0,25-0,35	0-0,03	0-0,03	0,1-0,15	0-0,03	0-0,03	0,05-0,15

Table 2 – Group of alloys, and related range of variation in composition in AlSi10MnMg0.3 sub-system

AlSi10MnMg0.2		*Si*	*Fe*	*Cu*	*Mn*	*Mg*	*Cr*	*Ni*	*Zn*	*Pb*	*Sn*	*Ti*
Set	6	9-11,5	0-0,2	0-0,03	0,45-0,65	0,15-0,25	0-0,03	0-0,03	0-0,07	0-0,03	0-0,03	0,05-0,15
Set	7	9-11,5	0,2-0,3	0-0,03	0,45-0,65	0,15-0,25	0-0,03	0-0,03	0-0,07	0-0,03	0-0,03	0,05-0,15
Set	8	9-11,5	0,2-0,3	0,05-0,1	0,6-0,8	0,15-0,25	0-0,03	0-0,03	0-0,07	0-0,03	0-0,03	0,05-0,15

Table 3 – Group of alloys, and related range of variation in composition in AlSi10MnMg0.2 sub-system

AlSi8MnMg0.3		*Si*	*Fe*	*Cu*	*Mn*	*Mg*	*Cr*	*Ni*	*Zn*	*Pb*	*Sn*	*Ti*
Set	9	7,5-9	0-0,2	0-0,03	0,45-0,65	0,25-0,35	0-0,03	0-0,03	0-0,07	0-0,03	0-0,03	0,05-0,15
Set	10	7,5-9	0-0,2	0-0,03	0,45-0,65	0,15-0,25	0-0,03	0-0,03	0-0,07	0-0,03	0-0,03	0,05-0,15
Set	11	7,5-9	0-0,2	0,2-0,3	0,45-0,65	0,15-0,25	0-0,03	0-0,03	0-0,07	0-0,03	0-0,03	0,05-0,15

Table 4 – Group of alloys, and related range of variation in composition in AlSi8MnMg0.3 sub-system

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Al-Mg System		Si	Fe	Cu	Mn	Mg	Zn	Ti	Co	Ca	Na
	min	0,2	0	0	0,8	2,4	0	0	0,3	0	0
	max	0,3	0,15	0,05	1,1	3	0,08	0,2	0,4	0,001	0,001
variant	1	0,2	0	0	0,8	2,4	0	0	0,3	0	0
variant	2	0,2	0	0	0,9	2,4	0	0	0,3	0	0
variant	3	0,2	0	0	1	2,4	0	0	0,3	0	0
variant	4	0,2	0	0	1,1	2,4	0	0	0,3	0	0
variant	5	0,2	0	0	1,2	2,4	0	0	0,3	0	0
variant	6	0,2	0,1	0	0,8	2,4	0	0	0,3	0	0
variant	7	0,2	0,1	0	1,1	2,4	0	0	0,3	0	0
variant	8	0,2	0,15	0	0,8	2,4	0	0	0,3	0	0
variant	9	0,2	0,15	0	1,1	2,4	0	0	0,3	0	0
variant	10	0,2	0,2	0	0,8	2,4	0	0	0,3	0	0
variant	11	0,2	0,2	0	1,1	2,4	0	0	0,3	0	0
variant	12	0,2	0	0	0,8	2,7	0	0	0,3	0	0
variant	13	0,2	0	0	0,9	2,7	0	0	0,3	0	0
variant	14	0,2	0	0	1	2,7	0	0	0,3	0	0
variant	15	0,2	0	0	1,1	2,7	0	0	0,3	0	0
variant	16	0,2	0	0	1,2	2,7	0	0	0,3	0	0
variant	17	0,2	0,1	0	0,8	2,7	0	0	0,3	0	0
variant	18	0,2	0,1	0	1,1	2,7	0	0	0,3	0	0
variant	19	0,2	0,15	0	0,8	2,7	0	0	0,3	0	0
variant	20	0,2	0,15	0	1,1	2,7	0	0	0,3	0	0
variant	21	0,2	0,2	0	0,8	2,7	0	0	0,3	0	0
variant	22	0,2	0,2	0	1,1	2,7	0	0	0,3	0	0
variant	23	0,2	0	0	0,8	2,1	0	0	0,3	0	0
variant	24	0,2	0	0	0,9	2,1	0	0	0,3	0	0
variant	25	0,2	0	0	1	2,1	0	0	0,3	0	0
variant	26	0,2	0	0	1,1	2,1	0	0	0,3	0	0
variant	27	0,2	0	0	1,2	2,1	0	0	0,3	0	0
variant	28	0,2	0,1	0	0,8	2,1	0	0	0,3	0	0
variant	29	0,2	0,1	0	1,1	2,1	0	0	0,3	0	0
variant	30	0,2	0,15	0	0,8	2,1	0	0	0,3	0	0
variant	31	0,2	0,15	0	1,1	2,1	0	0	0,3	0	0
variant	32	0,2	0,2	0	0,8	2,1	0	0	0,3	0	0
variant	33	0,2	0,2	0	1,1	2,1	0	0	0,3	0	0
variant	34	0,2	0	0	0,8	2,4	0,1	0	0,3	0	0
variant	35	0,2	0	0	0,9	2,4	0,1	0	0,3	0	0
variant	36	0,2	0	0	1	2,4	0,1	0	0,3	0	0
variant	37	0,2	0	0	1,1	2,4	0,1	0	0,3	0	0
variant	38	0,2	0	0	1,2	2,4	0,1	0	0,3	0	0
variant	39	0,2	0,1	0	0,8	2,4	0,1	0	0,3	0	0
variant	40	0,2	0,1	0	1,1	2,4	0,1	0	0,3	0	0
variant	41	0,2	0,15	0	0,8	2,4	0,1	0	0,3	0	0
variant	42	0,2	0,15	0	1,1	2,4	0,1	0	0,3	0	0
variant	43	0,2	0,2	0	0,8	2,4	0,1	0	0,3	0	0
variant	44	0,2	0,2	0	1,1	2,4	0,1	0	0,3	0	0

Table 5 – List of alloys, and related composition in AlMg system

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Al-Mg4-Fe System		Si	Fe	Cu	Mn	Mg	Zn	Ti	Co	Ca	Sr
min		0	1,5	0	0	4,1	0	0	0	0	0
max		0,2	1,7	0,2	0,15	4,5	0,3	0,2	0	0	0,1
variant	1	0,1	1,6	0	0	4,1	0	0	0	0	0
variant	2	0,1	1,6	0,1	0	4,1	0	0	0	0	0
variant	3	0,1	1,6	0,2	0	4,1	0	0	0	0	0
variant	4	0,1	1,6	0	0,1	4,1	0	0	0	0	0
variant	5	0,1	1,6	0,1	0,1	4,1	0	0	0	0	0
variant	6	0,1	1,6	0,2	0,1	4,1	0	0	0	0	0
variant	7	0,1	1,6	0	0,2	4,1	0	0	0	0	0
variant	8	0,1	1,6	0,1	0,2	4,1	0	0	0	0	0
variant	9	0,1	1,6	0,2	0,2	4,1	0	0	0	0	0
variant	10	0,1	1,6	0	0	4,1	0,2	0	0	0	0
variant	11	0,1	1,6	0,1	0	4,1	0,2	0	0	0	0
variant	12	0,1	1,6	0,2	0	4,1	0,2	0	0	0	0
variant	13	0,1	1,6	0	0,1	4,1	0,2	0	0	0	0
variant	14	0,1	1,6	0,1	0,1	4,1	0,2	0	0	0	0
variant	15	0,1	1,6	0,2	0,1	4,1	0,2	0	0	0	0
variant	16	0,1	1,6	0	0,2	4,1	0,2	0	0	0	0
variant	17	0,1	1,6	0,1	0,2	4,1	0,2	0	0	0	0
variant	18	0,1	1,6	0,2	0,2	4,1	0,2	0	0	0	0
variant	19	0,1	1,6	0	0	4,1	0,4	0	0	0	0
variant	20	0,1	1,6	0,1	0	4,1	0,4	0	0	0	0
variant	21	0,1	1,6	0,2	0	4,1	0,4	0	0	0	0
variant	22	0,1	1,6	0	0,1	4,1	0,4	0	0	0	0
variant	23	0,1	1,6	0,1	0,1	4,1	0,4	0	0	0	0
variant	24	0,1	1,6	0,2	0,1	4,1	0,4	0	0	0	0
variant	25	0,1	1,6	0	0,2	4,1	0,4	0	0	0	0
variant	26	0,1	1,6	0,1	0,2	4,1	0,4	0	0	0	0
variant	27	0,1	1,6	0,2	0,2	4,1	0,4	0	0	0	0
variant	28	0,1	1,6	0	0	3,8	0,2	0	0	0	0
variant	29	0,1	1,6	0,1	0	3,8	0,2	0	0	0	0
variant	30	0,1	1,6	0,2	0	3,8	0,2	0	0	0	0
variant	31	0,1	1,6	0	0,1	3,8	0,2	0	0	0	0
variant	32	0,1	1,6	0,1	0,1	3,8	0,2	0	0	0	0
variant	33	0,1	1,6	0,2	0,1	3,8	0,2	0	0	0	0
variant	34	0,1	1,6	0	0,2	3,8	0,2	0	0	0	0
variant	35	0,1	1,6	0,1	0,2	3,8	0,2	0	0	0	0
variant	36	0,1	1,6	0,2	0,2	3,8	0,2	0	0	0	0
variant	37	0,1	1,6	0	0	4,1	0,2	0,15	0	0	0
variant	38	0,1	1,6	0	0	4,1	0,2	0,1	0	0	0
variant	39	0,1	1,6	0,1	0	4,1	0,2	0,15	0	0	0
variant	40	0,1	1,6	0,1	0	4,1	0,2	0,1	0	0	0
variant	41	0,1	1,6	0,2	0	4,1	0,2	0,15	0	0	0
variant	42	0,1	1,6	0,2	0	4,1	0,2	0,1	0	0	0
variant	43	0,1	1,6	0	0,1	4,1	0,2	0,15	0	0	0
variant	44	0,1	1,6	0	0,1	4,1	0,2	0,1	0	0	0
variant	45	0,1	1,6	0,1	0,1	4,1	0,2	0,15	0	0	0
variant	46	0,1	1,6	0,1	0,1	4,1	0,2	0,1	0	0	0
variant	47	0,1	1,6	0,2	0,1	4,1	0,2	0,15	0	0	0
variant	48	0,1	1,6	0,2	0,1	4,1	0,2	0,1	0	0	0
variant	49	0,1	1,6	0	0,2	4,1	0,2	0,15	0	0	0
variant	50	0,1	1,6	0	0,2	4,1	0,2	0,1	0	0	0
variant	51	0,1	1,6	0,1	0,2	4,1	0,2	0,15	0	0	0
variant	52	0,1	1,6	0,1	0,2	4,1	0,2	0,1	0	0	0
variant	53	0,1	1,6	0,2	0,2	4,1	0,2	0,15	0	0	0
variant	54	0,1	1,6	0,2	0,2	4,1	0,2	0,1	0	0	0

Table 6 – List of alloys, and related composition in AlMg4Fe system

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AlSi10MnMg0.3 - Set 3		Si	Fe	Cu	Mn	Mg	Zn	Ti
Variant	1	9	0,2	0,02	0,45	0,25	0,05	0,1
Variant	2	9	0,2	0,02	0,55	0,25	0,05	0,1
Variant	3	9	0,2	0,02	0,65	0,25	0,05	0,1
Variant	4	9	0,2	0,02	0,45	0,3	0,05	0,1
Variant	5	9	0,2	0,02	0,55	0,3	0,05	0,1
Variant	6	9	0,2	0,02	0,65	0,3	0,05	0,1
Variant	7	9	0,2	0,02	0,45	0,35	0,05	0,1
Variant	8	9	0,2	0,02	0,55	0,35	0,05	0,1
Variant	9	9	0,2	0,02	0,65	0,35	0,05	0,1
Variant	10	10,25	0,2	0,02	0,45	0,25	0,05	0,1
Variant	11	10,25	0,2	0,02	0,55	0,25	0,05	0,1
Variant	12	10,25	0,2	0,02	0,65	0,25	0,05	0,1
Variant	13	10,25	0,2	0,02	0,45	0,3	0,05	0,1
Variant	14	10,25	0,2	0,02	0,55	0,3	0,05	0,1
Variant	15	10,25	0,2	0,02	0,65	0,3	0,05	0,1
Variant	16	10,25	0,2	0,02	0,45	0,35	0,05	0,1
Variant	17	10,25	0,2	0,02	0,55	0,35	0,05	0,1
Variant	18	10,25	0,2	0,02	0,65	0,35	0,05	0,1
Variant	19	11,5	0,2	0,02	0,45	0,25	0,05	0,1
Variant	20	11,5	0,2	0,02	0,55	0,25	0,05	0,1
Variant	21	11,5	0,2	0,02	0,65	0,25	0,05	0,1
Variant	22	11,5	0,2	0,02	0,45	0,3	0,05	0,1
Variant	23	11,5	0,2	0,02	0,55	0,3	0,05	0,1
Variant	24	11,5	0,2	0,02	0,65	0,3	0,05	0,1
Variant	25	11,5	0,2	0,02	0,45	0,35	0,05	0,1
Variant	26	11,5	0,2	0,02	0,55	0,35	0,05	0,1
Variant	27	11,5	0,2	0,02	0,65	0,35	0,05	0,1

Table 7 – List of alloys, and related composition in AlSi10MnMg0.3 sub-system, set 3

AlSi10MnMg0.3 - Set 4		Si	Fe	Cu	Mn	Mg	Zn	Ti
Variant	1	9	0,2	0,08	0,45	0,25	0,05	0,1
Variant	2	9	0,2	0,08	0,55	0,25	0,05	0,1
Variant	3	9	0,2	0,08	0,65	0,25	0,05	0,1
Variant	4	9	0,2	0,08	0,45	0,3	0,05	0,1
Variant	5	9	0,2	0,08	0,55	0,3	0,05	0,1
Variant	6	9	0,2	0,08	0,65	0,3	0,05	0,1
Variant	7	9	0,2	0,08	0,45	0,35	0,05	0,1
Variant	8	9	0,2	0,08	0,55	0,35	0,05	0,1
Variant	9	9	0,2	0,08	0,65	0,35	0,05	0,1
Variant	10	10,25	0,2	0,08	0,45	0,25	0,05	0,1
Variant	11	10,25	0,2	0,08	0,55	0,25	0,05	0,1
Variant	12	10,25	0,2	0,08	0,65	0,25	0,05	0,1
Variant	13	10,25	0,2	0,08	0,45	0,3	0,05	0,1
Variant	14	10,25	0,2	0,08	0,55	0,3	0,05	0,1
Variant	15	10,25	0,2	0,08	0,65	0,3	0,05	0,1
Variant	16	10,25	0,2	0,08	0,45	0,35	0,05	0,1
Variant	17	10,25	0,2	0,08	0,55	0,35	0,05	0,1
Variant	18	10,25	0,2	0,08	0,65	0,35	0,05	0,1
Variant	19	11,5	0,2	0,08	0,45	0,25	0,05	0,1
Variant	20	11,5	0,2	0,08	0,55	0,25	0,05	0,1
Variant	21	11,5	0,2	0,08	0,65	0,25	0,05	0,1
Variant	22	11,5	0,2	0,08	0,45	0,3	0,05	0,1
Variant	23	11,5	0,2	0,08	0,55	0,3	0,05	0,1
Variant	24	11,5	0,2	0,08	0,65	0,3	0,05	0,1
Variant	25	11,5	0,2	0,08	0,45	0,35	0,05	0,1
Variant	26	11,5	0,2	0,08	0,55	0,35	0,05	0,1
Variant	27	11,5	0,2	0,08	0,65	0,35	0,05	0,1

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003785

Table 8 – List of alloys, and related composition in AlSi10MnMg0.3 sub-system, set 4

AlSi10MnMg0.3 - Set 5		Si	Fe	Cu	Mn	Mg	Zn	Ti
Variant	1	9	0,2	0,08	0,45	0,25	0,12	0,1
Variant	2	9	0,2	0,08	0,55	0,25	0,12	0,1
Variant	3	9	0,2	0,08	0,65	0,25	0,12	0,1
Variant	4	9	0,2	0,08	0,45	0,3	0,12	0,1
Variant	5	9	0,2	0,08	0,55	0,3	0,12	0,1
Variant	6	9	0,2	0,08	0,65	0,3	0,12	0,1
Variant	7	9	0,2	0,08	0,45	0,35	0,12	0,1
Variant	8	9	0,2	0,08	0,55	0,35	0,12	0,1
Variant	9	9	0,2	0,08	0,65	0,35	0,12	0,1
Variant	10	10,25	0,2	0,08	0,45	0,25	0,12	0,1
Variant	11	10,25	0,2	0,08	0,55	0,25	0,12	0,1
Variant	12	10,25	0,2	0,08	0,65	0,25	0,12	0,1
Variant	13	10,25	0,2	0,08	0,45	0,3	0,12	0,1
Variant	14	10,25	0,2	0,08	0,55	0,3	0,12	0,1
Variant	15	10,25	0,2	0,08	0,65	0,3	0,12	0,1
Variant	16	10,25	0,2	0,08	0,45	0,35	0,12	0,1
Variant	17	10,25	0,2	0,08	0,55	0,35	0,12	0,1
Variant	18	10,25	0,2	0,08	0,65	0,35	0,12	0,1
Variant	19	11,5	0,2	0,08	0,45	0,25	0,12	0,1
Variant	20	11,5	0,2	0,08	0,55	0,25	0,12	0,1
Variant	21	11,5	0,2	0,08	0,65	0,25	0,12	0,1
Variant	22	11,5	0,2	0,08	0,45	0,3	0,12	0,1
Variant	23	11,5	0,2	0,08	0,55	0,3	0,12	0,1
Variant	24	11,5	0,2	0,08	0,65	0,3	0,12	0,1
Variant	25	11,5	0,2	0,08	0,45	0,35	0,12	0,1
Variant	26	11,5	0,2	0,08	0,55	0,35	0,12	0,1
Variant	27	11,5	0,2	0,08	0,65	0,35	0,12	0,1

Table 9 – List of alloys, and related composition in AlSi10MnMg0.3 sub-system, set 5

AlSi10MnMg0.2 - Set 6		Si	Fe	Cu	Mn	Mg	Zn	Ti
Variant	1	9	0,2	0,02	0,45	0,15	0,05	0,1
Variant	2	9	0,2	0,02	0,55	0,15	0,05	0,1
Variant	3	9	0,2	0,02	0,65	0,15	0,05	0,1
Variant	4	9	0,2	0,02	0,45	0,2	0,05	0,1
Variant	5	9	0,2	0,02	0,55	0,2	0,05	0,1
Variant	6	9	0,2	0,02	0,65	0,2	0,05	0,1
Variant	7	9	0,2	0,02	0,45	0,25	0,05	0,1
Variant	8	9	0,2	0,02	0,55	0,25	0,05	0,1
Variant	9	9	0,2	0,02	0,65	0,25	0,05	0,1
Variant	10	10,25	0,2	0,02	0,45	0,15	0,05	0,1
Variant	11	10,25	0,2	0,02	0,55	0,15	0,05	0,1
Variant	12	10,25	0,2	0,02	0,65	0,15	0,05	0,1
Variant	13	10,25	0,2	0,02	0,45	0,2	0,05	0,1
Variant	14	10,25	0,2	0,02	0,55	0,2	0,05	0,1
Variant	15	10,25	0,2	0,02	0,65	0,2	0,05	0,1
Variant	16	10,25	0,2	0,02	0,45	0,25	0,05	0,1
Variant	17	10,25	0,2	0,02	0,55	0,25	0,05	0,1
Variant	18	10,25	0,2	0,02	0,65	0,25	0,05	0,1
Variant	19	11,5	0,2	0,02	0,45	0,15	0,05	0,1
Variant	20	11,5	0,2	0,02	0,55	0,15	0,05	0,1
Variant	21	11,5	0,2	0,02	0,65	0,15	0,05	0,1
Variant	22	11,5	0,2	0,02	0,45	0,2	0,05	0,1
Variant	23	11,5	0,2	0,02	0,55	0,2	0,05	0,1
Variant	24	11,5	0,2	0,02	0,65	0,2	0,05	0,1
Variant	25	11,5	0,2	0,02	0,45	0,25	0,05	0,1
Variant	26	11,5	0,2	0,02	0,55	0,25	0,05	0,1

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Variant	27	11,5	0,2	0,02	0,65	0,25	0,05	0,1

Table 10 – List of alloys, and related composition in AlSi10MnMg0.2 sub-system, set 6

AlSi10MnMg0.2 - Set 7		***Si***	***Fe***	***Cu***	***Mn***	***Mg***	***Zn***	***Ti***
Variant	1	9	0,25	0,02	0,45	0,15	0,05	0,1
Variant	2	9	0,25	0,02	0,55	0,15	0,05	0,1
Variant	3	9	0,25	0,02	0,65	0,15	0,05	0,1
Variant	4	9	0,25	0,02	0,45	0,2	0,05	0,1
Variant	5	9	0,25	0,02	0,55	0,2	0,05	0,1
Variant	6	9	0,25	0,02	0,65	0,2	0,05	0,1
Variant	7	9	0,25	0,02	0,45	0,25	0,05	0,1
Variant	8	9	0,25	0,02	0,55	0,25	0,05	0,1
Variant	9	9	0,25	0,02	0,65	0,25	0,05	0,1
Variant	10	10,25	0,25	0,02	0,45	0,15	0,05	0,1
Variant	11	10,25	0,25	0,02	0,55	0,15	0,05	0,1
Variant	12	10,25	0,25	0,02	0,65	0,15	0,05	0,1
Variant	13	10,25	0,25	0,02	0,45	0,2	0,05	0,1
Variant	14	10,25	0,25	0,02	0,55	0,2	0,05	0,1
Variant	15	10,25	0,25	0,02	0,65	0,2	0,05	0,1
Variant	16	10,25	0,25	0,02	0,45	0,25	0,05	0,1
Variant	17	10,25	0,25	0,02	0,55	0,25	0,05	0,1
Variant	18	10,25	0,25	0,02	0,65	0,25	0,05	0,1
Variant	19	11,5	0,25	0,02	0,45	0,15	0,05	0,1
Variant	20	11,5	0,25	0,02	0,55	0,15	0,05	0,1
Variant	21	11,5	0,25	0,02	0,65	0,15	0,05	0,1
Variant	22	11,5	0,25	0,02	0,45	0,2	0,05	0,1
Variant	23	11,5	0,25	0,02	0,55	0,2	0,05	0,1
Variant	24	11,5	0,25	0,02	0,65	0,2	0,05	0,1
Variant	25	11,5	0,25	0,02	0,45	0,25	0,05	0,1
Variant	26	11,5	0,25	0,02	0,55	0,25	0,05	0,1
Variant	27	11,5	0,25	0,02	0,65	0,25	0,05	0,1

Table 11 – List of alloys, and related composition in AlSi10MnMg0.2 sub-system, set 7

AlSi10MnMg0.2 - Set 8		***Si***	***Fe***	***Cu***	***Mn***	***Mg***	***Zn***	***Ti***
Variant	1	9	0,2	0,08	0,6	0,15	0,05	0,1
Variant	2	9	0,2	0,08	0,7	0,15	0,05	0,1
Variant	3	9	0,2	0,08	0,8	0,15	0,05	0,1
Variant	4	9	0,2	0,08	0,6	0,2	0,05	0,1
Variant	5	9	0,2	0,08	0,7	0,2	0,05	0,1
Variant	6	9	0,2	0,08	0,8	0,2	0,05	0,1
Variant	7	9	0,2	0,08	0,6	0,25	0,05	0,1
Variant	8	9	0,2	0,08	0,7	0,25	0,05	0,1
Variant	9	9	0,2	0,08	0,8	0,25	0,05	0,1
Variant	10	10,25	0,2	0,08	0,6	0,15	0,05	0,1
Variant	11	10,25	0,2	0,08	0,7	0,15	0,05	0,1
Variant	12	10,25	0,2	0,08	0,8	0,15	0,05	0,1
Variant	13	10,25	0,2	0,08	0,6	0,2	0,05	0,1
Variant	14	10,25	0,2	0,08	0,7	0,2	0,05	0,1
Variant	15	10,25	0,2	0,08	0,8	0,2	0,05	0,1
Variant	16	10,25	0,2	0,08	0,6	0,25	0,05	0,1
Variant	17	10,25	0,2	0,08	0,7	0,25	0,05	0,1
Variant	18	10,25	0,2	0,08	0,8	0,25	0,05	0,1
Variant	19	11,5	0,2	0,08	0,6	0,15	0,05	0,1
Variant	20	11,5	0,2	0,08	0,7	0,15	0,05	0,1
Variant	21	11,5	0,2	0,08	0,8	0,15	0,05	0,1
Variant	22	11,5	0,2	0,08	0,6	0,2	0,05	0,1
Variant	23	11,5	0,2	0,08	0,7	0,2	0,05	0,1
Variant	24	11,5	0,2	0,08	0,8	0,2	0,05	0,1

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Variant	25	11,5	0,2	0,08	0,6	0,25	0,05	0,1
Variant	26	11,5	0,2	0,08	0,7	0,25	0,05	0,1
Variant	27	11,5	0,2	0,08	0,8	0,25	0,05	0,1

Table 12 – List of alloys, and related composition in AlSi10MnMg0.2 sub-system, set 8

AlSi10MnMg0.2 - Set 8.1		*Si*	*Fe*	*Cu*	*Mn*	*Mg*	*Zn*	*Ti*
Variant	1	9	0,3	0,08	0,6	0,15	0,05	0,1
Variant	2	9	0,3	0,08	0,7	0,15	0,05	0,1
Variant	3	9	0,3	0,08	0,8	0,15	0,05	0,1
Variant	4	9	0,3	0,08	0,6	0,2	0,05	0,1
Variant	5	9	0,3	0,08	0,7	0,2	0,05	0,1
Variant	6	9	0,3	0,08	0,8	0,2	0,05	0,1
Variant	7	9	0,3	0,08	0,6	0,25	0,05	0,1
Variant	8	9	0,3	0,08	0,7	0,25	0,05	0,1
Variant	9	9	0,3	0,08	0,8	0,25	0,05	0,1
Variant	10	10,25	0,3	0,08	0,6	0,15	0,05	0,1
Variant	11	10,25	0,3	0,08	0,7	0,15	0,05	0,1
Variant	12	10,25	0,3	0,08	0,8	0,15	0,05	0,1
Variant	13	10,25	0,3	0,08	0,6	0,2	0,05	0,1
Variant	14	10,25	0,3	0,08	0,7	0,2	0,05	0,1
Variant	15	10,25	0,3	0,08	0,8	0,2	0,05	0,1
Variant	16	10,25	0,3	0,08	0,6	0,25	0,05	0,1
Variant	17	10,25	0,3	0,08	0,7	0,25	0,05	0,1
Variant	18	10,25	0,3	0,08	0,8	0,25	0,05	0,1
Variant	19	11,5	0,3	0,08	0,6	0,15	0,05	0,1
Variant	20	11,5	0,3	0,08	0,7	0,15	0,05	0,1
Variant	21	11,5	0,3	0,08	0,8	0,15	0,05	0,1
Variant	22	11,5	0,3	0,08	0,6	0,2	0,05	0,1
Variant	23	11,5	0,3	0,08	0,7	0,2	0,05	0,1
Variant	24	11,5	0,3	0,08	0,8	0,2	0,05	0,1
Variant	25	11,5	0,3	0,08	0,6	0,25	0,05	0,1
Variant	26	11,5	0,3	0,08	0,7	0,25	0,05	0,1
Variant	27	11,5	0,3	0,08	0,8	0,25	0,05	0,1

Table 13 – List of alloys, and related composition in AlSi10MnMg0.2 sub-system, set 8.1

AlSi8MnMg0.3 - Set 9		*Si*	*Fe*	*Cu*	*Mn*	*Mg*	*Zn*	*Ti*
Variant	1	7,5	0,2	0,02	0,45	0,25	0,05	0,1
Variant	2	7,5	0,2	0,02	0,55	0,25	0,05	0,1
Variant	3	7,5	0,2	0,02	0,65	0,25	0,05	0,1
Variant	4	7,5	0,2	0,02	0,45	0,3	0,05	0,1
Variant	5	7,5	0,2	0,02	0,55	0,3	0,05	0,1
Variant	6	7,5	0,2	0,02	0,65	0,3	0,05	0,1
Variant	7	7,5	0,2	0,02	0,45	0,35	0,05	0,1
Variant	8	7,5	0,2	0,02	0,55	0,35	0,05	0,1
Variant	9	7,5	0,2	0,02	0,65	0,35	0,05	0,1
Variant	10	8,25	0,2	0,02	0,45	0,25	0,05	0,1
Variant	11	8,25	0,2	0,02	0,55	0,25	0,05	0,1
Variant	12	8,25	0,2	0,02	0,65	0,25	0,05	0,1
Variant	13	8,25	0,2	0,02	0,45	0,3	0,05	0,1
Variant	14	8,25	0,2	0,02	0,55	0,3	0,05	0,1
Variant	15	8,25	0,2	0,02	0,65	0,3	0,05	0,1
Variant	16	8,25	0,2	0,02	0,45	0,35	0,05	0,1
Variant	17	8,25	0,2	0,02	0,55	0,35	0,05	0,1
Variant	18	8,25	0,2	0,02	0,65	0,35	0,05	0,1
Variant	19	9	0,2	0,02	0,45	0,25	0,05	0,1
Variant	20	9	0,2	0,02	0,55	0,25	0,05	0,1
Variant	21	9	0,2	0,02	0,65	0,25	0,05	0,1
Variant	22	9	0,2	0,02	0,45	0,3	0,05	0,1

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Variant	23	9	0,2	0,02	0,55	0,3	0,05	0,1
Variant	24	9	0,2	0,02	0,65	0,3	0,05	0,1
Variant	25	9	0,2	0,02	0,45	0,35	0,05	0,1
Variant	26	9	0,2	0,02	0,55	0,35	0,05	0,1
Variant	27	9	0,2	0,02	0,65	0,35	0,05	0,1

Table 14 – List of alloys, and related composition in AlSi8MnMg0.3 sub-system, set 9

AlSi8MnMg0.3 - Set 10		*Si*	*Fe*	*Cu*	*Mn*	*Mg*	*Zn*	*Ti*
Variant	1	7,5	0,2	0,02	0,45	0,15	0,05	0,1
Variant	2	7,5	0,2	0,02	0,55	0,15	0,05	0,1
Variant	3	7,5	0,2	0,02	0,65	0,15	0,05	0,1
Variant	4	7,5	0,2	0,02	0,45	0,2	0,05	0,1
Variant	5	7,5	0,2	0,02	0,55	0,2	0,05	0,1
Variant	6	7,5	0,2	0,02	0,65	0,2	0,05	0,1
Variant	7	7,5	0,2	0,02	0,45	0,25	0,05	0,1
Variant	8	7,5	0,2	0,02	0,55	0,25	0,05	0,1
Variant	9	7,5	0,2	0,02	0,65	0,25	0,05	0,1
Variant	10	8,25	0,2	0,02	0,45	0,15	0,05	0,1
Variant	11	8,25	0,2	0,02	0,55	0,15	0,05	0,1
Variant	12	8,25	0,2	0,02	0,65	0,15	0,05	0,1
Variant	13	8,25	0,2	0,02	0,45	0,2	0,05	0,1
Variant	14	8,25	0,2	0,02	0,55	0,2	0,05	0,1
Variant	15	8,25	0,2	0,02	0,65	0,2	0,05	0,1
Variant	16	8,25	0,2	0,02	0,45	0,25	0,05	0,1
Variant	17	8,25	0,2	0,02	0,55	0,25	0,05	0,1
Variant	18	8,25	0,2	0,02	0,65	0,25	0,05	0,1
Variant	19	9	0,2	0,02	0,45	0,15	0,05	0,1
Variant	20	9	0,2	0,02	0,55	0,15	0,05	0,1
Variant	21	9	0,2	0,02	0,65	0,15	0,05	0,1
Variant	22	9	0,2	0,02	0,45	0,2	0,05	0,1
Variant	23	9	0,2	0,02	0,55	0,2	0,05	0,1
Variant	24	9	0,2	0,02	0,65	0,2	0,05	0,1
Variant	25	9	0,2	0,02	0,45	0,25	0,05	0,1
Variant	26	9	0,2	0,02	0,55	0,25	0,05	0,1
Variant	27	9	0,2	0,02	0,65	0,25	0,05	0,1

Table 15 – List of alloys, and related composition in AlSi8MnMg0.3 sub-system, set 10

AlSi8MnMg0.3 - Set 11		*Si*	*Fe*	*Cu*	*Mn*	*Mg*	*Zn*	*Ti*
Variant	1	7,5	0,2	0,25	0,45	0,15	0,05	0,1
Variant	2	7,5	0,2	0,25	0,55	0,15	0,05	0,1
Variant	3	7,5	0,2	0,25	0,65	0,15	0,05	0,1
Variant	4	7,5	0,2	0,25	0,45	0,2	0,05	0,1
Variant	5	7,5	0,2	0,25	0,55	0,2	0,05	0,1
Variant	6	7,5	0,2	0,25	0,65	0,2	0,05	0,1
Variant	7	7,5	0,2	0,25	0,45	0,25	0,05	0,1
Variant	8	7,5	0,2	0,25	0,55	0,25	0,05	0,1
Variant	9	7,5	0,2	0,25	0,65	0,25	0,05	0,1
Variant	10	8,25	0,2	0,25	0,45	0,15	0,05	0,1
Variant	11	8,25	0,2	0,25	0,55	0,15	0,05	0,1
Variant	12	8,25	0,2	0,25	0,65	0,15	0,05	0,1
Variant	13	8,25	0,2	0,25	0,45	0,2	0,05	0,1
Variant	14	8,25	0,2	0,25	0,55	0,2	0,05	0,1
Variant	15	8,25	0,2	0,25	0,65	0,2	0,05	0,1
Variant	16	8,25	0,2	0,25	0,45	0,25	0,05	0,1
Variant	17	8,25	0,2	0,25	0,55	0,25	0,05	0,1
Variant	18	8,25	0,2	0,25	0,65	0,25	0,05	0,1
Variant	19	9	0,2	0,25	0,45	0,15	0,05	0,1
Variant	20	9	0,2	0,25	0,55	0,15	0,05	0,1

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Variant	21	9	0,2	0,25	0,65	0,15	0,05	0,1
Variant	22	9	0,2	0,25	0,45	0,2	0,05	0,1
Variant	23	9	0,2	0,25	0,55	0,2	0,05	0,1
Variant	24	9	0,2	0,25	0,65	0,2	0,05	0,1
Variant	25	9	0,2	0,25	0,45	0,25	0,05	0,1
Variant	26	9	0,2	0,25	0,55	0,25	0,05	0,1
Variant	27	9	0,2	0,25	0,65	0,25	0,05	0,1

Table 16 – List of alloys, and related composition in AlSi8MnMg0.3 sub-system, set 11

Table 17 shows the characteristic or phenomenon which has been modelled to individuate optimal alloys for HPDC.

Conceptual area	Characteristic or phenomenon to be modelled	For HPDC
CRM content	Criticality Index	√
Castability	Fluidity (as the inverse of viscosity)	√
	Solidification shrinkage	√
	Slag/dross formation tendency	√
	Die soldering tendency	√
	Hot tearing tendency	√
Hot working attitude, extrudability	Solid solution element at processing temperature	
Mechanical compensation of Si and Mg decrease in alloys	Alternative elements for solid solution strengthening	√
	Grain refinement	√
	Improving of heat treatment	√
	Improving work hardening	

Table 17 – Models applied to individuate optimal alloys for HPDC

2.2. Evaluation of Criticality Index

The evaluation of Criticality Index has been performed on the basis of the model described in Deliverable D2.2 [2-5], applied to all systems and sub-systems individuated in the previous paragraph. To have a more compact and immediate vision of the Indexes, they are presented with reference to AlMg and AlMg4Fe sets and variants in Table 18 and of AlSi10MnMg sets and variants in Table 19. For each set, the variants showing best (i.e. lowest) Criticality Index are evidenced by a green background. A preliminary view of the results suggests the ranking shown in Figure 1, with the Al-Mg system offering the best performance.

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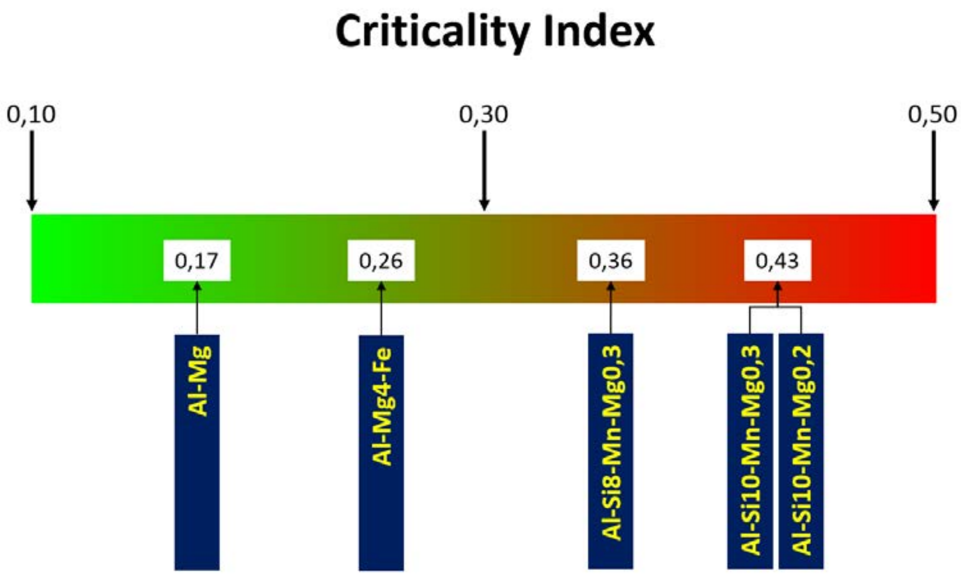

Figure 1 – Ranking in terms of Criticality Index for the alloy systems investigated

		Criticality Index	
Variants		**Al-Mg – set 1**	**Al-Mg4-Fe – Set 2**
variant	1	0,19	0,28
variant	2	0,19	0,28
variant	3	0,19	0,28
variant	4	0,19	0,28
variant	5	0,19	0,28
variant	6	0,19	0,28
variant	7	0,19	0,28
variant	8	0,19	0,28
variant	9	0,19	0,28
variant	10	0,19	0,28
variant	11	0,19	0,28
variant	12	0,21	0,28
variant	13	0,21	0,28
variant	14	0,21	0,28
variant	15	0,21	0,28
variant	16	0,21	0,28
variant	17	0,21	0,28
variant	18	0,21	0,28
variant	19	0,21	0,28
variant	20	0,21	0,28
variant	21	0,21	0,28
variant	22	0,21	0,28
variant	23	0,17	0,28
variant	24	0,17	0,28
variant	25	0,17	0,28
variant	26	0,17	0,28
variant	27	0,17	0,28
variant	28	0,17	0,28
variant	29	0,17	0,26
variant	30	0,17	0,26
variant	31	0,17	0,26
variant	32	0,17	0,26
variant	33	0,17	0,26
variant	34	0,19	0,26
variant	35	0,19	0,26

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variant	36	0,19	0,26
variant	37	0,19	0,26
variant	38	0,19	0,29
variant	39	0,19	0,29
variant	40	0,19	0,29
variant	41	0,19	0,29
variant	42	0,19	0,29
variant	43	0,19	0,29
variant	44	0,19	0,29
variant	45		0,29
variant	46		0,29
variant	47		0,29
variant	48		0,29
variant	49		0,29
variant	50		0,29
variant	51		0,29
variant	52		0,29
variant	53		0,29
variant	54		0,29

Table 18 – Value of Criticality Index for alloys of the Al-Ma and AlMg4Fe systems

		Criticality Index									
		AlSi10MnMg0.3			AlSi10MnMg0.2				AlSi8MnMg0.3		
Variants		**Set 3**	**Set 4**	**Set 5**	**Set 6**	**Set 7**	**Set 8**	**Set 8.1**	**Set 9**	**Set 10**	**Set 11**
variant	1	0,43	0,43	0,43	0,43	0,43	0,43	0,43	0,36	0,36	0,36
variant	2	0,43	0,43	0,43	0,43	0,43	0,43	0,43	0,36	0,36	0,36
variant	3	0,43	0,43	0,43	0,43	0,43	0,43	0,43	0,36	0,36	0,36
variant	4	0,44	0,44	0,44	0,43	0,43	0,43	0,43	0,37	0,36	0,36
variant	5	0,44	0,44	0,44	0,43	0,43	0,43	0,43	0,37	0,36	0,36
variant	6	0,44	0,44	0,44	0,43	0,43	0,43	0,43	0,37	0,36	0,36
variant	7	0,44	0,44	0,44	0,43	0,43	0,43	0,43	0,37	0,36	0,36
variant	8	0,44	0,44	0,44	0,43	0,43	0,43	0,43	0,37	0,36	0,36
variant	9	0,44	0,44	0,44	0,43	0,43	0,43	0,43	0,37	0,36	0,36
variant	10	0,49	0,49	0,49	0,48	0,48	0,48	0,48	0,40	0,39	0,39
variant	11	0,49	0,49	0,49	0,48	0,48	0,48	0,48	0,40	0,39	0,39
variant	12	0,49	0,49	0,49	0,48	0,48	0,48	0,48	0,40	0,39	0,39
variant	13	0,49	0,49	0,49	0,49	0,49	0,49	0,49	0,40	0,39	0,39
variant	14	0,49	0,49	0,49	0,49	0,49	0,49	0,49	0,40	0,39	0,39
variant	15	0,49	0,49	0,49	0,49	0,49	0,49	0,49	0,40	0,39	0,39
variant	16	0,50	0,50	0,50	0,49	0,49	0,49	0,49	0,40	0,40	0,40
variant	17	0,50	0,50	0,50	0,49	0,49	0,49	0,49	0,40	0,40	0,40
variant	18	0,50	0,50	0,50	0,49	0,49	0,49	0,49	0,40	0,40	0,40
variant	19	0,55	0,55	0,55	0,54	0,54	0,54	0,54	0,43	0,43	0,43
variant	20	0,55	0,55	0,55	0,54	0,54	0,54	0,54	0,43	0,43	0,43
variant	21	0,55	0,55	0,55	0,54	0,54	0,54	0,54	0,43	0,43	0,43
variant	22	0,55	0,55	0,55	0,54	0,54	0,54	0,54	0,44	0,43	0,43
variant	23	0,55	0,55	0,55	0,54	0,54	0,54	0,54	0,44	0,43	0,43
variant	24	0,55	0,55	0,55	0,54	0,54	0,54	0,54	0,44	0,43	0,43
variant	25	0,55	0,55	0,55	0,55	0,55	0,55	0,55	0,44	0,43	0,43
variant	26	0,55	0,55	0,55	0,55	0,55	0,55	0,55	0,44	0,43	0,43
variant	27	0,55	0,55	0,55	0,55	0,55	0,55	0,55	0,44	0,43	0,43

Table 19 – Value of Criticality Index for alloys of the AlSi10MnMg systems and sub-systems

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2.3. Evaluation of Castability

As discussed in Deliverable D2.2, castability can be seen as a technological property of metals and alloys, associated to set of various conditions, parameters and characteristics [6]. Its evaluation, with reference to various alloying systems, must be carried out considering the effect that composition has on

- Fluidity (which, in a simplified approach, can be considered as the inverse of viscosity)
- Solidification shrinkage,
- Slag/dross formation tendency,
- Die soldering tendency,
- Hot tearing tendency.

The comprehensive evaluation of castability derives from an integrated view of such characteristics, taking into account information coming from the models and tools identified in Deliverable D2.2. In the next sections, results and considerations obtained by using these models and tools to the various sets of variants will be presented and discussed.

2.3.1. Fluidity

Tables 20 and 21 display the viscosity values for all sets of alloys, calculated at 680°C, which is the typical casting temperature for HPDC alloys (calculations have been performed also at 650°C and 700°C, with substantially similar results). Green background highlights the best variants.

		Kinematic Viscosity at 680°C [m^2/s] · 10^{-7}	
Variants		Al-Mg – set 1	Al-Mg4-Fe – Set 2
variant	1	5,2739	5,2514
variant	2	5,2804	5,2510
variant	3	5,2870	5,2506
variant	4	5,2935	5,2579
variant	5	5,3001	5,2575
variant	6	5,2853	5,2571
variant	7	5,3050	5,2644
variant	8	5,2911	5,2640
variant	9	5,3108	5,2636
variant	10	5,2968	5,2462
variant	11	5,3165	5,2457
variant	12	5,2494	5,2453
variant	13	5,2559	5,2527
variant	14	5,2624	5,2522
variant	15	5,2689	5,2518
variant	16	5,2754	5,2592
variant	17	5,2607	5,2588
variant	18	5,2803	5,2584
variant	19	5,2664	5,2409
variant	20	5,2860	5,2405
variant	21	5,2721	5,2401
variant	22	5,2918	5,2474
variant	23	5,2988	5,2470
variant	24	5,3054	5,2466
variant	25	5,3119	5,2539
variant	26	5,3185	5,2535
variant	27	5,3251	5,2531
variant	28	5,3103	5,2698
variant	29	5,3301	5,2694
variant	30	5,3160	5,2689

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variant	31	5,3359	5,2764
variant	32	5,3218	5,2759
variant	33	5,3417	5,2755
variant	34	5,2712	5,2829
variant	35	5,2777	5,2825
variant	36	5,2843	5,2820
variant	37	5,2908	5,2584
variant	38	5,2974	5,2566
variant	39	5,2826	5,2579
variant	40	5,3023	5,2562
variant	41	5,2884	5,2575
variant	42	5,3081	5,2558
variant	43	5,2941	5,2649
variant	44	5,3138	5,2631
variant	45		5,2645
variant	46		5,2627
variant	47		5,2641
variant	48		5,2623
variant	49		5,2714
variant	50		5,2696
variant	51		5,2710
variant	52		5,2692
variant	53		5,2706
variant	54		5,2689

Table 20 – Value of Viscosity, at 680°C, for alloys of the Al-Mg and AlMg4Fe systems

		Kinematic Viscosity at 680°C [m²/s] · 10^{-7}									
		AlSi10MnMg0.3			AlSi10MnMg0.2				AlSi8MnMg0.3		
Variants		**Set 3**	**Set 4**	**Set 5**	**Set 6**	**Set 7**	**Set 8**	**Set 8.1**	**Set 9**	**Set 10**	**Set 11**
variant	1	3,8459	3,8464	3,8456	3,85	3,85	3,8568	3,8666	4,0215	4,0241	4,0255
variant	2	3,8516	3,8522	3,8513	3,85	3,86	3,8625	3,8724	4,0273	4,0299	4,0313
variant	3	3,8573	3,8579	3,8570	3,86	3,86	3,8683	3,8781	4,0331	4,0357	4,0371
variant	4	3,8450	3,8450	3,8482	3,85	3,85	3,8559	3,8657	4,0202	4,0228	4,0242
variant	5	3,8507	3,8513	3,8504	3,85	3,86	3,8616	3,8715	4,0260	4,0286	4,0300
variant	6	3,8565	3,8570	3,8562	3,86	3,86	3,8674	3,8773	4,0318	4,0344	4,0358
variant	7	3,8442	3,8447	3,8439	3,85	3,85	3,8550	3,8649	4,0189	4,0215	4,0229
variant	8	3,8499	3,8504	3,8496	3,85	3,86	3,8608	3,8706	4,0247	4,0273	4,0287
variant	9	3,8556	3,8561	3,8553	3,86	3,86	3,8665	3,8764	4,0305	4,0331	4,0346
variant	10	3,7209	3,7216	3,7208	3,72	3,73	3,7312	3,7410	3,9300	3,9322	3,9339
variant	11	3,7265	3,7272	3,7265	3,73	3,73	3,7369	3,7467	3,9358	3,9379	3,9397
variant	12	3,7322	3,7329	3,7322	3,73	3,74	3,7426	3,7524	3,9415	3,9437	3,9455
variant	13	3,7203	3,7210	3,7203	3,72	3,73	3,7306	3,7404	3,9289	3,9311	3,9329
variant	14	3,7260	3,7267	3,7260	3,73	3,73	3,7363	3,7461	3,9347	3,9368	3,9386
variant	15	3,7317	3,7324	3,7316	3,73	3,74	3,7421	3,7518	3,9404	3,9426	3,9444
variant	16	3,7198	3,7204	3,7197	3,72	3,73	3,7301	3,7398	3,9279	3,9300	3,9318
variant	17	3,7254	3,7261	3,7254	3,73	3,73	3,7358	3,7455	3,9336	3,9358	3,9376
variant	18	3,7311	3,7318	3,7311	3,73	3,74	3,7415	3,7513	3,9394	3,9415	3,9433
variant	19	3,6132	3,6140	3,6134	3,61	3,62	3,6231	3,6328	3,8459	3,8477	3,8497
variant	20	3,6188	3,6197	3,6191	3,62	3,62	3,6288	3,6385	3,8516	3,8534	3,8555
variant	21	3,6245	3,6254	3,6248	3,63	3,63	3,6345	3,6442	3,8573	3,8591	3,8612
variant	22	3,6129	3,6137	3,6131	3,61	3,62	3,6228	3,6325	3,8450	3,8468	3,8489
variant	23	3,6186	3,6194	3,6188	3,62	3,62	3,6285	3,6382	3,8507	3,8525	3,8546
variant	24	3,6242	3,6251	3,6245	3,62	3,63	3,6342	3,6439	3,8565	3,8582	3,8604
variant	25	3,6126	3,6134	3,6129	3,61	3,62	3,6225	3,6322	3,8442	3,8459	3,8480
variant	26	3,6183	3,6191	3,6185	3,62	3,62	3,6282	3,6379	3,8499	3,8516	3,8537
variant	27	3,6240	3,6248	3,6242	3,62	3,63	3,6339	3,6436	3,8556	3,8573	3,8595

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Table 21 – Value of Viscosity, at 680°C, for alloys of the AlSi10MnMg systems and sub-systems

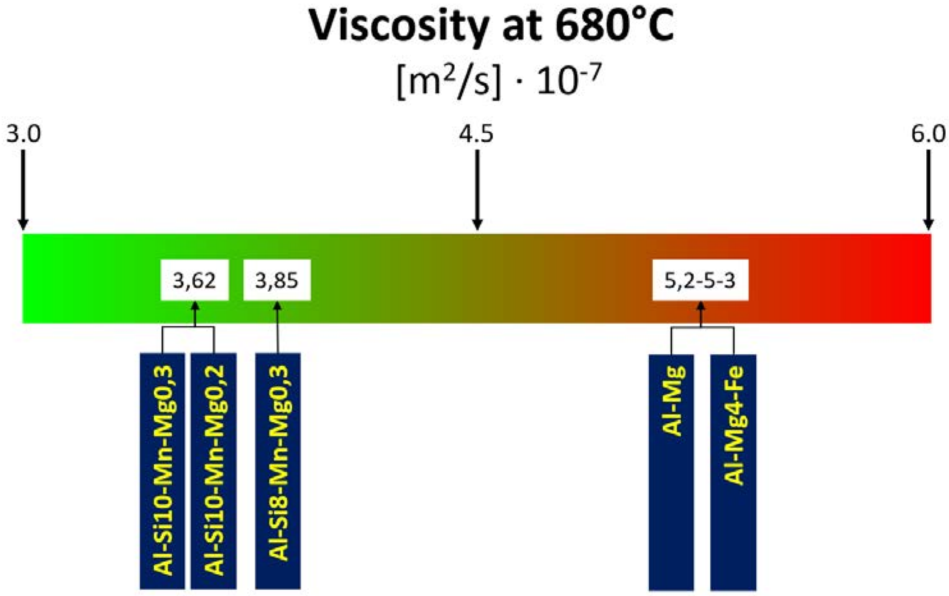

Figure 2 – Ranking in terms of Viscosity for the alloy systems investigated

Figure 2 summarise the results achieved, showing the well-known better behaviour of Al-Si systems with respect to Al-Mg ones. Al-Si10-Mn-Mg0,2 and Al-Si10-Mn-Mg0,3 present the lowest values of viscosity, i.e. the best fluidity. In particular, variants 19-27 in all Al-Si systems are the best options, due to their higher content of Silicon.

2.3.2. Solidification Shrinkage

Examples of Thermocalc output are shown in Figure 3a-c. Considering the alloy volume at the start and at the end of solidification, the solidification shrinkage has been calculated. Tables 22-25 display the solidus and liquidus Temperature (calculated under equilibrium conditions) as well as the volume solidification shrinkage values for all sets of alloys. As usual, green background evidences the best variants.

Figure 4 summarises the results achieved, showing the well-known better behaviour of Al-Si systems with respect to Al-Mg ones. Al-Si10-Mn-Mg0,2 and Al-Si10-Mn-Mg0,3 present the lowest values of viscosity, i.e. the best fluidity. In particular, variants 19-27 in Al-Si systems are the best options, due to their higher content of Silicon.

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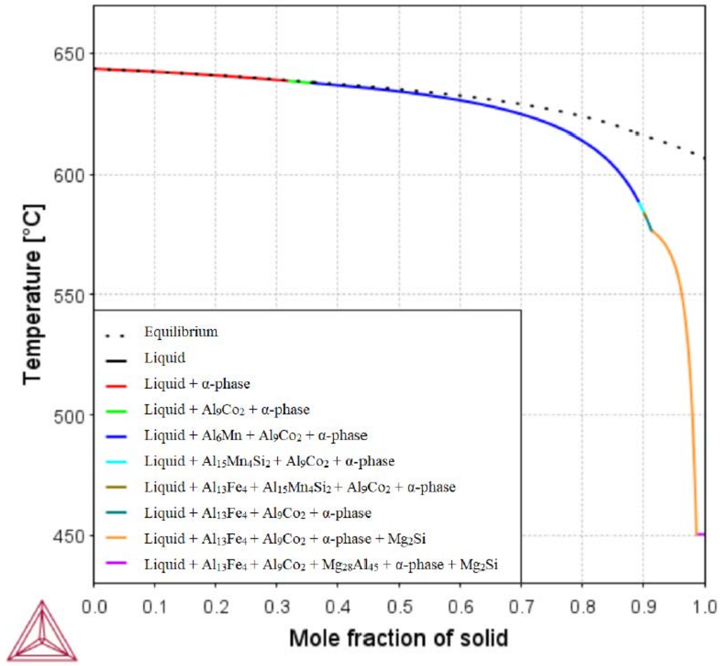

Figure 3a – Example of solidification curves for an alloy of Al-Mg system (set 1, variant n. 7)

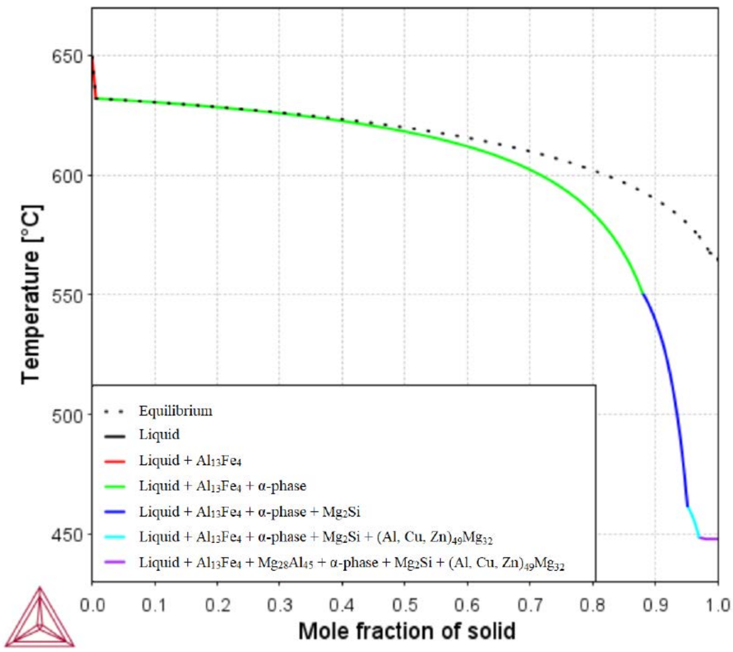

Figure 3b – Example of solidification curves for an alloy of Al-Mg4-Fe system (set 2, variant n. 15)

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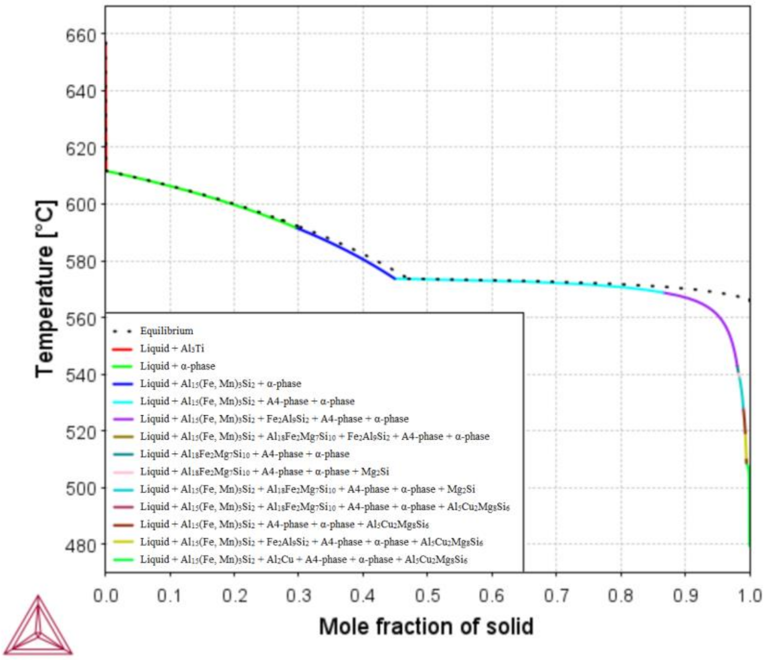

Figure 3c – Example of solidification curves for an alloy of AlSi8MnMg0.3 system (set 11, variant n. 1)

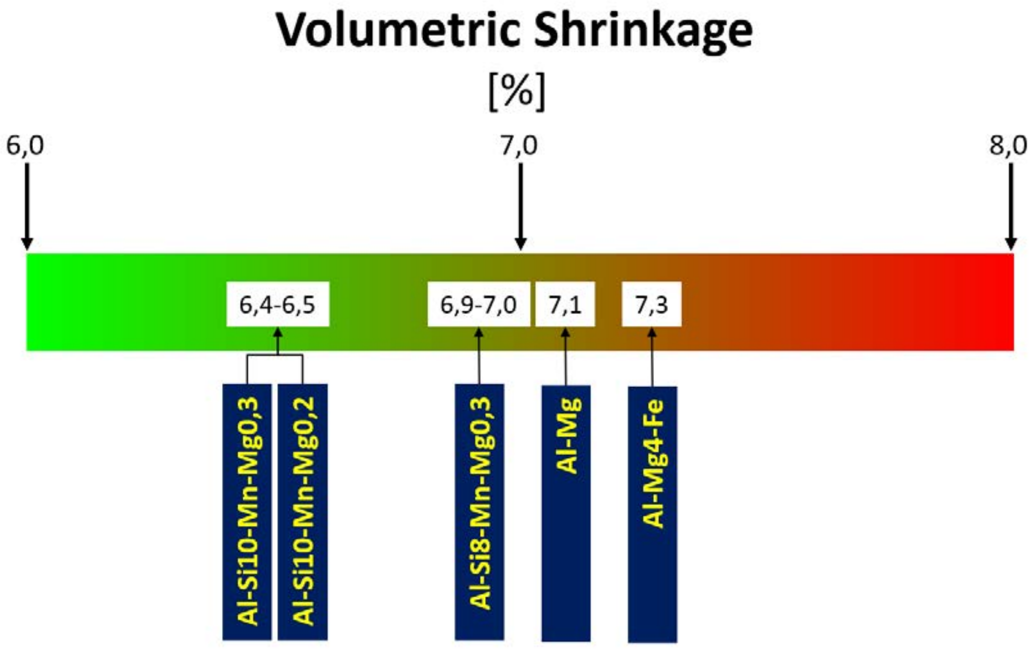

Figure 4 – Ranking in terms of Volumetric Shrinkage for the alloy systems investigated

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Variants		Al-Mg – set 1			Al-Mg4-Fe – Set 2		
		T_{liq} [°C]	T_{sol} [°C]	Shrinkage [%]	T_{liq} [°C]	T_{sol} [°C]	Shrinkage [%]
variant	1	644,37	604,05	7,12	645,30	574,93	7,26
variant	2	644,19	605,18	7,11	645,77	570,54	7,30
variant	3	644,01	606,19	7,11	646,24	566,31	7,34
variant	4	643,83	607,09	7,10	647,50	574,71	7,28
variant	5	643,65	607,89	7,09	647,95	570,52	7,32
variant	6	644,01	604,85	7,14	648,41	566,26	7,36
variant	7	643,46	606,77	7,14	649,63	574,62	7,31
variant	8	643,83	604,82	7,16	650,07	570,40	7,35
variant	9	643,28	606,02	7,18	650,51	566,11	7,39
variant	10	643,64	604,23	7,19	646,09	573,65	7,29
variant	11	643,10	605,39	7,22	646,57	569,42	7,33
variant	12	642,78	598,99	7,14	647,04	565,12	7,37
variant	13	642,60	600,15	7,13	648,26	573,65	7,31
variant	14	642,42	601,18	7,12	648,71	569,39	7,36
variant	15	642,23	602,10	7,12	649,17	565,07	7,40
variant	16	642,05	602,90	7,11	650,36	573,55	7,34
variant	17	642,42	599,94	7,15	650,80	569,26	7,38
variant	18	641,86	601,69	7,16	651,24	564,90	7,42
variant	19	642,23	599,87	7,17	646,89	572,58	7,33
variant	20	641,68	600,93	7,20	647,36	568,29	7,37
variant	21	642,05	599,26	7,21	647,84	563,92	7,41
variant	22	641,49	600,29	7,24	649,02	572,57	7,35
variant	23	645,96	609,13	7,10	649,47	568,25	7,39
variant	24	645,78	610,23	7,09	649,93	563,85	7,43
variant	25	645,60	611,21	7,08	651,09	572,46	7,37
variant	26	645,43	612,01	7,08	651,53	568,11	7,41
variant	27	645,25	612,89	7,07	651,97	563,68	7,46
variant	28	645,60	609,78	7,13	645,71	578,83	7,26
variant	29	645,07	611,84	7,12	646,18	573,59	7,31
variant	30	645,42	609,76	7,14	646,66	568,39	7,37
variant	31	644,89	611,10	7,16	647,83	577,56	7,30
variant	32	645,24	609,19	7,18	648,29	572,40	7,35
variant	33	644,70	610,48	7,20	648,74	568,37	7,39
variant	34	644,20	603,50	7,13	649,89	577,11	7,33
variant	35	644,02	604,62	7,12	650,33	572,30	7,37
variant	36	643,84	605,64	7,12	650,77	568,24	7,41
variant	37	643,65	606,54	7,11	701,33	572,83	7,94
variant	38	643,47	607,34	7,11	668,44	573,09	7,55
variant	39	643,83	604,33	7,15	701,43	568,49	7,98
variant	40	643,29	606,24	7,15	668,55	568,78	7,59
variant	41	643,65	604,33	7,17	701,54	564,07	8,02
variant	42	643,10	605,50	7,20	668,65	564,39	7,62
variant	43	643,47	603,74	7,20	701,45	572,82	7,95
variant	44	642,92	604,88	7,23	668,57	573,08	7,55
variant	45				701,56	568,45	7,98
variant	46				668,68	568,74	7,59
variant	47				701,66	564,00	8,02
variant	48				668,79	564,33	7,62
variant	49				701,57	572,70	7,94
variant	50				668,70	572,97	7,55
variant	51				701,68	568,30	7,98
variant	52				668,81	568,60	7,59
variant	53				701,79	563,82	8,02
variant	54				668,92	564,15	7,62

Table 22 – Value of $T_{liquidus}$ and $T_{solidus}$ (equilibrium) and volumetric shrinkage of the Al-Mg and AlMg4Fe systems

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003785

Variants		AlSi10MnMg0.3 – Set 3			AlSi10MnMg0.3 – Set 4			AlSi10MnMg0.3 – Set 5		
		T_{liq} [°C]	T_{sol} [°C]	Shrinkage [%]	T_{liq} [°C]	T_{sol} [°C]	Shrinkage [%]	T_{liq} [°C]	T_{sol} [°C]	Shrinkage [%]
variant	1	649,21	568,45	6,94	649,27	567,17	6,95	649,28	566,98	6,96
variant	2	649,34	568,55	6,97	649,40	567,25	6,98	649,41	567,07	6,98
variant	3	649,46	568,63	6,99	649,53	567,32	7,00	649,54	567,13	7,00
variant	4	649,55	567,24	6,95	649,62	565,94	6,96	649,62	565,75	6,96
variant	5	649,68	567,34	6,98	649,75	566,02	6,98	649,75	565,83	6,99
variant	6	649,80	567,41	7,00	649,87	567,41	7,00	649,88	565,89	7,00
variant	7	649,89	566,03	6,96	649,96	564,71	6,97	649,96	564,52	6,97
variant	8	650,02	566,12	6,98	650,09	564,79	6,99	650,09	564,60	6,99
variant	9	650,14	566,19	7,01	650,21	564,84	7,02	650,22	564,64	7,02
variant	10	642,02	568,35	7,09	642,09	567,05	6,63	642,09	566,87	6,63
variant	11	642,16	568,46	6,64	642,22	567,14	6,65	642,23	566,95	6,65
variant	12	642,29	568,53	6,67	642,36	567,20	6,67	642,36	567,01	6,68
variant	13	642,38	567,13	6,62	642,45	565,81	6,63	642,45	565,62	6,64
variant	14	642,51	567,23	6,65	642,58	565,89	6,66	642,58	565,70	6,66
variant	15	642,64	567,29	6,67	642,71	565,94	6,68	642,72	565,75	6,69
variant	16	642,74	565,90	6,63	642,80	564,56	6,64	642,81	564,37	6,65
variant	17	642,87	565,99	6,66	642,94	564,64	6,66	642,94	564,44	6,67
variant	18	643,00	566,06	6,68	643,07	564,69	6,69	643,08	564,49	6,69
variant	19	646,03	568,26	6,42	646,16	566,94	6,43	646,29	566,75	6,43
variant	20	646,05	568,36	6,44	646,18	567,02	6,45	646,31	566,83	6,45
variant	21	646,07	568,43	6,46	646,20	567,08	6,47	646,33	566,89	6,48
variant	22	646,34	567,02	6,42	646,47	565,67	6,43	646,59	565,48	6,44
variant	23	646,35	567,11	6,45	646,49	565,75	6,46	646,61	565,56	6,46
variant	24	646,37	567,41	6,74	646,51	566,07	6,75	646,63	565,89	6,76
variant	25	646,64	565,77	6,43	646,77	564,41	6,44	646,90	564,22	6,44
variant	26	646,66	565,86	6,45	646,79	564,48	6,46	646,92	564,29	6,47
variant	27	646,68	565,92	6,48	646,81	564,53	6,49	646,94	564,33	6,49

Table 23 – Value of $T_{liquidus}$ and $T_{solidus}$ (equilibrium) and volumetric shrinkage of the AlSi10MnMg0.3 sub-systems

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003785

Variants		AlSi10MnMg0.2 – Set 6			AlSi10MnMg0.2 – Set 7			AlSi10MnMg0.2 – Set 8			AlSi10MnMg0.2 – Set 8.1		
		T_{liq} [°C]	T_{sol} [°C]	Shrink. [%]	T_{liq} [°C]	T_{sol} [°C]	Shrink. [%]	T_{liq} [°C]	T_{sol} [°C]	Shrink. [%]	T_{liq} [°C]	T_{sol} [°C]	Shrink. [%]
variant	1	648,53	570,87	6,93	648,53	570,73	6,94	648,79	569,76	6,98	648,79	569,54	6,99
variant	2	648,66	570,98	6,95	648,66	570,86	6,96	648,92	569,83	7,00	648,92	569,62	7,01
variant	3	648,79	571,07	6,98	648,79	570,95	6,99	649,05	569,87	7,03	649,05	569,67	7,04
variant	4	648,87	569,66	6,94	648,87	569,52	6,95	649,13	568,53	6,98	649,13	568,30	7,00
variant	5	649,00	569,77	6,96	649,00	569,64	6,97	649,26	568,58	7,01	649,26	568,37	7,02
variant	6	649,13	569,85	6,99	649,13	569,73	6,99	649,38	568,62	7,03	649,39	568,42	7,05
variant	7	649,21	568,45	6,94	649,21	568,31	6,95	649,47	567,29	6,99	649,47	567,06	7,00
variant	8	649,34	568,55	6,97	649,34	568,42	6,98	649,60	567,34	7,02	649,60	567,12	7,03
variant	9	649,46	568,63	6,99	649,47	568,50	7,00	649,72	567,37	7,04	649,73	567,17	7,06
variant	10	641,31	570,81	6,60	641,31	570,64	6,61	641,58	569,69	6,65	641,59	569,46	6,66
variant	11	641,44	570,93	6,63	641,45	570,80	6,63	641,72	569,75	6,67	641,72	569,54	6,69
variant	12	641,58	571,01	6,65	641,58	570,89	6,66	641,85	569,79	6,70	641,86	569,59	6,71
variant	13	641,66	569,58	6,61	641,67	569,45	6,62	641,94	568,43	6,65	641,94	568,21	6,67
variant	14	641,80	569,69	6,63	641,80	569,56	6,64	642,07	568,49	6,68	642,08	568,27	6,70
variant	15	641,93	569,77	6,66	641,94	569,65	6,67	642,21	568,52	6,71	642,21	568,32	6,72
variant	16	642,02	568,35	6,62	642,02	568,22	6,62	642,29	567,17	6,66	642,30	566,95	6,68
variant	17	642,16	568,46	6,64	642,16	568,33	6,65	642,43	567,22	6,69	642,43	567,01	6,70
variant	18	642,29	568,53	6,67	642,29	568,41	6,67	642,56	567,26	6,71	642,57	567,05	6,73
variant	19	645,42	570,75	6,40	645,35	570,61	6,41	645,59	569,61	6,45	645,44	569,38	6,46
variant	20	645,44	570,87	6,43	645,37	570,74	6,43	645,61	569,67	6,47	645,46	569,45	6,48
variant	21	645,46	570,95	6,45	645,39	570,83	6,45	645,63	569,71	6,49	645,49	569,51	6,51
variant	22	645,73	569,50	6,41	645,66	569,37	6,42	645,89	568,33	6,45	645,75	568,11	6,47
variant	23	645,75	569,61	6,43	645,68	569,48	6,44	645,91	568,34	6,48	645,77	568,17	6,49
variant	24	645,77	569,69	6,46	645,70	569,57	6,46	645,93	568,42	6,50	645,79	568,22	6,51
variant	25	646,03	568,26	6,42	645,96	568,12	6,42	646,19	567,06	6,46	646,05	566,83	6,47
variant	26	646,05	568,36	6,44	645,98	568,23	6,45	646,21	567,10	6,48	646,07	566,89	6,50
variant	27	646,07	568,43	6,46	646,07	568,43	6,46	646,23	567,14	6,51	646,09	566,93	6,52

Table 24 – Value of $T_{liquidus}$ and $T_{solidus}$ (equilibrium) and volumetric shrinkage of the AlSi10MnMg0.2 sub-systems

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003785

Variants		AlSi8MnMg0.3 – Set 9			AlSi8MnMg0.3 – Set 10			AlSi8MnMg0.3 – Set 11		
		T_{liq} [°C]	T_{sol} [°C]	Shrinkage [%]	T_{liq} [°C]	T_{sol} [°C]	Shrinkage [%]	T_{liq} [°C]	T_{sol} [°C]	Shrinkage [%]
variant	1	657,16	568,55	7,31	656,52	570,93	7,30	656,76	566,36	7,32
variant	2	657,29	568,66	7,33	656,64	571,05	7,32	656,88	566,43	7,35
variant	3	657,41	568,74	7,36	656,77	571,14	7,34	657,01	566,47	7,37
variant	4	657,49	567,37	7,31	656,84	569,74	7,30	657,08	565,11	7,33
variant	5	657,61	567,47	7,34	656,96	569,86	7,32	657,21	565,16	7,36
variant	6	657,73	567,54	7,36	657,09	569,94	7,35	657,33	565,20	7,38
variant	7	657,81	566,18	7,32	657,16	568,55	7,31	657,40	563,85	7,34
variant	8	657,93	566,27	7,35	657,29	568,66	7,33	657,53	563,90	7,36
variant	9	658,05	566,34	7,37	657,41	568,74	7,36	657,65	563,93	7,39
variant	10	653,30	568,50	7,13	652,63	570,90	7,12	652,88	566,29	7,15
variant	11	653,42	568,61	7,15	652,76	571,02	7,14	653,01	566,35	7,17
variant	12	653,55	568,68	7,18	652,89	571,11	7,17	653,14	566,39	7,20
variant	13	653,63	567,30	7,14	652,96	569,70	7,12	653,21	565,02	7,15
variant	14	653,75	567,40	7,16	653,09	569,81	7,15	653,34	565,08	7,18
variant	15	653,88	567,47	7,19	653,22	569,89	7,17	653,47	565,11	7,20
variant	16	653,96	566,11	7,14	653,30	568,50	7,13	653,54	563,75	7,16
variant	17	654,08	566,20	7,17	653,42	568,61	7,15	653,67	563,80	7,18
variant	18	654,21	566,26	7,19	653,55	568,68	7,18	653,80	563,83	7,21
variant	19	649,21	568,45	6,94	648,53	570,87	6,93	648,78	566,22	6,96
variant	20	649,34	568,55	6,97	648,66	570,98	6,95	648,91	566,28	6,98
variant	21	649,46	568,63	6,99	648,79	571,07	6,98	649,04	566,32	7,01
variant	22	649,55	567,24	6,95	648,87	569,66	6,94	649,12	564,94	6,97
variant	23	649,68	567,34	6,98	649,00	569,77	6,96	649,25	564,99	6,99
variant	24	649,80	567,41	7,00	649,13	569,85	6,99	649,38	565,03	7,02
variant	25	649,89	566,03	6,96	649,21	568,45	6,94	649,46	563,66	6,98
variant	26	650,02	566,12	6,98	649,34	568,55	6,97	649,59	563,71	7,00
variant	27	650,14	566,19	7,01	649,46	568,63	6,99	649,72	563,74	7,03

Table 25 – Value of $T_{liquidus}$ and $T_{solidus}$ (equilibrium) and volumetric shrinkage of the AlSi8MnMg0.3 sub-systems

2.3.3. Slag/dross formation tendency

As reported in Deliverable D2.2, the tendency to slag/dross formation in alloys can be predicted by means of the Sludge Factor (SF, related to Fe, Mn and Cr content); models based on SF allow the estimation of sludge fraction [7].

Tables 26-29 display the SF and Sludge prediction for all sets of alloys. As usual, green background puts into evidence the best variants.

Figure 5 summarises the results achieved, showing that

- Al-Mg and AlMg4Fe present the highest values of Sludge Fraction, ranging, in the more favorable cases, from 0,5 tp 0,8%,
- AlSi8-Mn-Mg0,3 and Al-Si10-Mn-Mg0,3 present the lowest values of Sludge Fraction, ranging, in more favorable cases, from 0 to 0,35%,
- Al-Si10-Mn-Mg0,2 sub-systems show high variability, with Sludge Fraction values ranging from 0 to 0.8%.

Relevant information can be obtained also by Thermocalc simulations, from which the typical amount of $Al_{15}(Fe,Mn,Cr)_3Si_2$-type phase, both under equilibrium and non-equilibrium (Scheil equation) conditions, have been estimated. This intermetallic phase is usually associated to the presence of sludge phases in alloys. Table 30 shows the calculated amount of intermetallic ($Al_{15}(Fe,Mn,Cr)_3Si_2$-type) phase in all systems and sets of alloys investigated, with results in good agreement with the ranking presented in Figure 5.

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Variants		Al-Mg – set 1		Al-Mg4-Fe – Set 2	
		Sludge Factor (SF)	Sludge fraction (%)	Sludge Factor (SF)	Sludge fraction (%)
variant	1	1,60	0,500	1,60	0,50
variant	2	1,80	0,800	1,60	0,50
variant	3	2,00	1,100	1,60	0,50
variant	4	2,20	1,400	1,80	0,80
variant	5	2,40	1,700	1,80	0,80
variant	6	1,70	0,650	1,80	0,80
variant	7	2,30	1,550	2,00	1,10
variant	8	1,75	0,725	2,00	1,10
variant	9	2,35	1,625	2,00	1,10
variant	10	1,80	0,800	1,60	0,50
variant	11	2,40	1,700	1,60	0,50
variant	12	1,60	0,500	1,60	0,50
variant	13	1,80	0,800	1,80	0,80
variant	14	2,00	1,100	1,80	0,80
variant	15	2,20	1,400	1,80	0,80
variant	16	2,40	1,700	2,00	1,10
variant	17	1,70	0,650	2,00	1,10
variant	18	2,30	1,550	2,00	1,10
variant	19	1,75	0,725	1,60	0,50
variant	20	2,35	1,625	1,60	0,50
variant	21	1,80	0,800	1,60	0,50
variant	22	2,40	1,700	1,80	0,80
variant	23	1,60	0,500	1,80	0,80
variant	24	1,80	0,800	1,80	0,80
variant	25	2,00	1,100	2,00	1,10
variant	26	2,20	1,400	2,00	1,10
variant	27	2,40	1,700	2,00	1,10
variant	28	1,70	0,650	1,60	0,50
variant	29	2,30	1,550	1,60	0,50
variant	30	1,75	0,725	1,60	0,50
variant	31	2,35	1,625	1,80	0,80
variant	32	1,80	0,800	1,80	0,80
variant	33	2,40	1,700	1,80	0,80
variant	34	1,60	0,500	2,00	1,10
variant	35	1,80	0,800	2,00	1,10
variant	36	2,00	1,100	2,00	1,10
variant	37	2,20	1,400	1,60	0,50
variant	38	2,40	1,700	1,60	0,50
variant	39	1,70	0,650	1,60	0,50
variant	40	2,30	1,550	1,60	0,50
variant	41	1,75	0,725	1,60	0,50
variant	42	2,35	1,625	1,60	0,50
variant	43	1,80	0,800	1,80	0,80
variant	44	2,40	1,700	1,80	0,80
variant	45			1,80	0,80
variant	46			1,80	0,80
variant	47			1,80	0,80
variant	48			1,80	0,80
variant	49			2,00	1,10
variant	50			2,00	1,10
variant	51			2,00	1,10
variant	52			2,00	1,10
variant	53			2,00	1,10

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variant	54			2,00	1,10

Table 26 – Values of Sludge Factor and Sludge fraction for alloys of the Al-Mg and AlMg4Fe systems

Variants		AlSi10MnMg0.3 – Set 3		AlSi10MnMg0.3 – Set 4		AlSi10MnMg0.3 – Set 5	
		Sludge Factor (SF)	Sludge fraction (%)	Sludge Factor (SF)	Sludge fraction (%)	Sludge Factor (SF)	Sludge fraction (%)
variant	1	1,1	0,00	1,1	0,00	1,1	0,00
variant	2	1,3	0,05	1,3	0,05	1,3	0,05
variant	3	1,5	0,35	1,5	0,35	1,5	0,35
variant	4	1,1	0,00	1,1	0,00	1,1	0,00
variant	5	1,3	0,05	1,3	0,05	1,3	0,05
variant	6	1,5	0,35	1,5	0,35	1,5	0,35
variant	7	1,1	0,00	1,1	0,00	1,1	0,00
variant	8	1,3	0,05	1,3	0,05	1,3	0,05
variant	9	1,5	0,35	1,5	0,35	1,5	0,35
variant	10	1,1	0,00	1,1	0,00	1,1	0,00
variant	11	1,3	0,05	1,3	0,05	1,3	0,05
variant	12	1,5	0,35	1,5	0,35	1,5	0,35
variant	13	1,1	0,00	1,1	0,00	1,1	0,00
variant	14	1,3	0,05	1,3	0,05	1,3	0,05
variant	15	1,5	0,35	1,5	0,35	1,5	0,35
variant	16	1,1	0,00	1,1	0,00	1,1	0,00
variant	17	1,3	0,05	1,3	0,05	1,3	0,05
variant	18	1,5	0,35	1,5	0,35	1,5	0,35
variant	19	1,1	0,00	1,1	0,00	1,1	0,00
variant	20	1,3	0,05	1,3	0,05	1,3	0,05
variant	21	1,5	0,35	1,5	0,35	1,5	0,35
variant	22	1,1	0,00	1,1	0,00	1,1	0,00
variant	23	1,3	0,05	1,3	0,05	1,3	0,05
variant	24	1,5	0,35	1,5	0,35	1,5	0,35
variant	25	1,1	0,00	1,1	0,00	1,1	0,00
variant	26	1,3	0,05	1,3	0,05	1,3	0,05
variant	27	1,5	0,35	1,5	0,35	1,5	0,35

Table 27 – Values of Sludge Factor and Sludge fraction for alloys of the AlSi10MnMg0.3 sub-systems

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003785

Variants		AlSi10MnMg0.2 – Set 6		AlSi10MnMg0.2 – Set 7		AlSi10MnMg0.2 – Set 8		AlSi10MnMg0.2 – Set 8.1	
		Sludge Factor (SF)	Sludge fraction (%)	Sludge Factor (SF)	Sludge fraction (%)	Sludge Factor (SF)	Sludge fraction (%)	Sludge Factor (SF)	Sludge fraction (%)
variant	1	1,1	-0,25	1,15	-0,175	1,4	0,2	1,5	0,35
variant	2	1,3	0,05	1,35	0,125	1,6	0,5	1,7	0,65
variant	3	1,5	0,35	1,55	0,425	1,8	0,8	1,9	0,95
variant	4	1,1	-0,25	1,15	-0,175	1,4	0,2	1,5	0,35
variant	5	1,3	0,05	1,35	0,125	1,6	0,5	1,7	0,65
variant	6	1,5	0,35	1,55	0,425	1,8	0,8	1,9	0,95
variant	7	1,1	-0,25	1,15	-0,175	1,4	0,2	1,5	0,35
variant	8	1,3	0,05	1,35	0,125	1,6	0,5	1,7	0,65
variant	9	1,5	0,35	1,55	0,425	1,8	0,8	1,9	0,95
variant	10	1,1	-0,25	1,15	-0,175	1,4	0,2	1,5	0,35
variant	11	1,3	0,05	1,35	0,125	1,6	0,5	1,7	0,65
variant	12	1,5	0,35	1,55	0,425	1,8	0,8	1,9	0,95
variant	13	1,1	-0,25	1,15	-0,175	1,4	0,2	1,5	0,35
variant	14	1,3	0,05	1,35	0,125	1,6	0,5	1,7	0,65
variant	15	1,5	0,35	1,55	0,425	1,8	0,8	1,9	0,95
variant	16	1,1	-0,25	1,15	-0,175	1,4	0,2	1,5	0,35
variant	17	1,3	0,05	1,35	0,125	1,6	0,5	1,7	0,65
variant	18	1,5	0,35	1,55	0,425	1,8	0,8	1,9	0,95
variant	19	1,1	-0,25	1,15	-0,175	1,4	0,2	1,5	0,35
variant	20	1,3	0,05	1,35	0,125	1,6	0,5	1,7	0,65
variant	21	1,5	0,35	1,55	0,425	1,8	0,8	1,9	0,95
variant	22	1,1	-0,25	1,15	-0,175	1,4	0,2	1,5	0,35
variant	23	1,3	0,05	1,35	0,125	1,6	0,5	1,7	0,65
variant	24	1,5	0,35	1,55	0,425	1,8	0,8	1,9	0,95
variant	25	1,1	-0,25	1,15	-0,175	1,4	0,2	1,5	0,35
variant	26	1,3	0,05	1,35	0,125	1,6	0,5	1,7	0,65
variant	27	1,5	0,35	1,55	0,425	1,8	0,8	1,9	0,95

Table 28 – Values of Sludge Factor and Sludge fraction for alloys of the AlSi10MnMg0.2 sub-systems

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003785

Variants		AlSi8MnMg0.3 – Set 9		AlSi8MnMg0.3 – Set 10		AlSi8MnMg0.3 – Set 11	
		Sludge Factor (SF)	Sludge fraction (%)	Sludge Factor (SF)	Sludge fraction (%)	Sludge Factor (SF)	Sludge fraction (%)
variant	1	1,1	0,00	1,1	0,00	1,1	0,00
variant	2	1,3	0,05	1,3	0,05	1,3	0,05
variant	3	1,5	0,35	1,5	0,35	1,5	0,35
variant	4	1,1	0,00	1,1	0,00	1,1	0,00
variant	5	1,3	0,05	1,3	0,05	1,3	0,05
variant	6	1,5	0,35	1,5	0,35	1,5	0,35
variant	7	1,1	0,00	1,1	0,00	1,1	0,00
variant	8	1,3	0,05	1,3	0,05	1,3	0,05
variant	9	1,5	0,35	1,5	0,35	1,5	0,35
variant	10	1,1	0,00	1,1	0,00	1,1	0,00
variant	11	1,3	0,05	1,3	0,05	1,3	0,05
variant	12	1,5	0,35	1,5	0,35	1,5	0,35
variant	13	1,1	0,00	1,1	0,00	1,1	0,00
variant	14	1,3	0,05	1,3	0,05	1,3	0,05
variant	15	1,5	0,35	1,5	0,35	1,5	0,35
variant	16	1,1	0,00	1,1	0,00	1,1	0,00
variant	17	1,3	0,05	1,3	0,05	1,3	0,05
variant	18	1,5	0,35	1,5	0,35	1,5	0,35
variant	19	1,1	0,00	1,1	0,00	1,1	0,00
variant	20	1,3	0,05	1,3	0,05	1,3	0,05
variant	21	1,5	0,35	1,5	0,35	1,5	0,35
variant	22	1,1	0,00	1,1	0,00	1,1	0,00
variant	23	1,3	0,05	1,3	0,05	1,3	0,05
variant	24	1,5	0,35	1,5	0,35	1,5	0,35
variant	25	1,1	0,00	1,1	0,00	1,1	0,00
variant	26	1,3	0,05	1,3	0,05	1,3	0,05
variant	27	1,5	0,35	1,5	0,35	1,5	0,35

Table 29 – Values of Sludge Factor and Sludge fraction for alloys of the AlSi8MnMg0.3 sub-systems

System	Set	Amount [%] of $Al_{15}(Fe,Mn,Cr)_3Si_2$-type phase [Equilibrium]	Amount [%] of $Al_{15}(Fe,Mn,Cr)_3Si_2$-type phase [non-equilibrium, Scheil equation]
Al-Mg	1	1.9-3.3	0.000-0.002
Al4MgFe	2	Not determined	Not determined
AlSi10MnMg0.3	3	2.1-2-7	0.015-0.023
	4	2.1-2.8	0.015-0.023
	5	2.1-2.8	0.015-0.023
AlSi10MnMg0.2	6	2.1-2.8	0.016-0.023
	7	2.3-3.0	0.016-0.024
	8	2.6-3.3	0.021-0.028
	8.1	2.9-3.6	0.023-0.030
AlSi8MnMg0.3	9	2.1-2.8	0.015-0.022
	10	2.1-2.8	0.016-0.022
	11	2.1-2.8	0.016-0.022

Table 30 – Calculated amount of intermetallic ($Al_{15}(Fe,Mn,Cr)_3Si_2$-type) phase in all systems and sets of alloys investigated

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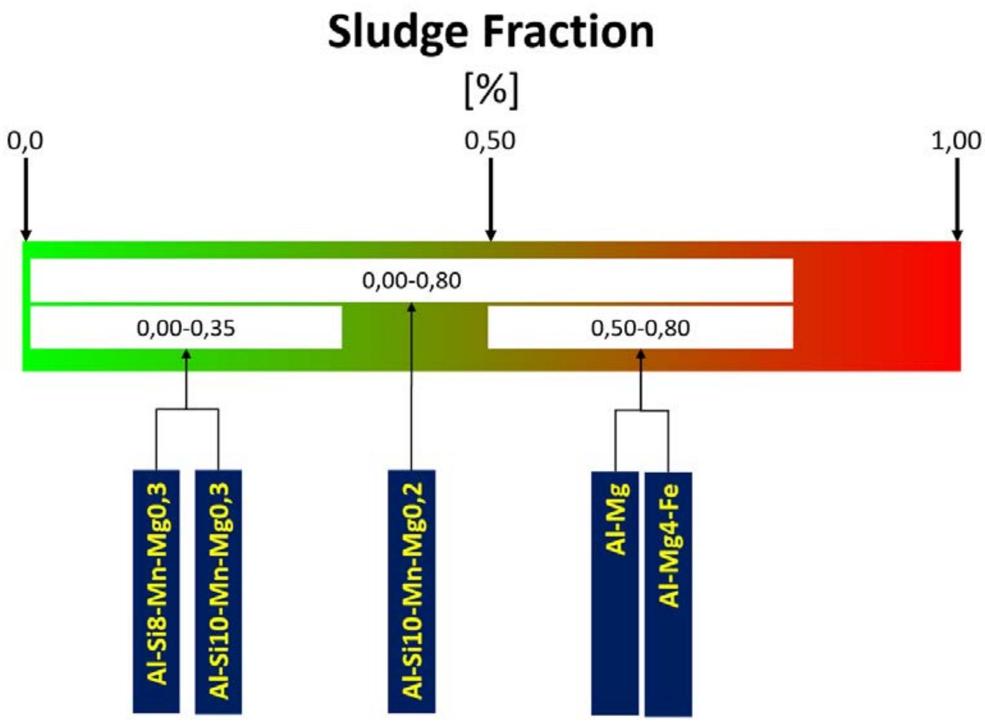

Figure 5 – Ranking in terms of Sludge Fraction for the alloy systems investigated

2.3.4. Die soldering tendency

As described in Deliverable D2.2, die soldering is a typical defect which may occur in HPDC. Several literature information suggest that this problem is minimised and controlled by the presence, into the alloy, of Fe and Mn. For this reason, the Extraction Index (EI) has been introduced as the sum of Fe and Mn amount in the alloy.

Tables 31-34 display the SF and Sludge prediction for all sets of alloys. As usual, green background evidences the best variants.

For alloys of the AlSi8-Mn-Mg0,3, also the DSI (Die Soldering Index can be estimated), using the diagram shown in Figure 6. In this case, DSI ranges

- from 6 to 8, if Mn amount is 0,45%,
- from 3 to 5, if Mn amount is 0,55%,
- from 0 to 1, if Mn amount is 0,65%.

For what concerns AlSi10-Mn-Mg0,2 and AlSi10-Mn-Mg0,3 systems, it can be considered that

- the values of Mn amount are in the 0,45-0,65 range,
- the value of Fe amount is kept at 0,2%,
- an increase in Si amount (from 8 to 10) is certainly associated in a decrease of DSI (as it can be argued by diagram in Figure 6).

This means that all the alloys in the Al-Si system selected can be associated to a low value of DSI, i.e. to limited problems in terms of die soldering defects.

Figure 7 summarises the results achieved in terms of Extraction Index, showing that

- Al-Mg and AlMg4Fe present the highest of Extraction Index, ranging, in the more favorable cases, from 1,2 to 1,8%,
- Some of the AlSi10-Mn-Mg0,2 sub-systems present the good values of Extraction Index, ranging, in more favorable cases, from 1,0 to 1,1%.

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Variants		Al-Mg – set 1	Al-Mg4-Fe – Set 2
		Extraction Index	Extraction Index
variant	1	0,80	1,60
variant	2	0,90	1,60
variant	3	1,00	1,60
variant	4	1,10	1,70
variant	5	1,20	1,70
variant	6	0,90	1,70
variant	7	1,20	1,80
variant	8	0,95	1,80
variant	9	1,25	1,80
variant	10	1,00	1,60
variant	11	1,30	1,60
variant	12	0,80	1,60
variant	13	0,90	1,70
variant	14	1,00	1,70
variant	15	1,10	1,70
variant	16	1,20	1,80
variant	17	0,90	1,80
variant	18	1,20	1,80
variant	19	0,95	1,60
variant	20	1,25	1,60
variant	21	1,00	1,60
variant	22	1,30	1,70
variant	23	0,80	1,70
variant	24	0,90	1,70
variant	25	1,00	1,80
variant	26	1,10	1,80
variant	27	1,20	1,80
variant	28	0,90	1,60
variant	29	1,20	1,60
variant	30	0,95	1,60
variant	31	1,25	1,70
variant	32	1,00	1,70
variant	33	1,30	1,70
variant	34	0,80	1,80
variant	35	0,90	1,80
variant	36	1,00	1,80
variant	37	1,10	1,60
variant	38	1,20	1,60
variant	39	0,90	1,60
variant	40	1,20	1,60
variant	41	0,95	1,60
variant	42	1,25	1,60
variant	43	1,00	1,70
variant	44	1,30	1,70
variant	45		1,70
variant	46		1,70
variant	47		1,70
variant	48		1,70
variant	49		1,80
variant	50		1,80
variant	51		1,80
variant	52		1,80
variant	53		1,80
variant	54		1,80

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Table 31 – Values of Extraction Index for alloys of the Al-Mg and AlMg4Fe systems

Variants		**AlSi10MnMg0.3 – Set 3**	**AlSi10MnMg0.3 – Set 4**	**AlSi10MnMg0.3 – Set 5**
		Extraction Index	**Extraction Index**	**Extraction Index**
variant	1	0,65	0,65	0,65
variant	2	0,75	0,75	0,75
variant	3	0,85	0,85	0,85
variant	4	0,65	0,65	0,65
variant	5	0,75	0,75	0,75
variant	6	0,85	0,85	0,85
variant	7	0,65	0,65	0,65
variant	8	0,75	0,75	0,75
variant	9	0,85	0,85	0,85
variant	10	0,65	0,65	0,65
variant	11	0,75	0,75	0,75
variant	12	0,85	0,85	0,85
variant	13	0,65	0,65	0,65
variant	14	0,75	0,75	0,75
variant	15	0,85	0,85	0,85
variant	16	0,65	0,65	0,65
variant	17	0,75	0,75	0,75
variant	18	0,85	0,85	0,85
variant	19	0,65	0,65	0,65
variant	20	0,75	0,75	0,75
variant	21	0,85	0,85	0,85
variant	22	0,65	0,65	0,65
variant	23	0,75	0,75	0,75
variant	24	0,85	0,85	0,85
variant	25	0,65	0,65	0,65
variant	26	0,75	0,75	0,75
variant	27	0,85	0,85	0,85

Table 32 – Values of Extraction Index for alloys of the AlSi10MnMg0.3 sub-systems

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Variants		AlSi10MnMg0.2 Set 6	AlSi10MnMg0.2 Set 7	AlSi10MnMg0.2 Set 8	AlSi10MnMg0.2 Set 8.1
		Extraction Index	Extraction Index	Extraction Index	Extraction Index
variant	1	0,65	0,7	0,8	0,9
variant	2	0,75	0,8	0,9	1,0
variant	3	0,85	0,9	1,0	1,1
variant	4	0,65	0,7	0,8	0,9
variant	5	0,75	0,8	0,9	1,0
variant	6	0,85	0,9	1,0	1,1
variant	7	0,65	0,7	0,8	0,9
variant	8	0,75	0,8	0,9	1,0
variant	9	0,85	0,9	1,0	1,1
variant	10	0,65	0,7	0,8	0,9
variant	11	0,75	0,8	0,9	1,0
variant	12	0,85	0,9	1,0	1,1
variant	13	0,65	0,7	0,8	0,9
variant	14	0,75	0,8	0,9	1,0
variant	15	0,85	0,9	1,0	1,1
variant	16	0,65	0,7	0,8	0,9
variant	17	0,75	0,8	0,9	1,0
variant	18	0,85	0,9	1,0	1,1
variant	19	0,65	0,7	0,8	0,9
variant	20	0,75	0,8	0,9	1,0
variant	21	0,85	0,9	1,0	1,1
variant	22	0,65	0,7	0,8	0,9
variant	23	0,75	0,8	0,9	1,0
variant	24	0,85	0,9	1,0	1,1
variant	25	0,65	0,7	0,8	0,9
variant	26	0,75	0,8	0,9	1,0
variant	27	0,85	0,9	1,0	1,1

Table 33 – Values of Extraction Index for alloys of the AlSi10MnMg0.2 sub-systems

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Variants		AlSi8MnMg0.3 – Set 9	AlSi8MnMg0.3 – Set 10	AlSi8MnMg0.3 – Set 11
		Extraction Index	Extraction Index	Extraction Index
variant	1	0,65	0,65	0,65
variant	2	0,75	0,75	0,75
variant	3	0,85	0,85	0,85
variant	4	0,65	0,65	0,65
variant	5	0,75	0,75	0,75
variant	6	0,85	0,85	0,85
variant	7	0,65	0,65	0,65
variant	8	0,75	0,75	0,75
variant	9	0,85	0,85	0,85
variant	10	0,65	0,65	0,65
variant	11	0,75	0,75	0,75
variant	12	0,85	0,85	0,85
variant	13	0,65	0,65	0,65
variant	14	0,75	0,75	0,75
variant	15	0,85	0,85	0,85
variant	16	0,65	0,65	0,65
variant	17	0,75	0,75	0,75
variant	18	0,85	0,85	0,85
variant	19	0,65	0,65	0,65
variant	20	0,75	0,75	0,75
variant	21	0,85	0,85	0,85
variant	22	0,65	0,65	0,65
variant	23	0,75	0,75	0,75
variant	24	0,85	0,85	0,85
variant	25	0,65	0,65	0,65
variant	26	0,75	0,75	0,75
variant	27	0,85	0,85	0,85

Table 34 – Values of Extraction Index for alloys of the AlSi8MnMg0.3 sub-systems

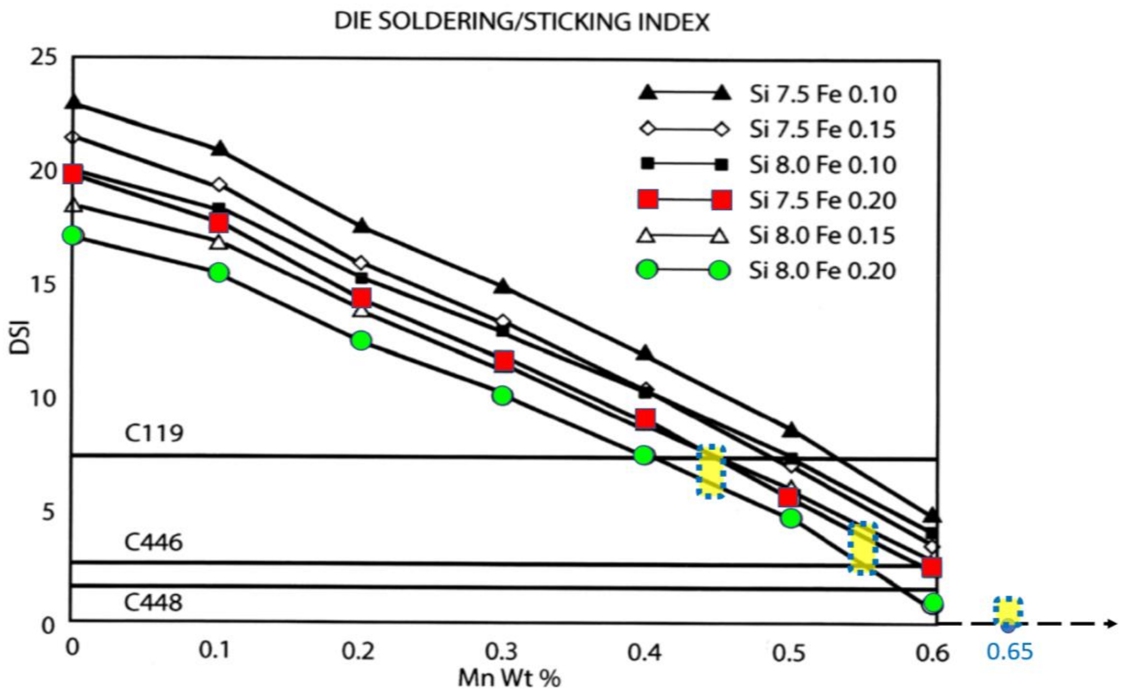

Figure 6 – Estimation of Die Soldering Index (DSI) for alloys of the AlSi8MnMg0.3 sub-systems (yellow boxes), elaborated from [8]

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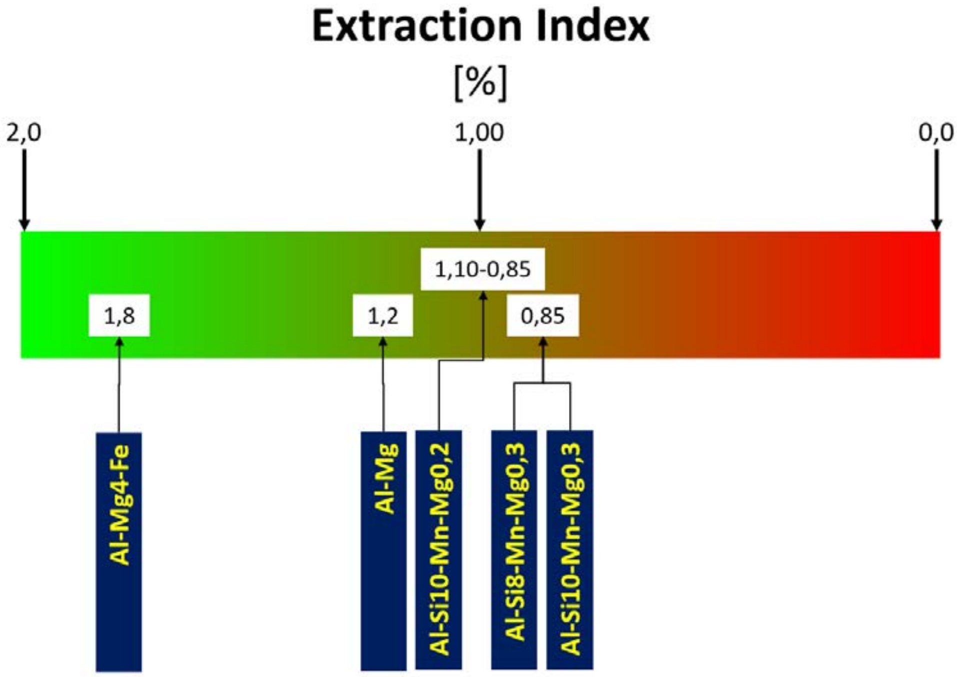

Figure 7 – Ranking in terms of Extraction Index for the alloy systems investigated

2.3.5. Hot Tearing tendency

As described in Deliverable D2.2, hot tearing can be primarily associated to the extension of the overall solidification range (which means, for HPDC, that calculated under Scheil conditions). A further estimation can be done considering the Terminal Freezing Range (TFR), i.e. the temperature interval between 95% and completion of solidification [9]. An example of the calculation of TFR by Thermocalc software is shown in Figure 8. These results (with TFR shown for the three highest and lowest values) are collected in Tables 35-36 (Al-Mg and Al-Mg4-Fe systems) and in Tables 37-42 for the Al-Si based systems.

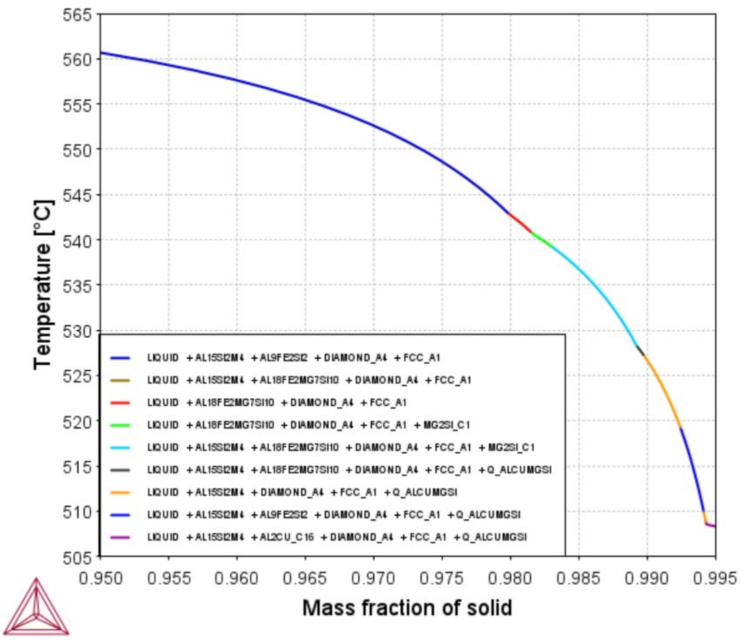

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Figure 8 – Example of calculation of TFR using Thermocalc software

Variants		Non-equilibrium conditions (Scheil Equation)					
		Al-Mg – set 1			Al-Mg4-Fe – Set 2		
		T_{liq} [°C]	T_{sol} [°C]	$\Delta T_{liq-sol}$ [°C]	T_{liq} [°C]	T_{sol} [°C]	$\Delta T_{liq-sol}$ [°C]
variant	1	644,36	450,50	193,86	645,29	450,47	194,82
variant	2	644,18	450,47	193,71	645,76	447,63	198,13
variant	3	644,00	450,50	193,5	646,24	447,62	198,62
variant	4	643,83	450,48	193,35	646,49	450,49	196,00
variant	5	643,64	450,49	193,15	647,95	447,65	200,30
variant	6	644,00	450,47	193,53	648,40	447,65	200,75
variant	7	643,46	450,47	192,99	649,63	450,49	199,14
variant	8	643,82	450,49	193,33	650,06	447,64	202,42
variant	9	643,28	450,47	192,81	650,50	447,62	202,88
variant	10	643,63	450,49	193,14	646,09	450,71	195,38
variant	11	643,10	450,50	192,6	646,56	447,97	198,59
variant	12	642,78	450,48	192,3	647,03	447,97	199,06
variant	13	642,60	450,50	192,1	648,25	450,72	197,53
variant	14	642,41	450,48	191,93	648,71	447,95	200,76
variant	15	642,23	450,49	191,74	649,16	447,95	201,21
variant	16	642,04	450,49	191,55	650,35	450,73	199,62
variant	17	642,41	450,77	191,64	650,79	447,98	202,81
variant	18	641,86	450,50	191,36	651,23	447,69	203,54
variant	19	642,23	450,48	191,75	646,88	450,64	196,24
variant	20	641,67	450,48	191,19	647,36	448,09	199,27
variant	21	642,05	450,47	191,58	647,83	448,11	199,72
variant	22	641,48	450,48	191	649,01	450,14	198,87
variant	23	645,96	450,50	195,46	649,47	448,11	201,36
variant	24	645,78	450,49	195,29	649,93	448,11	201,82
variant	25	645,60	450,47	195,13	651,08	450,63	200,45
variant	26	645,42	450,50	194,92	651,53	448,10	203,43
variant	27	645,25	450,47	194,78	651,97	448,09	203,88
variant	28	645,59	450,49	195,1	645,71	450,72	194,99
variant	29	645,06	450,49	194,57	646,18	447,98	198,20
variant	30	645,42	450,47	194,95	646,65	447,98	198,67
variant	31	644,88	450,47	194,41	647,83	450,72	197,11
variant	32	645,23	450,49	194,74	648,28	448,00	200,28
variant	33	644,70	450,49	194,21	648,74	447,96	200,78
variant	34	644,19	450,71	193,48	649,89	450,72	199,17
variant	35	644,01	450,71	193,3	650,33	447,98	202,35
variant	36	643,83	450,71	193,12	650,76	448,00	202,76
variant	37	643,65	450,72	192,93	701,32	450,74	250,58
variant	38	643,56	450,71	192,85	668,43	450,71	217,72
variant	39	643,83	450,72	193,11	701,43	447,95	253,48
variant	40	643,28	450,70	192,58	668,54	447,97	220,57
variant	41	643,64	450,73	192,91	701,53	447,95	253,58
variant	42	643,10	450,71	192,39	668,65	447,97	220,68
variant	43	643,46	450,71	192,75	701,45	450,70	250,75
variant	44	642,91	450,71	192,2	668,56	450,71	217,85
variant	45				701,55	447,97	253,58
variant	46				668,67	447,96	220,71
variant	47				701,66	447,95	253,71
variant	48				668,78	447,98	220,80
variant	49				701,57	450,73	250,84
variant	50				668,69	450,71	217,98
variant	51				701,67	447,97	253,70
variant	52				668,80	447,96	220,84
variant	53				701,78	447,96	253,82
variant	54				668,91	447,95	220,96

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Table 35 – Evaluation of solidification interval (non-equilibrium) for Al-Mg and AlMg4Fe systems

Variants		Non-equilibrium conditions (Scheil Equation)					
		Al-Mg – set 1			Al-Mg4-Fe – Set 2		
		T, 95% solid [°C]	T, 99.5% solid [°C]	TFR [°C]	T at 95% solid [°C]	T, 99.5% solid [°C]	TFR [°C]
variant		554,84	450,77	104,07	463,26	448,12	15,14
variant		554,72	450,50	104,22	466,44	447,96	18,48
variant		554,59	450,51	104,08	466,74	448,09	18,65
variant		572,81	450,94	121,87	496,96	450,72	46,24
variant		572,74	450,51	122,23	489,90	447,98	41,92
variant		572,68	450,49	122,19	496,74	450,77	45,97

Table 36 – Evaluation of TFR for selected variants of the Al-Mg and AlMg4Fe systems

Variants		Non-equilibrium conditions (Scheil Equation)								
		AlSi10MnMg0.3 – Set 3			AlSi10MnMg0.3 – Set 4			AlSi10MnMg0.3 – Set 5		
		T_{liq} [°C]	T_{sol} [°C]	$\Delta T_{liq\text{-}sol}$ [°C]	T_{liq} [°C]	T_{sol} [°C]	$\Delta T_{liq\text{-}sol}$ [°C]	T_{liq} [°C]	T_{sol} [°C]	$\Delta T_{liq\text{-}sol}$ [°C]
variant	1	649,20	490,29	158,91	649,27	483,80	165,47	649,27	450,30	198,97
variant	2	649,33	490,25	159,08	649,40	483,81	165,59	649,40	450,28	199,12
variant	3	649,46	490,25	159,21	649,53	482,79	166,74	649,54	449,27	200,27
variant	4	649,55	490,24	159,31	649,62	482,77	166,85	649,62	449,17	200,45
variant	5	649,67	490,27	159,40	649,75	482,75	167,00	649,74	449,20	200,54
variant	6	649,80	490,27	159,53	649,87	482,75	167,12	649,87	448,14	201,73
variant	7	649,89	490,28	159,61	649,95	482,74	167,21	649,96	448,09	201,87
variant	8	650,02	490,26	159,76	650,09	482,69	167,40	650,09	448,08	202,01
variant	9	650,14	490,28	159,86	650,21	482,69	167,52	650,21	448,05	202,16
variant	10	642,02	490,35	151,67	642,08	483,82	158,26	642,09	450,32	191,77
variant	11	642,15	490,32	151,83	642,22	483,81	158,41	642,22	450,31	191,91
variant	12	642,28	490,31	151,97	642,36	483,81	158,55	642,36	450,29	192,07
variant	13	642,37	490,30	152,07	642,45	482,78	159,67	642,44	449,22	193,22
variant	14	642,51	490,28	152,23	642,58	482,77	159,81	642,58	449,18	193,40
variant	15	642,64	490,27	152,37	642,71	482,75	159,96	642,71	449,16	193,55
variant	16	642,73	490,31	152,42	642,80	482,73	160,07	642,80	448,12	194,68
variant	17	642,87	490,27	152,60	642,93	482,72	160,21	642,94	448,07	194,87
variant	18	643,00	490,28	152,72	643,06	482,71	160,35	643,07	448,07	195,00
variant	19	646,03	490,40	155,63	646,16	483,83	162,33	646,28	450,34	195,94
variant	20	646,04	490,35	155,69	646,18	483,83	162,35	646,30	450,33	195,97
variant	21	646,06	490,34	155,72	646,20	483,82	162,38	646,32	450,32	196,00
variant	22	646,33	490,35	155,98	646,46	482,79	163,67	646,59	449,23	197,36
variant	23	646,35	490,34	156,01	646,48	482,78	163,70	646,61	449,21	197,40
variant	24	646,37	490,32	156,05	646,50	482,76	163,74	646,63	449,20	197,43
variant	25	646,64	490,36	156,28	646,77	482,74	164,03	646,89	448,12	198,77
variant	26	646,65	490,32	156,33	646,79	482,72	164,07	646,91	448,07	198,84
variant	27	646,67	490,30	156,37	646,81	482,72	164,09	646,93	448,07	198,86

Table 37 – Evaluation of solidification interval (non-equilibrium) for AlSi10MnMg0.3 sub-systems

Variants		Non-equilibrium conditions (Scheil Equation)								
		AlSi10MnMg0.3 – Set 3			AlSi10MnMg0.3 – Set 4			AlSi10MnMg0.3 – Set 5		
		T, 95% solid [°C]	T, 99.5% solid [°C]	TFR [°C]	T, 95% solid [°C]	T, 99.5% solid [°C]	TFR [°C]	T, 95% solid [°C]	T, 99.5% solid [°C]	TFR [°C]
variant	7	557,50	552,45	5,05	555,94	538,21	17,73	555,56	536,17	19,39
variant	8	557,38	552,44	4,94	555,88	538,20	17,68	555,45	536,16	19,29
variant	9	557,38	552,44	4,94	555,90	538,19	17,71	555,49	536,14	19,35
variant	10	562,26	552,45	9,81	560,62	538,49	22,13	560,21	536,56	23,65
variant	11	562,27	552,44	9,83	560,62	538,47	22,15	560,19	536,52	23,67
variant	12	562,26	552,45	9,81	560,62	538,46	22,16	560,21	536,51	23,70

Table 38 – Evaluation of TFR for selected variants for AlSi10MnMg0.3 sub-systems

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003785

Variants		Non-equilibrium conditions (Scheil Equation)											
		AlSi10MnMg0.2 – Set 6			AlSi10MnMg0.2 – Set 7			AlSi10MnMg0.2 – Set 8			AlSi10MnMg0.2 – Set 8.1		
		T_{liq} [°C]	T_{sol} [°C]	$\Delta T_{liq-sol}$ [°C]	T_{liq} [°C]	T_{sol} [°C]	$\Delta T_{liq-sol}$ [°C]	T_{liq} [°C]	T_{sol} [°C]	$\Delta T_{liq-sol}$ [°C]	T_{liq} [°C]	T_{sol} [°C]	$\Delta T_{liq-sol}$ [°C]
variant	1	648,52	491,58	156,94	648,52	491,58	156,94	648,78	484,99	163,79	648,78	484,96	163,82
variant	2	648,65	491,54	157,11	648,65	491,52	157,13	648,91	484,98	163,93	648,91	484,97	163,94
variant	3	648,78	491,54	157,24	648,78	491,54	157,24	649,04	484,95	164,09	649,04	484,95	164,09
variant	4	648,86	490,37	158,49	648,86	490,39	158,47	649,12	483,86	165,26	649,12	483,87	165,25
variant	5	649,00	490,40	158,60	649,00	490,36	158,64	649,25	483,88	165,37	649,25	483,85	165,40
variant	6	649,12	490,36	158,76	649,12	490,35	158,77	649,38	483,86	165,52	649,38	483,86	165,52
variant	7	649,20	490,29	158,91	649,20	490,33	158,87	649,46	482,79	166,67	649,47	483,80	165,67
variant	8	649,33	490,25	159,08	649,33	490,29	159,04	649,59	482,81	166,78	649,59	482,81	166,78
variant	9	649,46	490,25	159,21	649,45	490,25	159,20	649,72	482,79	166,93	649,72	482,79	166,93
variant	10	641,31	491,64	149,67	641,30	491,64	149,66	641,58	485,00	156,58	641,58	485,00	156,58
variant	11	641,44	491,62	149,82	641,44	491,60	149,84	641,71	484,97	156,74	641,72	485,00	156,72
variant	12	641,57	491,61	149,96	641,58	491,60	149,98	641,85	484,99	156,86	641,85	484,99	156,86
variant	13	641,66	491,46	150,20	641,66	491,43	150,23	641,93	483,87	158,06	641,94	483,87	158,07
variant	14	641,79	490,43	151,36	641,80	491,43	150,37	642,07	483,88	158,19	642,07	483,89	158,18
variant	15	641,93	490,42	151,51	641,93	490,43	151,50	642,20	483,88	158,32	642,21	483,88	158,33
variant	16	642,01	490,35	151,66	642,02	490,35	151,67	642,28	483,82	158,46	642,29	483,82	158,47
variant	17	642,15	490,32	151,83	642,15	490,32	151,83	642,42	483,81	158,61	642,43	483,82	158,61
variant	18	642,28	490,31	151,97	642,29	490,31	151,98	642,55	482,82	159,73	642,56	483,79	158,77
variant	19	645,42	491,69	153,73	645,34	491,69	153,65	645,58	486,00	159,58	645,44	485,99	159,45
variant	20	645,44	491,69	153,75	645,37	491,68	153,69	645,60	486,02	159,58	645,46	486,01	159,45
variant	21	645,46	491,68	153,78	645,39	491,65	153,74	645,62	486,01	159,61	645,48	485,00	160,48
variant	22	645,72	491,50	154,22	645,65	491,51	154,14	645,88	484,90	160,98	645,74	484,92	160,82
variant	23	645,74	491,47	154,27	645,67	491,46	154,21	645,90	484,91	160,99	645,76	483,90	161,86
variant	24	645,76	491,49	154,27	645,69	491,45	154,24	645,92	483,91	162,01	645,78	483,90	161,88
variant	25	646,03	490,40	155,63	645,96	490,40	155,56	646,18	483,81	162,37	646,05	483,83	162,22
variant	26	646,04	490,35	155,69	645,98	490,35	155,63	646,21	483,82	162,39	646,07	483,82	162,25
variant	27	646,06	490,35	155,71	646,00	490,36	155,64	646,23	483,82	162,41	646,09	483,81	162,28

Table 39 – Evaluation of solidification interval (non-equilibrium) for AlSi10MnMg0.2 sub-systems

Variants		Non-equilibrium conditions (Scheil Equation)											
		AlSi10MnMg0.2 – Set 6			AlSi10MnMg0.2 – Set 7			AlSi10MnMg0.2 – Set 8			AlSi10MnMg0.2 – Set 8.1		
		T, 95% solid [°C]	T, 99.5% solid [°C]	TFR [°C]	T, 95% solid [°C]	T, 99.5% solid [°C]	TFR [°C]	T, 95% solid [°C]	T, 99.5% solid [°C]	TFR [°C]	T, 95% solid [°C]	T, 99.5% solid [°C]	TFR [°C]
variant	1	562,23	552,42	9,81	562,22	552,45	9,77	560,59	538,40	22,19	560,55	538,43	22,12
variant	2	562,23	552,43	9,80	562,20	552,43	9,77	560,58	538,39	22,19	560,56	538,42	22,14
variant	3	562,23	552,42	9,81	562,20	552,42	9,78	560,57	538,38	22,19	560,54	538,40	22,14
variant	4	567,13	552,59	14,54	567,11	552,58	14,53	565,50	539,02	26,48	565,46	539,03	26,43
variant	5	567,13	552,58	14,55	567,11	552,57	14,54	565,49	539,02	26,47	565,43	538,99	26,44
variant	6	567,15	552,57	14,58	567,12	552,58	14,54	565,48	539,02	26,46	565,43	538,99	26,44

Table 40 – Evaluation of TFR for selected variants for AlSi10MnMg0.2 sub-systems

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003785

Variants		Non-equilibrium conditions (Scheil Equation)								
		AlSi8MnMg0.3 – Set 9			AlSi8MnMg0.3 – Set 10			AlSi8MnMg0.3 – Set 11		
		T_{liq} [°C]	T_{sol} [°C]	$\Delta T_{liq-sol}$ [°C]	T_{liq} [°C]	T_{sol} [°C]	$\Delta T_{liq-sol}$ [°C]	T_{liq} [°C]	T_{sol} [°C]	$\Delta T_{liq-sol}$ [°C]
variant	1	657,16	490,24	166,92	656,51	491,48	165,03	656,75	479,57	177,18
variant	2	657,28	490,20	167,08	656,63	491,46	165,17	656,87	479,55	177,32
variant	3	657,40	490,23	167,17	656,76	491,44	165,32	657,00	479,53	177,47
variant	4	657,48	490,25	167,23	656,84	490,33	166,51	657,07	478,51	178,56
variant	5	657,60	490,27	167,33	656,96	490,30	166,66	657,20	478,52	178,68
variant	6	657,72	490,23	167,49	657,08	490,29	166,79	657,33	478,52	178,81
variant	7	657,80	490,25	167,55	657,15	490,24	166,91	657,40	477,50	179,90
variant	8	657,92	490,27	167,65	657,28	490,20	167,08	657,52	477,50	180,02
variant	9	658,04	490,27	167,77	657,40	490,23	167,17	657,65	477,48	180,17
variant	10	653,30	490,27	163,03	652,63	491,55	161,08	652,87	479,55	173,32
variant	11	653,42	490,27	163,15	652,75	491,53	161,22	653,00	479,55	173,45
variant	12	653,54	490,27	163,27	652,88	491,49	161,39	653,13	479,53	173,60
variant	13	653,62	490,24	163,38	652,96	490,34	162,62	653,20	478,50	174,70
variant	14	653,74	490,22	163,52	653,08	490,34	162,74	653,33	478,51	174,82
variant	15	653,87	490,22	163,65	653,21	490,31	162,90	653,46	478,50	174,96
variant	16	653,96	490,27	163,69	653,29	490,27	163,02	653,53	477,48	176,05
variant	17	654,07	490,27	163,80	653,42	490,27	163,15	653,67	477,48	176,19
variant	18	654,20	490,28	163,92	653,54	490,27	163,27	653,79	477,49	176,30
variant	19	649,20	490,29	158,91	648,52	491,58	156,94	648,77	479,56	169,21
variant	20	649,33	490,25	159,08	648,65	491,54	157,11	648,90	479,56	169,34
variant	21	649,46	490,25	159,21	648,78	491,54	157,24	649,04	479,56	169,48
variant	22	649,55	490,24	159,31	648,87	490,38	158,49	649,11	478,53	170,58
variant	23	649,67	490,27	159,40	649,00	490,40	158,60	649,25	478,52	170,73
variant	24	649,80	490,27	159,53	649,12	490,36	158,76	649,38	478,51	170,87
variant	25	649,89	490,28	159,61	649,20	490,29	158,91	649,46	477,51	171,95
variant	26	650,02	490,26	159,76	649,33	490,25	159,08	649,59	477,49	172,10
variant	27	650,14	490,28	159,86	649,46	490,25	159,21	649,73	477,47	172,26

Table 41 – Evaluation of solidification interval (non-equilibrium) for AlSi8MnMg0.3 sub-systems

Variants		Non-equilibrium conditions (Scheil Equation)								
		AlSi8MnMg0.3 – Set 9			AlSi8MnMg0.3 – Set 10			AlSi8MnMg0.3 – Set 11		
		T, 95% solid [°C]	T, 99.5% solid [°C]	TFR [°C]	T, 95% solid [°C]	T, 99.5% solid [°C]	TFR [°C]	T, 95% solid [°C]	T, 99.5% solid [°C]	TFR [°C]
variant		557,63	552,44	5,19	562,24	552,41	9,83	555,89	508,27	47,62
variant		557,51	552,44	5,07	562,23	552,40	9,83	556,01	508,27	47,74
variant		557,44	552,44	5,00	562,24	552,41	9,83	555,87	508,26	47,61
variant		562,23	552,42	9,81	567,10	552,56	14,54	560,99	508,37	52,62
variant		562,24	552,44	9,80	567,08	552,54	14,54	560,85	508,43	52,42
variant		562,22	552,42	9,80	567,11	552,54	14,57	560,69	508,35	52,34

Table 42 – Evaluation of TFR for selected variants for AlSi8MnMg0.3 sub-systems

Figures 9 and 10 summarise, respectively, the results achieved in terms of overall solidification interval and Terminal Freezing Range, both evaluated under non-equilibrium conditions. Extraction Index, showing that

- Al-Mg system presents the most critical behavior, with relevant risk of high sensitivity to hot tearing phenomena;
- AlMg4Fe presents a slightly better behavior;
- All the Al-Si based systems are certainly the best solution, showing minimum values of TFR.

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003785

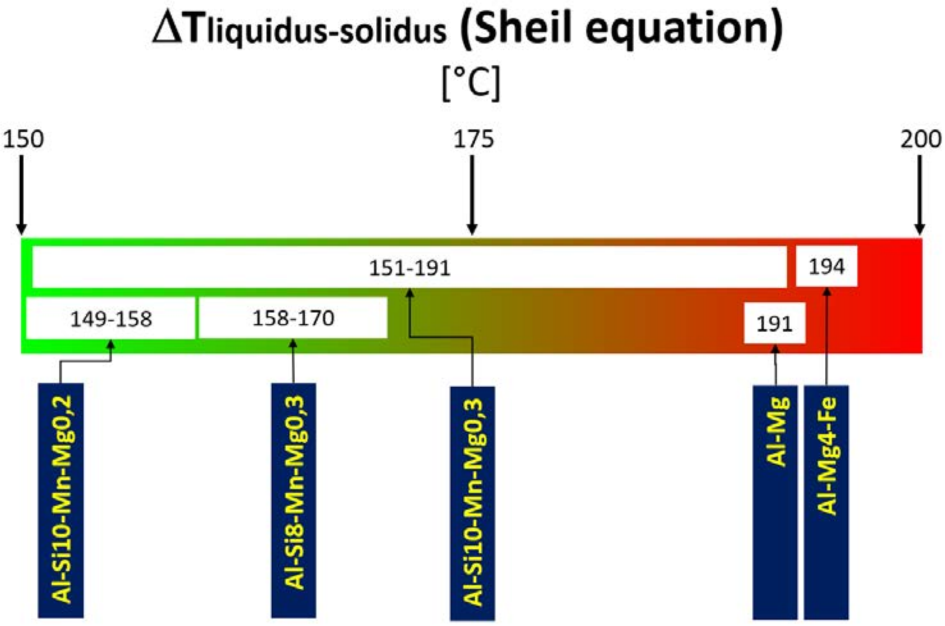

Figure 9 – Ranking in terms of solidification interval, evaluated under non-equilibrium (Sheil) conditions) for the alloy systems investigated

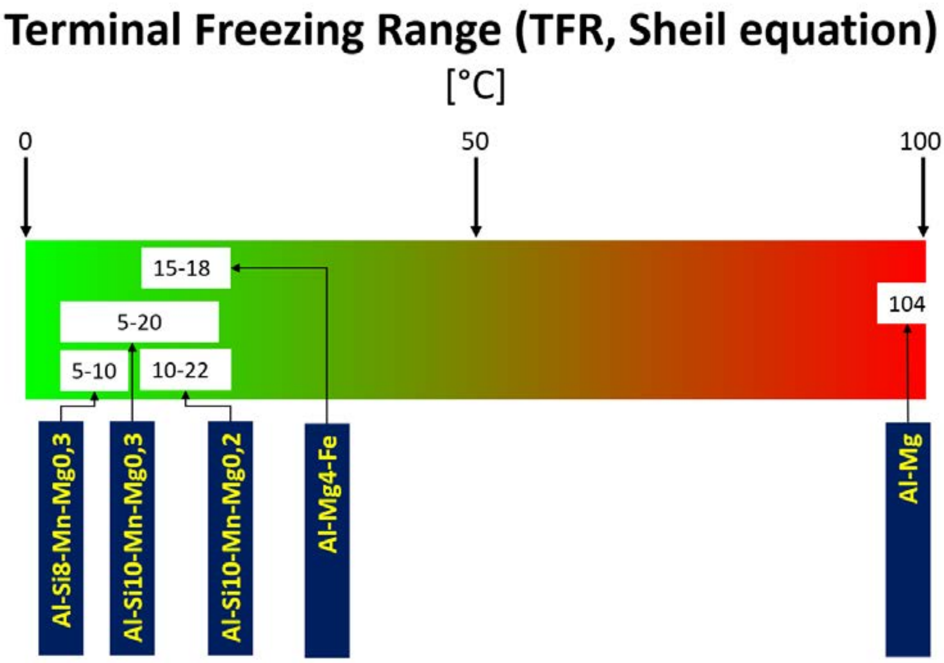

Figure 10 – Ranking in terms of Terminal Freezing Range, evaluated under non-equilibrium (Sheil) conditions) for the alloy systems investigated

2.3.6. Ranking of alloys in terms of castability

The criteria and tools adopted led to the estimation of the various characteristics contributing to the castability of alloys. In order to have an overall evaluation and ranking of the sets investigated, a score (1 for the worst behaviour, 5 for the best) has been attributed to each set. For each set, the best performing variants (i.e. those evidenced by the green background in previous Tables) have been considered. The partial and overall ranking is reported in Table 43.

		Ranking					
System	**Set**	**Fluidity**	**Solidification Shrinkage**	**Sludge formation**	**Die Soldering**	**Hot Tearing**	**CASTABILITY TOTAL**
Al-Mg	1	2,0	3,0	3,0	4,0	1,0	13,0
Al4MgFe	2	2,0	2,0	3,0	5,0	3,0	15,0
AlSi10MnMg0.3	3	5,0	5,0	5,0	3,0	5,0	23,0
	4	5,0	5,0	5,0	3,0	3,0	21,0
	5	5,0	5,0	5,0	3,0	3,0	21,0
AlSi10MnMg0.2	6	5,0	5,0	5,0	3,0	4,0	22,0
	7	5,0	5,0	5,0	3,0	4,0	22,0
	8	5,0	5,0	4,0	3,0	3,0	20,0
	8.1	5,0	5,0	4,0	3,0	3,0	20,0
AlSi8MnMg0.3	9	4,5	4,0	5,0	3,0	5,0	21,5
	10	4,5	4,0	5,0	3,0	4,0	20,5
	11	4,5	4,0	5,0	3,0	3,0	19,5

Table 43 – Partial and overall castability ranking for the alloy systems and sub-systems investigated

A more accurate definition of ranking can be performed by weighting the different characteristics, according to the following rules:

- The sum of weights is set equal to 1;
- In HPDC **fluidity** is essential, due to the complex shape of components to be manufactured: the weight is set equal to 0,3;
- **Sludge fraction** predicted for most part of alloy systems is null or very low, thus not so relevant for systems selection: the weight is set equal to 0,1;
- **Solidification shrinkage, die soldering and hot tearing** can be considered as equally critical for the behavior of HPDC alloys: the related weights are set equal to 0,2.

Table 44 summarizes the weighted ranking.

		Ranking					
System	**Set**	**Fluidity**	**Solidification Shrinkage**	**Sludge formation**	**Die Soldering**	**Hot Tearing**	**CASTABILITY TOTAL**
Al-Mg	1	0,6	0,6	0,3	0,8	0,2	2,5
Al4MgFe	2	0,6	0,4	0,3	1	0,6	2,9
AlSi10MnMg0.3	3	1,5	1	0,5	0,6	1	4,6
	4	1,5	1	0,5	0,6	0,6	4,2
	5	1,5	1	0,5	0,6	0,6	4,2
AlSi10MnMg0.2	6	1,5	1	0,5	0,6	0,8	4,4
	7	1,5	1	0,5	0,6	0,8	4,4
	8	1,5	1	0,4	0,6	0,6	4,1
	8.1	1,5	1	0,4	0,6	0,6	4,1
AlSi8MnMg0.3	9	1,35	0,8	0,5	0,6	1	4,25
	10	1,35	0,8	0,5	0,6	0,8	4,05
	11	1,35	0,8	0,5	0,6	0,6	3,85

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Table 44 – Partial and overall weighted castability ranking for the alloy systems and sub-systems investigated

2.4. Evaluation of Mechanical compensation of Si and Mg decrease in alloys

2.4.1. Solid solution strengthening

The potential of solid solution strengthening has been already described in Deliverable D2.2, introducing $\Delta\sigma_{ss}$ as the solid solution strengthening;

$$\Delta\sigma_{SS} = \sum_j k^j C_i^{j\frac{2}{3}} \quad (1),$$

or

$$\Delta\sigma_{SS} = \sum_j k^j C_i^j \quad (2),$$

$\Delta\sigma_{ss}$ is expressed in MPa, k^i is the scaling factor for the j^{th} element and C_i^j is the concentration in weight of the j^{th} solute in the matrix. The specific values of k^i to be implemented in equations (1) are collected in Table 45.

Element	Difference in atomic radii (%) with Al	Yield strength/ % addition		Tensile strength/ % addition	
		MPa/at%	MPa/wt%	MPa/at%	MPa/wt%
Si	-3.8	9.3	9.2	40.0	39.6
Zn	-6.0	6.6	2.9	20.7	15.2
Cu	-10.7	16.2	13.8	88.3	43.1
Mn	-11.3	n.a.	30.3	n.a.	53.8
Mg	+11.8	17.2	18.6	51.0	50.3

Table 45 – Solid-solution effects on strenght of principal solute elements in super purity Aluminium

Some considerations are due for what concerns the effective amounts of elements in solid solution in castings, after HPDC process. The high cooling rate certainly results in super-saturation of alloying elements, whose quantification is quite difficult.
However, taking into account the systems and sub-systems investigated, attention must be paid to some specific elements, such as Cu, Fe, Mg, Mn, Si and Zn. Among them (see Table 46), the best maximum solubility (obviously at binary eutectic temperature) is shown by Zn, Mg and Cu. It is reasonable to consider that these elements, when present in limited amounts in Al-alloys, could be in solid solution after HPDC. On the other side, variation of content of Fe, Mn and Si, does not change the amount of super-saturation of these elements after HPDC.

Element	Temperature for maximum solubility [°C]	Maximum solubility [wt%]
Cu	548	5.65
Fe	655	0.05
Mg	450	17.40
Mn	658	1.82
Si	577	1.65
Zn	443	70.00

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Table 46 – Temperature at which maximum solubility is achieved and the related values for key-alloying elements in Aluminium

Under these hypotheses, Tables 47-48 collect the expected contributions of selected alloying elements in terms of solid solution strengthening.

Element	Amount [wt%]	$\Delta\sigma_{ss}$ [MPa] (equation 1)	$\Delta\sigma_{ss}$ [MPa] (equation 2)	Set
Zn	0,2	1	0,6	2
	0,4	1,6	1,2	2
Mg	2,1	30,5	39,1	1
	2,4	33,3	44,6	1
	2,7	36,1	50,2	1
	3,1	45,3	70,7	2
	4,1	47,6	76,3	2
Cu	0,1	3	1,4	2
	0,2	4,7	2,8	2

Table 47 – Expected contributions of selected alloying elements in terms of solid solution strengthening (Al-Mg and Al4MgFe systems)

Element	Amount [wt%]	$\Delta\sigma_{ss}$ [MPa] (equation 1)	$\Delta\sigma_{ss}$ [MPa] (equation 2)	Set
Zn	0,05	0,4	0,1	3, 4, 6, 7, 8, 8.1, 9, 10, 11
	0,10	0,6	0,3	5
	0,15	0,8	0,4	5
Mg	0,15	5,3	2,8	6, 7, 8, 8.1, 10, 11
	0,25	7,4	4,7	3, 4, 5, 6, 7, 8, 8.1, 9, 10, 11
	0,35	9,2	6,5	3, 4, 5, 9
Cu	0,05	1,9	0,7	4, 5, 8, 8.1
	0,10	3	1,4	4, 5, 8, 8.1
	0,20	4,7	2,8	10
	0,30	6,2	4,1	11

Table 48 – Expected contributions of selected alloying elements in terms of solid solution strengthening (Al-Si systems and sub-systems)

2.4.2. Grain refinement

Reinforcement by grain refinement is a mechanism certainly relevant for castings, and Ti is the alloying elements typically used to achieve this effect. On the other side, it must be considered that HPDC process is characterised by high cooling rates (due to the high thermal conductivity of Al-alloys and to the thin walls of castings). This leads “naturally” to the achievement of small grain size, and specific alloy additions or modifications can not determine a relevant effect of mechanical behavior of HPDC castings.
For this reason, no actions for grain refinement are suggested and considered for the development of SALEMA alloys with low content of CRM.

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2.4.3. Optimisation of heat treatment

From a general viewpoint, different processing solutions can be applied in precipitation hardening heat treatments for castings:

T4: solution heat treatment and naturally aged,
T5: cooled and artificially aged,
T6: solution heat treatment and artificially aged,
T7: solution heat treatment and artificially overaged or stabilised.

Also in this case, peculiarities of HPDC process can be considered. When complex shape and/or big size castings are produced, solutioning treatment, followed by quenching may easily result in deformations and/or residual stresses. For these reasons, simple T5 treatment (with the cooling associated to the HPDC process) is usually adopted or, in some cases, a so-called stabilisation treatment (at temperature up to 300°C) is performed on as cast components.

As it will described below (with reference to wrought alloys), these heat treatment solutions can lead to different amount, size, distribution of the reinforcement phase Mg_2Si, which practically means that different combinations of elongation, YS and UTS can be achieved by the treated alloy. This concept is well visualised in Figure 11.

On the basis of these considerations, the optimisation of heat treatment can be performed as an additional task in experimental campaigns, taking advantage from the processing maps approach.

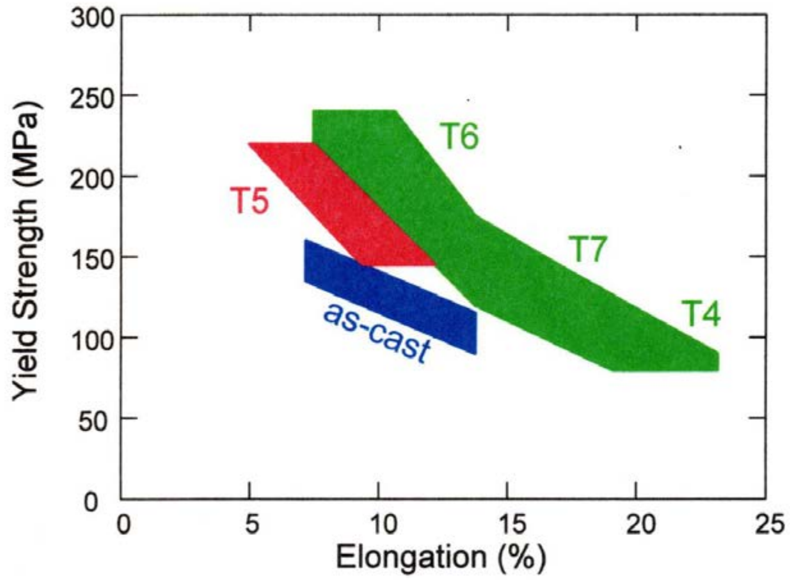

Figure 11 – Range of properties available in structural diecastings, as a function of heat treatment [8]

2.5. Individuation of optimal alloys

Individuation of best variants, on which experimental campaigns have to be performed can be based on a balanced score, including Criticality Index and Castability (weighted values, collected in Table 44). Also in this case, weighting is fundamental, and has been assessed as follows:

- Criticality Index: the weight has been set to 0,33
- Castability: the weight has been set to 0,67, considering HPDC processability as primary requirement.

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Results are collected in Table 49, with best performing systems evidenced by green background, while Table 50 shows the individuation of best variables in terms of Criticality Index and Castability Requirements.
Finally, Table 51 shows the individuation of best variables on which experimental campaigns can be based, with systems and sub-systems ordered according to the ranking established.

System	Set	CRITICALITY INDEX	CASTABILITY TOTAL	BALANCED SCORE
Al-Mg	1	5	2,5	3,3
Al4MgFe	2	4	2,9	3,3
AlSi10MnMg0.3	3	2	4,6	3,7
	4	2	4,2	3,5
	5	2	4,2	3,5
AlSi10MnMg0.2	6	2	4,4	3,6
	7	2	4,4	3,6
	8	2	4,1	3,4
	8.1	2	4,1	3,4
AlSi8MnMg0.3	9	3	4,25	3,8
	10	3	4,05	3,7
	11	3	3,85	3,6

Table 49 – Balanced (between Criticality Index and Castability) ranking for the alloy systems and sub-systems investigated

		CRITICALITY INDEX	Fluidity	Solidification Shrinkage	Sludge Fraction	Die soldering	Hot tearing
System	**Set**	**Best variants**					
Al-Mg	1	22-33	(A)	1-7, 12-16, 23-30, 34-38	1, 6, 12, 17, 23, 28, 34, 39	5, 7, 9, 11, 16, 18, 20, 22 27, 29, 31, 33, 38, 40, 42, 44	(C)
Al4MgFe	2	29-37	(A)	23-27	1-3, 10-12, 19-21, 28-30, 37-42	7-9, 16-18, 25-27, 34-36, 49-54	1, 4, 10, 13, 28, 30
AlSi10MnMg0.3	3	1-9	(B)	19-23, 25-27	(F)	3, 6, 9, 12, 15, 18, 21, 24, 27	(D)
	4	1-9	(B)	19-23, 25-27	(F)	3, 6, 9, 12, 15, 18, 21, 24, 27	(E)
	5	1-9	(B)	19-23, 25-27	(F)	3, 6, 9, 12, 15, 18, 21, 24, 27	(E)
AlSi10MnMg0.2	6	1-9	(B)	19-27	(F)	3, 6, 9, 12, 15, 18, 21, 24, 27	(D)
	7	1-9	(B)	19-27	(F)	3, 6, 9, 12, 15, 18, 21, 24, 27	(D)
	8	1-9	(B)	19-27	(F)	3, 6, 9, 12, 15, 18, 21, 24, 27	(E)
	8.1	1-9	(B)	19-27	(F)	3, 6, 9, 12, 15, 18, 21, 24, 27	(E)
AlSi8MnMg0.3	9	1-9	(B)	19-27	(F)	3, 6, 9, 12, 15, 18, 21, 24, 27	(D)
	10	1-9	(B)	19-27	(F)	3, 6, 9, 12, 15, 18, 21, 24, 27	(D)

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	11	1-9	(B)	19-27	(F)	3, 6, 9, 12, 15, 18, 21, 24, 27	19-25

Notes:
A) Very Limited (< 1%) differences among variants; B) Limited (maximum 6%) differences among variants; C) Very high risk of hot tearing, for all variants; D) Very limited risk of hot tearing, for all variants; E) Limited risk of hot tearing, for all variants; F) Very low values of Sludge fraction, for all variants

Table 50 – Individuation of best variables in terms of Criticality Index and Castability Requirements

		RANKING	BALANCED SCORE	Suggested variants
System	**Set**			
AlSi8MnMg0.3	9	1	3,8	3, 6, 9, 21, 24, 27
AlSi10MnMg0.3	3	2	3,7	3, 6, 9, 21, 27
AlSi8MnMg0.3	10	2	3,7	3, 6, 9, 21, 24, 27
AlSi10MnMg0.2	6	4	3,6	3, 6, 9, 21, 24, 27
AlSi10MnMg0.2	7	4	3,6	3, 6, 9, 21, 24, 27
AlSi8MnMg0.3	11	4	3,6	3, 6, 9, 21, 24, 27
AlSi10MnMg0.3	4	6	3,5	3, 6, 9, 21, 27
AlSi10MnMg0.3	5	6	3,5	3, 6, 9, 21, 27
AlSi10MnMg0.2	8	8	3,4	3, 6, 9, 21, 24, 27
AlSi10MnMg0.2	8.1	8	3,4	3, 6, 9, 21, 24, 27
Al-Mg	1	10	3,3	22, 23, 27, 28,
Al4MgFe	2	10	3,3	28, 30

Table 51 – Individuation of best variables on which experimental campaigns can be based

The suggested strategy, based on the ranking presented in Table 51 is:

- **Al-Si alloys**: to develop experimantal campaigns based on the selected variants of **set 9, 3 and 6-7**, allowing the validation of the three groups individuated (AlSi8MnMg0.3, AlSi10MnMg0.3 and AlSi10MnMg0.3)
- **Al-Mg alloys**: to develop experimantal campaigns giving priority to the selected variants of **set 1**, which is associated to low Criticality Index and to a better behaviour in terms of solidification shrinkage; <u>the limited number of interesting variants as well as the high Criticality Index susggest to not carry out specific investigations on Al4MgFe alloys (set 2)</u>.

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3. New wrought alloys with reduced CRM content

3.1. Systems investigated and design of variants

Deliverable D2.1 individuated the specifications required by the low CRM aluminium wrought alloys, focusing on 5000 and 6000 series. Being 5000 alloys basically constituted in the Al-Mg system and 6000 alloys constituted in Al-Mg-Si system, the strategy for the investigation and design of variants can be as follow:

- Individuate specific alloys in 5000 and 6000 systems, on which Mg and Si is minimised, and calculate related Criticality Index;
- Verify the attitude to hot working of these alloys;
- Preliminary estimate the mechanical compensation of Si and Mg decrease in alloys which can be achieved by heat treatment or work hardening.

The situation in terms of models and tools is summarised in Table 52.

Conceptual area	Characteristic or phenomenon to be modelled	For extrusion	For rolling & stamping
CRM content	Criticality Index	√	√
Castability	Fluidity (as the inverse of viscosity)		
	Solidification shrinkage		
	Slag/dross formation tendency		
	Die soldering tendency		
	Hot tearing tendency		
Hot working attitude, extrudability	Solid solution element at processing temperature	√	√
Mechanical compensation of Si and Mg decrease in alloys	Alternative elements for solid solution strengthening	√	√
	Grain refinement		√
	Improving of heat treatment	√	√
	Improving work hardening		√

Table 52 – Models applied to individuate optimal alloys for extrusion and stamping

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	V	Others each	Others total
6016	1,0	≤ 0,5	≤ 0,2	≤ 0,2	0,25	≤ 0,1	≤ 0,2	≤ 0,15	--	≤ 0,05	≤ 0,15
	1,5	≤ 0,5	≤ 0,2	≤ 0,2	0,60	≤ 0,1	≤ 0,2	≤ 0,15	--	≤ 0,05	≤ 0,15
6082	0,7	≤ 0,5	≤ 0,1	0,4	0,6	≤ 0,25	≤ 0,2	≤ 0,15	--	≤ 0,05	≤ 0,15
	1,3	≤ 0,5	≤ 0,1	1,0	1,2	≤ 0,25	≤ 0,2	≤ 0,15	--	≤ 0,05	≤ 0,15
6181	0,8	0,4	≤ 0,25	0,2	0,6	≤ 0,15	≤ 0,3	≤ 0,25	≤ 0,1	≤ 0,05	≤ 0,15
6451	0,95	0,4	≤ 0,25	0,4	0,8	≤ 0,15	≤ 0,3	≤ 0,25	≤ 0,1	≤ 0,05	≤ 0,15
6111	0,6	≤ 0,4	0,5	0,1	0,6	≤ 0,1	≤ 0,15	≤ 0,25	≤ 0,1	≤ 0,05	≤ 0,15
	1,1	≤ 0,4	0,9	0,45	1,0	≤ 0,1	≤ 0,15	≤ 0,25	≤ 0,1	≤ 0,05	≤ 0,15
5754	≤ 0,4	≤ 0,4	≤ 0,1	≤ 0,5	2,6	≤ 0,3	≤ 0,2	≤ 0,15	--	≤ 0,05	≤ 0,15
	≤ 0,4	≤ 0,4	≤ 0,1	≤ 0,5	3,6	≤ 0,3	≤ 0,2	≤ 0,15	--	≤ 0,05	≤ 0,15
5182	≤ 0,2	≤ 0,35	≤ 0,15	0,2	4,0	≤ 0,1	≤ 0,25	≤ 0,1	--	≤ 0,05	≤ 0,15
	≤ 0,2	≤ 0,35	≤ 0,15	0,5	5,0	≤ 0,1	≤ 0,25	≤ 0,1	--	≤ 0,05	≤ 0,15

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Table 53 – Compositions (%wt) of the wrought alloys investigated

On the basis of several contacts with SALEMA Partners involved in rolling & stamping (5000 and 6000 alloys) and in extrusion (6000 alloys) the systems to be investigated have been individuated. Composition ranges (including minimum and maximum amount of Si and Mg) are shown in Table 53.

3.2. Evaluation of Criticality Index

The evaluation of Criticality Index has been performed on the basis of the model described in Deliverable D2.2, applied to all range of compositions reported in Table 53.

To have a more compact and immediate vision of the Indexes, they are presented in Table 54; the compositions showing best (i.e. lowest) Criticality Index are evidenced by a green background. Figure 12 shows the ranking among different alloys.

Alloy	Si	Mg	Criticality Index
6016	1,0	0,25	0,06
	1,5	0,60	0,11
6082	0,7	0,6	0,07
	1,3	1,2	0,14
6181	0,8	0,6	0,08
6451	0,95	0,8	0,10
6111	0,6	0,6	0,07
	1,1	1,0	0,12
5754	≤ 0,4	2,6	0,19
	≤ 0,4	3,6	0,26
5182	≤ 0,2	4,0	0,28
	≤ 0,2	5,0	0,34

Table 54 – Evaluation of Criticality Index of the wrought alloys investigated

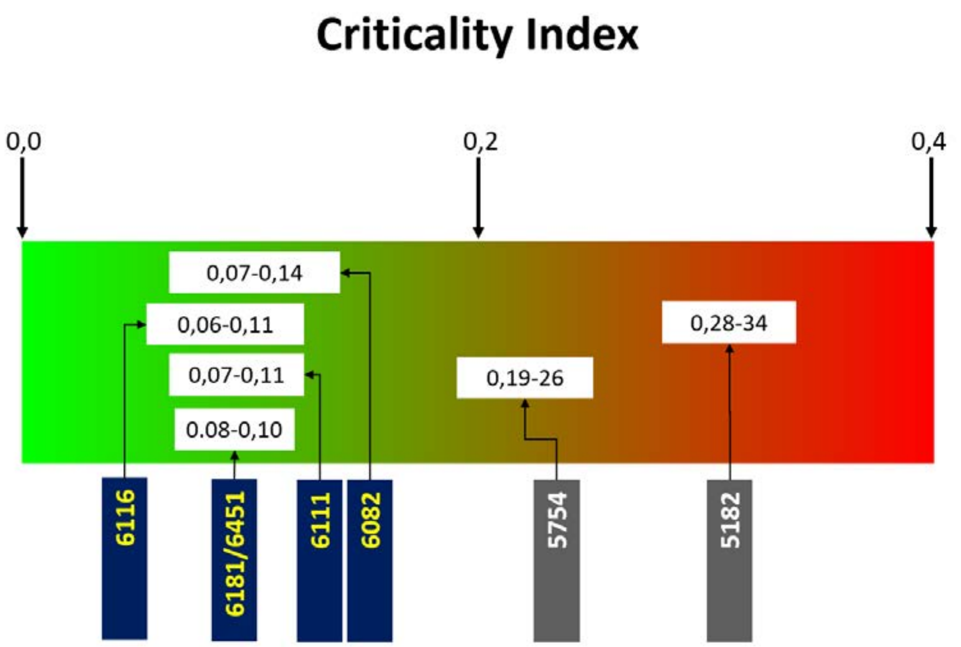

Figure 12 – Ranking among selected wrought alloys in terms of Criticality Index

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3.3. Evaluation of Hot Working attitude & Extrudability

Deliverable D2.2 suggested, as a tool to estimate attitude to hot workability of alloys, the use of simplified models based on solid solution strengthening as a function of alloys composition and of their intrinsic capability of increasing yield strength. Such capability is essentially related to the atomic size of elements involved (as solvent and as solutes) and to their interactions. Thus, it seems reasonable to adopt the coefficient collected in Table 45, to estimate how solute elements can increase yield strength (i.e. making more difficult hot working) of alloys under investigation. Furthermore, at typical hot working temperature range (500-600 °C), all key elements can be considered to be in solid solution (see also Table 46).
Under these assumptions, a parameter describing difficulty level in hot working of these alloys can be introduced, given by

$$\sum_{1}^{n} C_i(\%X_i) \tag{3}$$

where C_i are the coefficients given in Table 45 and X_i are the weight percent values of the key-alloying elements (i.e. Si, Mg, Cu, Mn, Zn).
With reference to composition ranges reported in Table 53 and considering the abovementioned elements, Table 55 displays the estimation of difficulty level in hot working, with best results evidenced by the green background.
Some considerations can be done:

- It is well known that 6000 alloys are easier to be hot worked with respect to 5000 alloys, and this is confirmed by the calculations performed;
- The presence of alloying elements tends to increase difficulty in hot working,
- Obviously, the reduction in Si and Mg amounts in these alloys results not only in a decrease in Criticality Index but also in a better processability;
- The expected decrease in mechanical performance due a decrease in Mg and Si contents must be counterbalanced by proper work hardening or heat treatment processes.

Figure 13 shows the ranking among selected alloys in terms of difficulty in hot working.

Alloy	Contribution to parametr of equation (3) of					Difficulty level in hot working
	Si	Cu	Mn	Mg	Zn	
6016	9,2	1,4	3	4,7	0,3	18,6
	13,8	1,4	3	11,2	0,3	29,7
6082	6,4	0,7	12,1	11,2	0,3	30,7
	12	0,7	30,3	22,3	0,3	65,6
6181	7,4	1,7	6,1	11,2	0,4	26,8
6451	8,7	1,7	12,1	14,9	0,4	37,8
6111	5,5	6,9	3	11,2	0,2	26,8
	10,1	12,4	13,6	18,6	0,2	54,9
5754	1,8	0,7	7,6	48,4	0,3	58,8
	1,8	0,7	7,6	67	0,3	77,4
5182	0,9	1	6,1	74,4	0,4	82,8
	0,9	1	15,2	93	0,4	110,5

Table 55: Difficulty level in hot working for the alloys investigated

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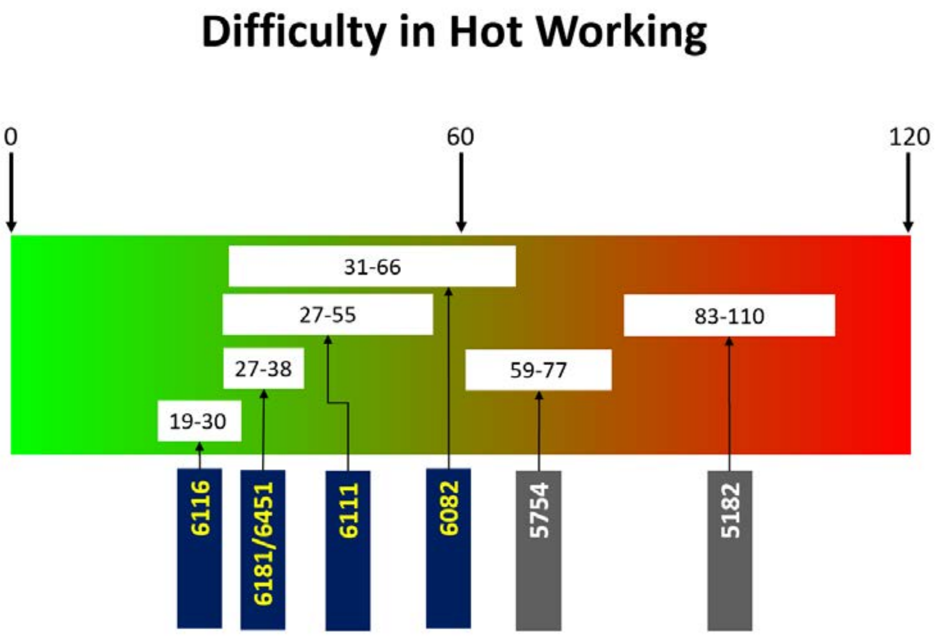

Figure 13 – Ranking among selected alloys in terms of attitude to hot working

3.4. Evaluation of Mechanical compensation of Si and Mg decrease in alloys

Strengthening mechanisms in 5000 and 6000 alloys are summarised in Table 56. Decreasing CRM content in these alloys means, basically, reduce the amount of Mg and Si. For understanding possible compensations, in terms of mechanical behaviour, of these reductions, some issues must be highlighted:

- For 6000 alloys, due to their intrinsic composition, only slight reductions of Mg and Si content are possible; being final properties mainly due to heat treatment (e.g. T6), i.e. precipitation hardening, it must be considered that Aluminium-rich matrix has to be always saturated in Mg and Si, in order to have precipitation phenomena; reduction in Mg and Si content may affect the extent of precipitation, but not solid solution strengthening;
- For 5000 alloys, Si is practically absent, while Mg content is relatively high; as shown in Table 45, reducing of 1% the amount of Mg (under the hypothesis that this element in fully in solid solution) means a decrease of about 17 MPa in YS; which can be eventually recovered by work hardening;
- For both 5000 and 6000 alloys, grain refinement can be considered as a possible and further mechanism for improving mechanical performance; it is reasonable to consider this option as a specific issue of experimental campaigns.

Strengthening mechanism	Wrought alloys	
	5000 (Al-Mg)	6000 (Al-Mg-Si)
Solid solution	√	√
Grain refinement	√	√
Precipitation		√
Work hardening	√	

Table 56 – Strengthening mechanisms in wrought Aluminium alloys

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Thus, the evaluation of Mechanical compensation of Si and Mg decrease in alloys has to be focussed on

- Optimisation of precipitation hardening treatments for 6000 alloys,
- Optimisation of work hardening processes for 5000 alloys.

Precipitation hardening of 6000 alloys

As mentioned in Deliverable D2.2, models considering various modifications of Orowan equation, thermodynamics for precipitation and diffusional transformation with appropriate consideration of temperature and time are available in literature [10-11]. These models can be successfully used to estimate the effect that temperature of ageing (TA) and time of ageing (tA) play on fraction, average size, characteristics of precipitates, and consequently on mechanical behaviour of alloys. This approach is usually known as the elaboration process maps. With reference to the 6000 alloys under investigation, the process maps are collected in Figures 14-17, achieved considering both minimum and maximum level of Mg and Si.

Another possible approach is that of Molecular Orbital Calculation, with definition of alloying parameters Mk for Al-based systems [12]. List of Mk Values for Alloying Elements in Al is reported in Table 57.

Element	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	V	Zn
Mk	3,344	4,601	4,037	4,328	4,136	4,443	2,68	5,009	4,782	3,29

Table 57 - List of Mk Values for Alloying Elements in Al

According to [12], the parameter

$$\Delta\overline{Mk} = \Sigma X_i |Mk_i - Mk_{Al}| \quad (4)$$

(where Xi is the molar fraction of alloying element) con be used for estimating YS of heat treatable Al alloys. Different terms of equation (4) are collected in Table 58, with final value of $\Delta\overline{Mk}$, calculated for the heat treatable 6000 alloys under investigation.

Alloy	Cr	Cu	Fe	Mg	Mn	Si	Ti	V	Zn	$\Delta\overline{Mk}$
6016 min	0,000	0,000	0,001	0,002	0,000	0,007	0,000	0,000	0,000	0,010
6016 max	0,000	0,000	0,001	0,006	0,000	0,009	0,000	0,000	0,000	0,016
6082 min	0,001	0,000	0,001	0,006	0,002	0,005	0,000	0,000	0,000	0,015
6082 max	0,001	0,000	0,001	0,010	0,005	0,009	0,000	0,000	0,000	0,027
6181 min	0,000	0,001	0,002	0,006	0,001	0,005	0,002	0,000	0,000	0,016
6181 max	0,000	0,001	0,002	0,007	0,002	0,006	0,002	0,000	0,000	0,020
6111 min	0,000	0,001	0,001	0,006	0,000	0,004	0,002	0,000	0,000	0,014
6111 max	0,000	0,003	0,001	0,009	0,002	0,007	0,002	0,000	0,000	0,024

Table 58 – Calculation of $\Delta\overline{Mk}$ for investigated 6000 alloys

Figure 18, elaborated from reference [12], shows the expected behaviour, in terms of YS, of the alloys investigated. Results are in good agreement with those shown in Figures 14-17.

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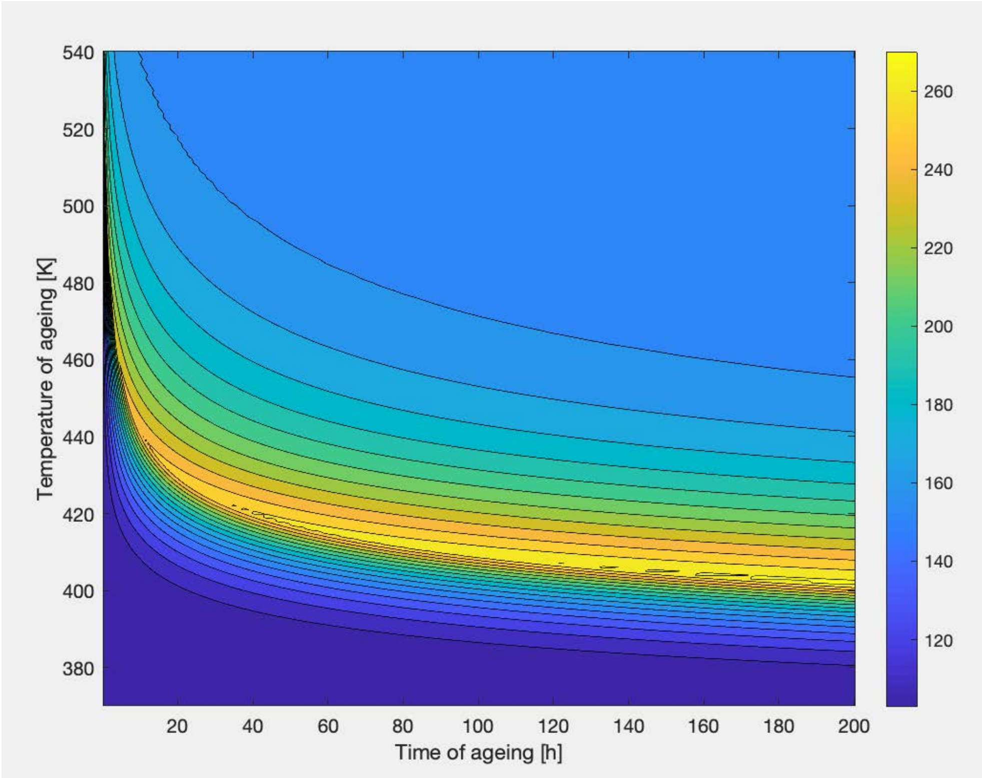
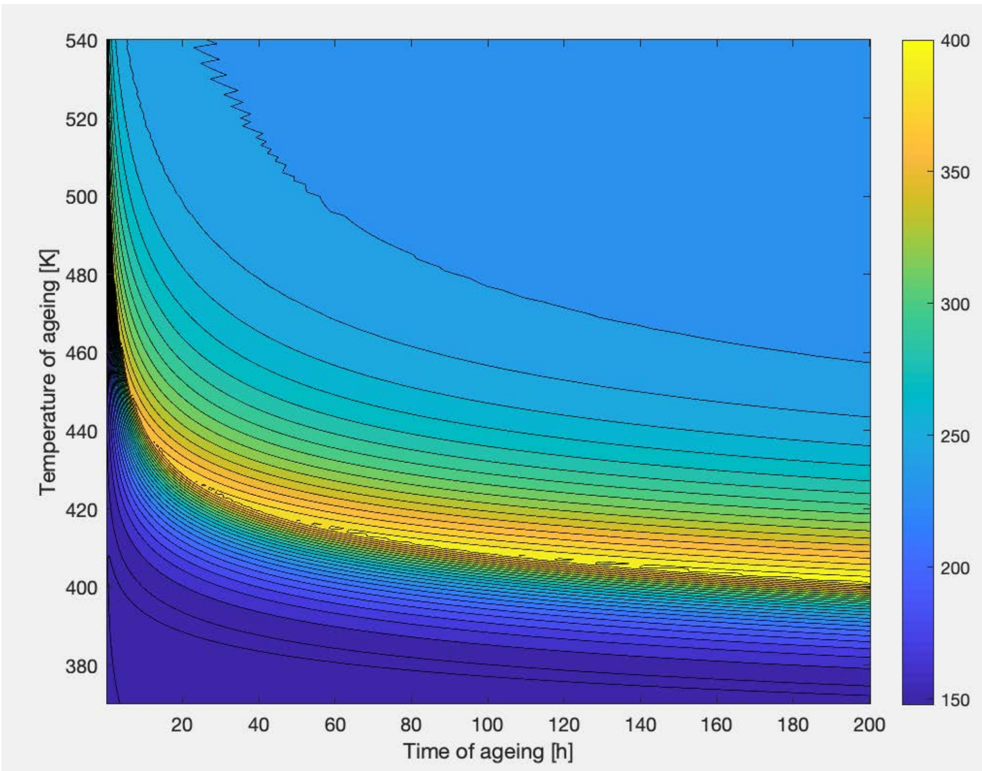


(a)



(b)

Figure 14 – Yield stress [MPa] versus process parameters (process map^{UNIPD}), evaluated with minimum (a) and maximum (b) amount of Si and Mg in 6016 alloy (grain size: 50 μm)

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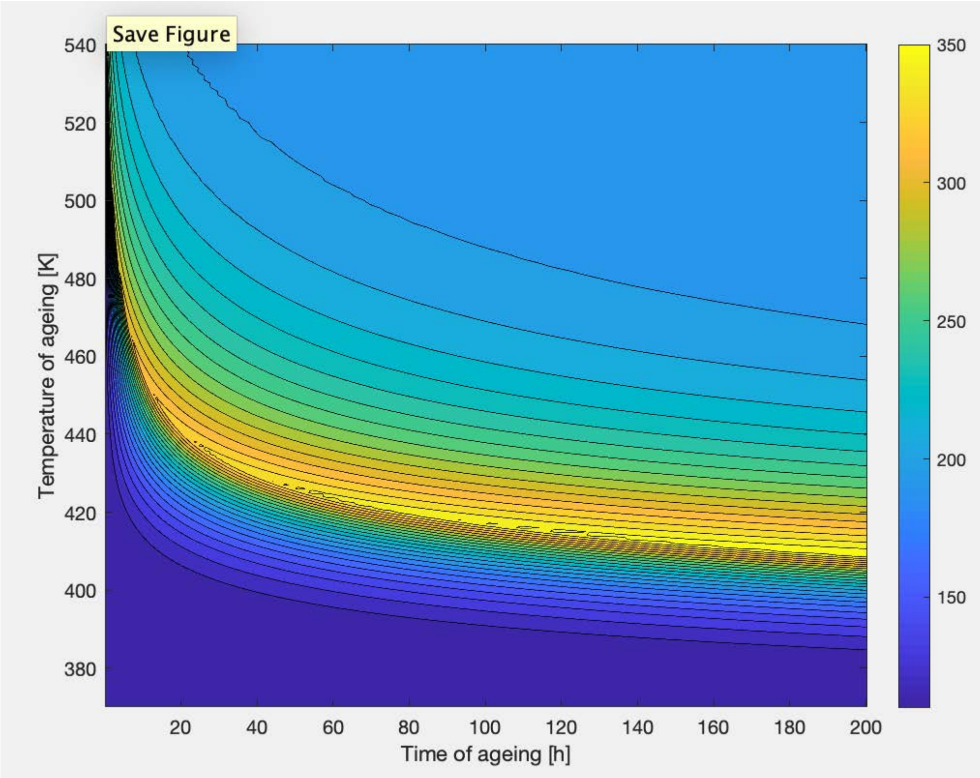

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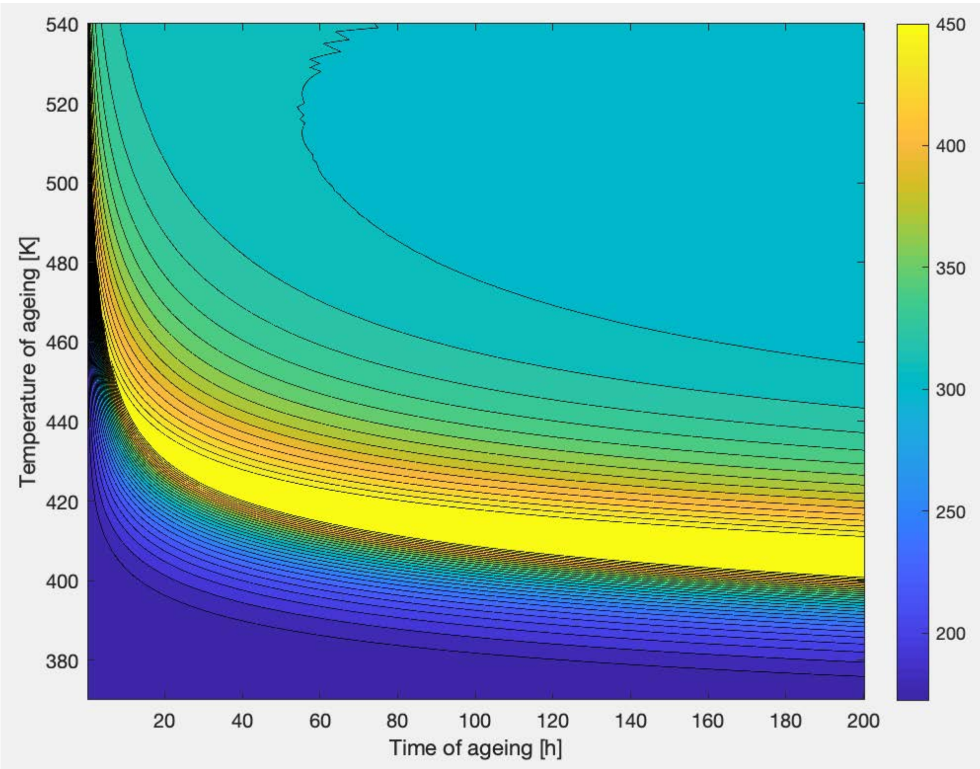

(b)

Figure 15 – Yield stress [MPa] versus process parameters (process map^{UNIPD}), evaluated with minimum (a) and maximum (b) amount of Si and Mg in 6082 alloy (grain size: 50 μm)

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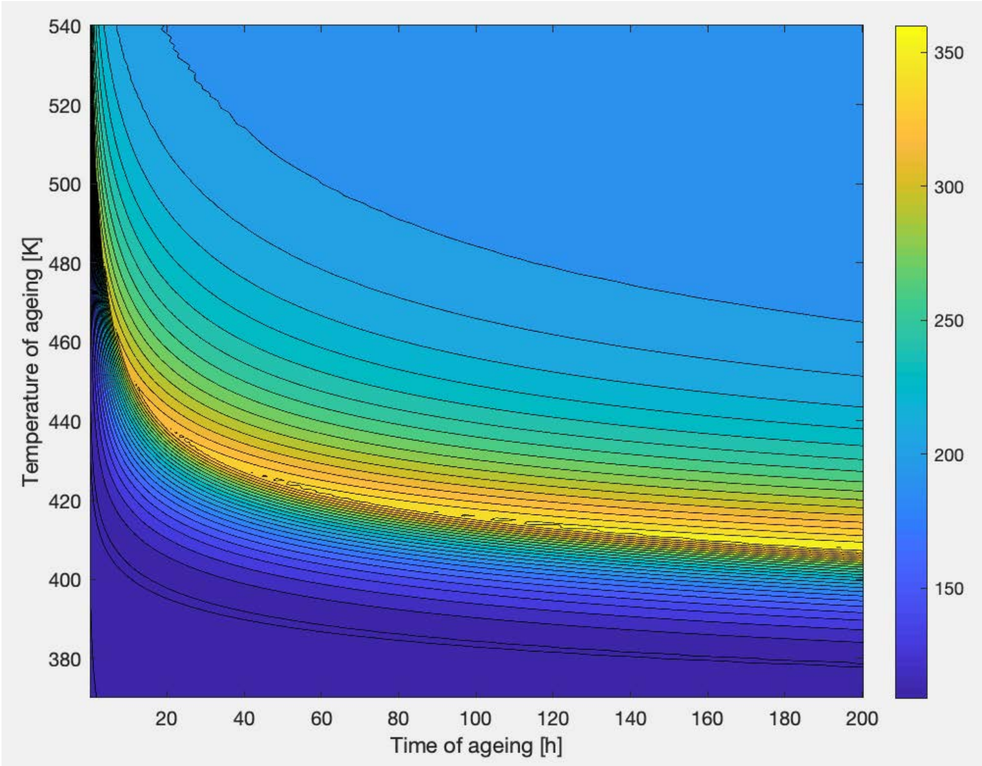
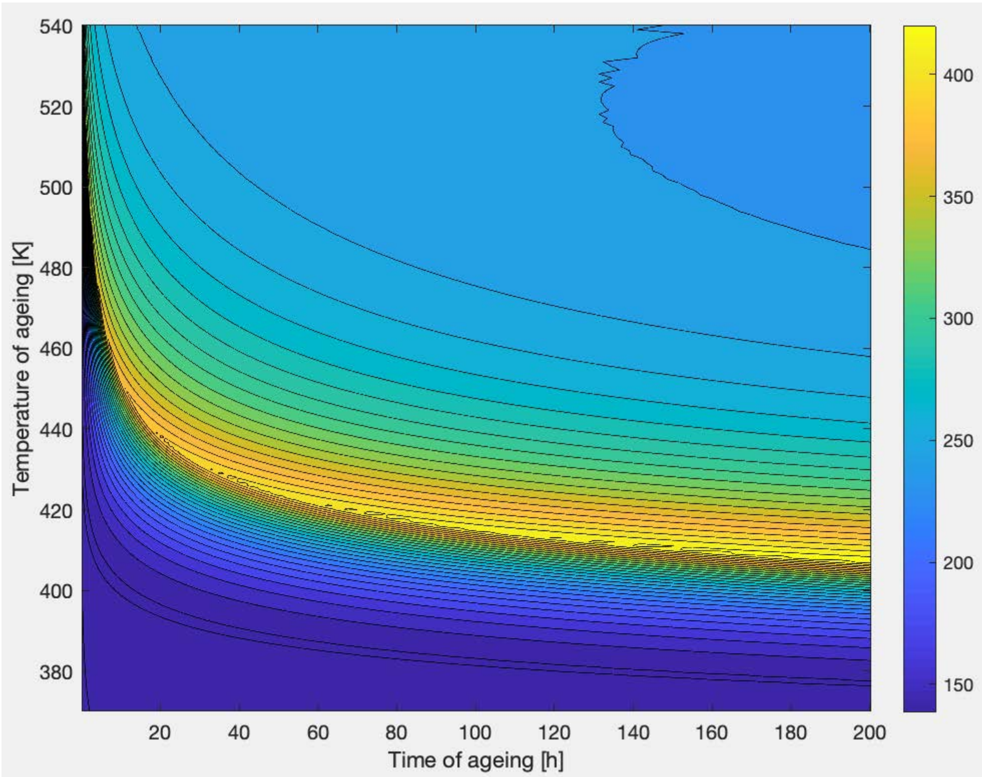


(a)



(b)

Figure 16 – Yield stress [MPa] versus process parameters (process map^{UNIPD}), evaluated with minimum (a) and maximum (b) amount of Si and Mg in 6181/6451 alloy (grain size: 50 μm)

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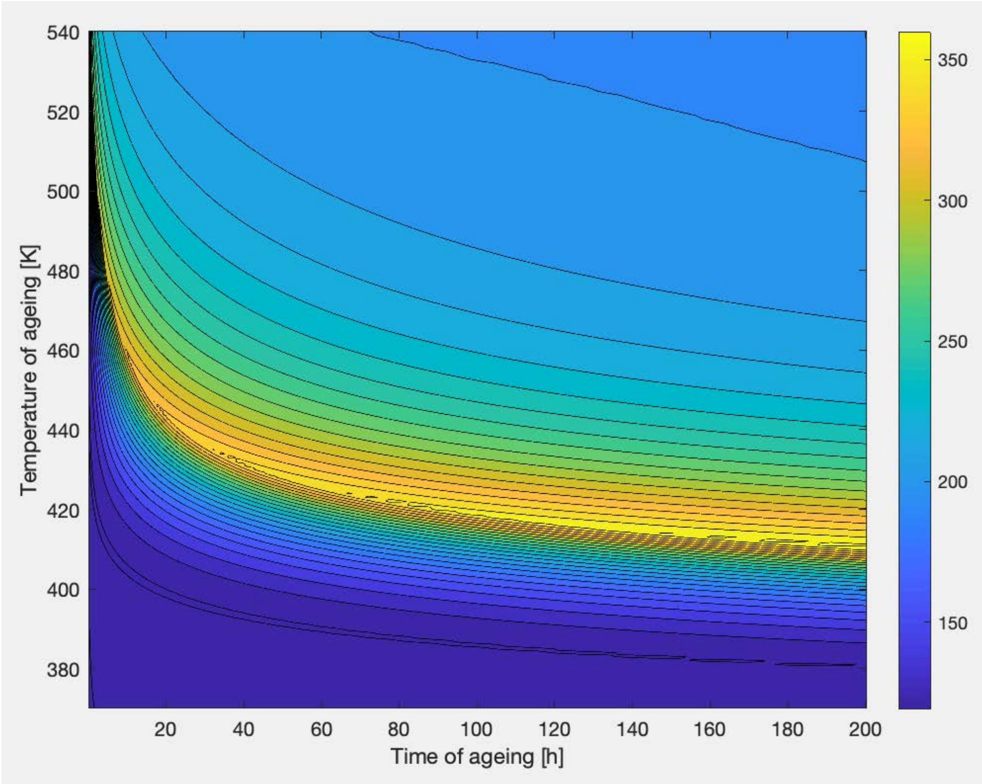
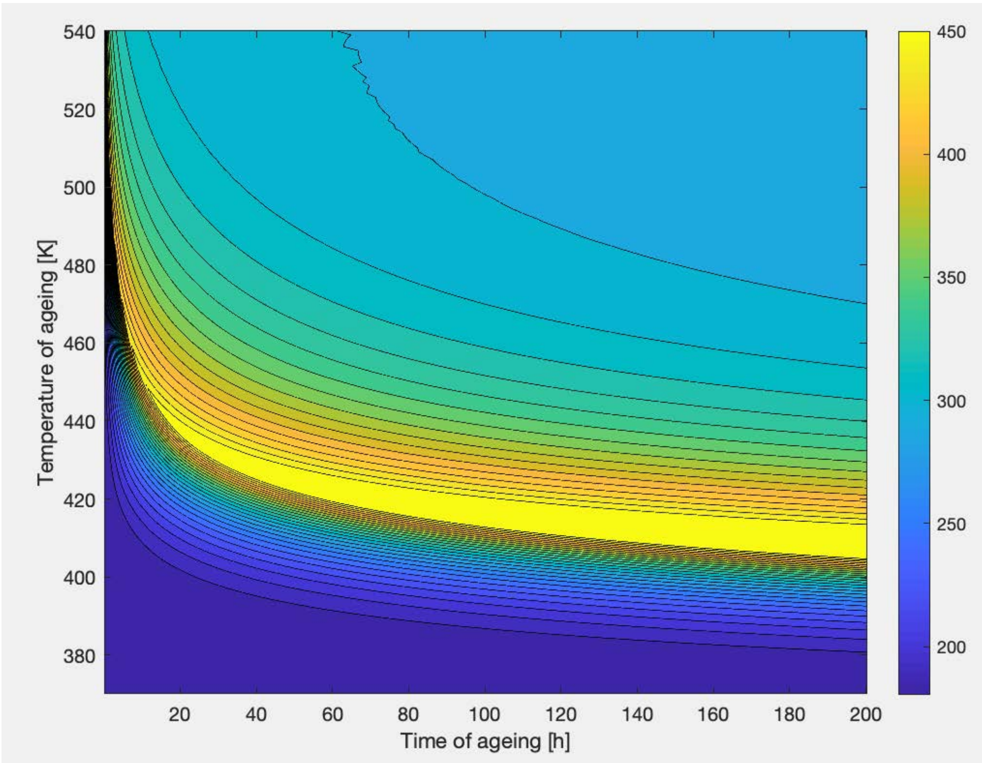


(a)



(b)

Figure 17 – Yield stress [MPa] versus process parameters (process map^{UNIPD}), evaluated with minimum (a) and maximum (b) amount of Si and Mg in 6111 alloy (grain size: 50 μm)

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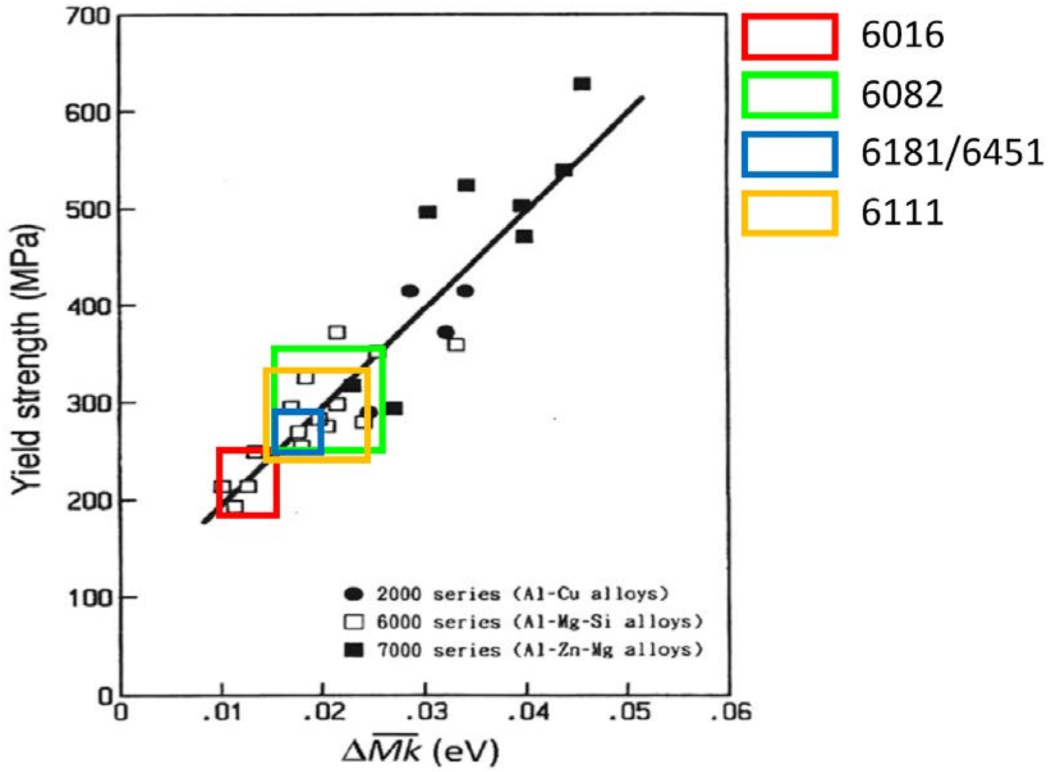

Figure 18 – Yield stress [MPa] estimated for 6000 alloys investigated, according to [12]

During experimental campaigns, both process maps and Molecular Orbital Calculation will constitute the guidelines for optimising mechanical properties of alloys with minimised content of Si and Mg. Such maps will be coupled on specific investigations concerning

- How solutioning temperatures must be corrected, taking into account changes in amount of Si and Mg,
- Possible individuation of improved treatments strategies (e.g. T5: cooled and artificially aged; T6: solution heat treatment and artificially aged; pre-straining treatments before ageing, such as T62 or T82).

Assessment of specific parameters for the development of process maps will be performed during the preliminary test of experimental campaigns.

Work hardening of 5000 alloys

In the context of Al-alloys systems addressed by SALEMA Project, the strengthening effect due to work hardening mechanism is associated to 5000 (i.e. Al-Mg) alloys. Also in this case, Molecular Orbital Calculation [12] can be performed, adopting the parameter

$$\overline{Mk} = \Sigma X_i Mk_i \quad (5).$$

Table 59 collects the different contribution of alloying elements and final values of the above parameter.

Alloy	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	V	Zn	$\overline{Mk}$
5754 min	3,227	0,005	0,000	0,004	0,120	0,004	0,005	0,000	0,000	0,000	3,366
5754 max	3,190	0,005	0,000	0,004	0,165	0,004	0,005	0,000	0,000	0,000	3,374
5182 min	3,180	0,000	0,000	0,004	0,182	0,004	0,003	0,000	0,000	0,003	3,377
5182 max	3,140	0,000	0,000	0,004	0,227	0,009	0,003	0,000	0,000	0,003	3,387

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Table 59 – Calculation of $\overline{Mk}$ for investigated 5000 alloys

Figure 19 shown the estimation of YS, according to the work hardening state, performed by elaborating the diagram reported in [12] and based on a wide set of experimental data.

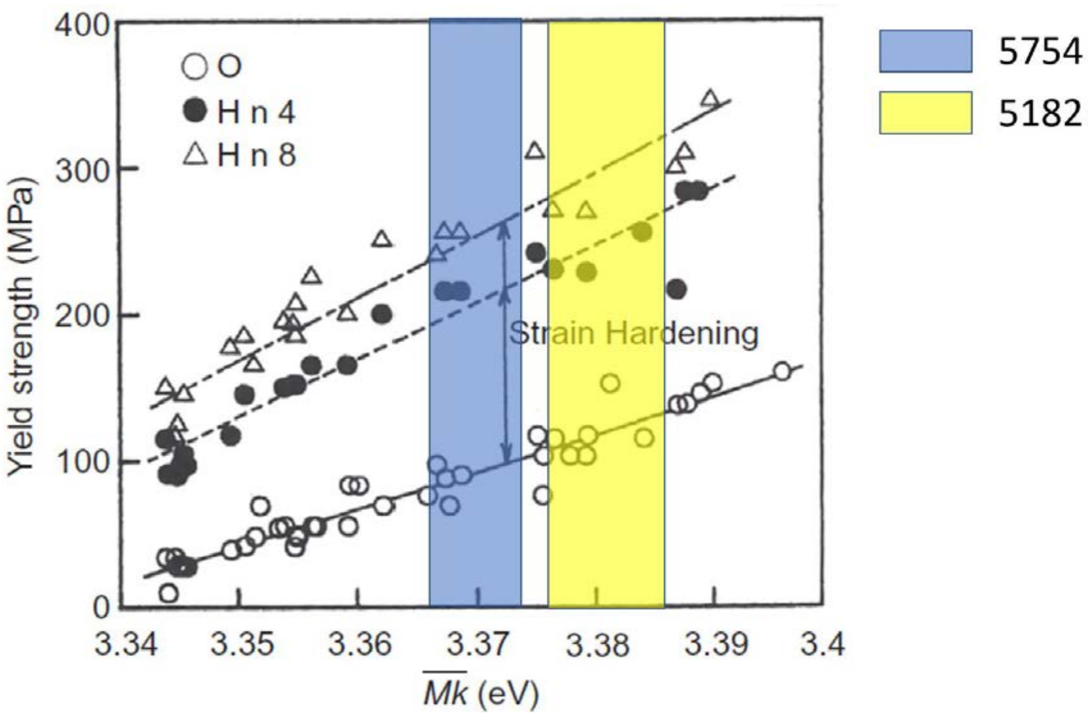

Figure 19 – Yield stress [MPa] estimated for 5000 alloys investigated, according to [12]

According to the metallurgical state of the alloys, related to the deformation grades applied in various processing stages, different combination of elongation and yield strength can be achieved. In other terms, also in the case of work hardening strengthening mechanism, an approach based on process maps can be introduced, as shown in Deliverable D2.2.

3.5. Individuation of optimal alloys

For the purpose of optimisation of SALEMA wrougth alloys, the approach seems relatively simple, and consists in reducing the amount of Mg and Si content (to decrease Criticality Index and having good attitude to hot working), but adopting process maps and Molecular Orbital Calculation to assess and optimise mechanical performance.
In this scenario, experimental campaigns on wrougth alloys can be based on **6016, 6181/6451, 6111 and 5754 systems**, exploring the lower part of Mg and Si composition windows and targeting (by heat treatment and work hardening solutions) the requirements individuated for SALEMA Demonstrators.

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4. Identification of new alloys with reduced CRM content

According to the calculations presented in this Deliverable, new alloys with reduced CRM, on which experimental campaigns can be based, are the following:

- **Foundry alloys of Al-Si system:** selected variants of **set 9, 3 and 6-7**, allowing the validation of the three groups individuated (AlSi8MnMg0.3, AlSi10MnMg0.3 and AlSi10MnMg0.3)

- **Foundry alloys of Al-Mg system**: priority must be given to selected variants of **set 1**; the limited number of interesting variants as well as the high Criticality Index susggest to NOT carry out specific investigations on Al4MgFe alloys (set 2)

- **Wrougth alloys of the 6000 group: 6016, 6181/6451, 6111 systems,** exploring the lower part of Mg and Si composition windows and addressing performance optimisation by tuning heat treatment parameters.

- **Wrougth alloys of the 5000 group: 5754 system,** exploring the lower part of Mg composition window and addressing performance optimisation by tuning work hardening parameters.

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