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Aluminium and aluminium alloys — Mechanical potential of Al-Si alloys for high pressure, low pressure and gravity die casting

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Aluminium and aluminium alloys - Mechanical potential of Al-Si alloys for high pressure, low pressure and gravity die casting

Aluminium et alliages d'aluminium - Potentiel mécanique des alliages Al-Si coulés sous pression et dans des moules permanents pour moulage par gravité et basse pression

Aluminium und Aluminiumlegierungen - Potential der mechanischen Eigenschaften von AlSi-Legierungen für Druckguss, Niederdruckguss und Schwerkraftkokillenguss

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Foreword

This document (CEN/TR 16748:2014) has been prepared by Technical Committee CEN/TC 132 “Aluminium and aluminium alloys”, the secretariat of which is held by AFNOR.

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1 Scope

This Technical Report presents the characteristics of reference dies and reference castings, to be used for evaluating the mechanical potential (in terms of Ultimate Tensile Strength, Yield Strength and Elongation) which can be expected by Al-Si based alloys, cast by high pressure, low pressure and gravity (permanent mould) processes. These properties are measured on separately cast test specimens produced with state-of-the-art knowledge on die design, process management and alloy treatments correctly applied to minimize defects and imperfections.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1559-1, *Founding - Technical conditions of delivery - Part 1: General*

EN 1559-4, *Founding - Technical conditions of delivery - Part 4: Additional requirements for aluminium alloy castings*

EN 1676, *Aluminium and aluminium alloys - Alloyed ingots for remelting - Specifications*

EN 1706, *Aluminium and aluminium alloys - Castings - Chemical composition and mechanical properties*

EN 12258-1:2012, *Aluminium and aluminium alloys - Terms and definitions - Part 1: General terms*

EN ISO 6892-1, *Metallic materials - Tensile testing - Part 1: Method of test at room temperature (ISO 6892-1)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 12258-1:2012 and the following apply.

3.1
casting process
process in which molten metal is introduced into a mould where it solidifies

[SOURCE: EN 12258-1:2012, 3.1.1]

3.2
die casting process
casting process in which molten metal is injected under substantial pressure, typically above 7 MPa, into a metal die and solidifies under this pressure

Note 1 to entry: Die casting process is also referred to as “pressure die casting (process)” or “high pressure die casting (process)”.

[SOURCE: EN 12258-1:2012, 3.1.10]

3.3
permanent mould casting process
casting process in which molten metal is introduced by gravity or low pressure into a mould constructed of durable material, typically iron or steel

Note 1 to entry: A permanent mould casting process where the metal solidifies in a metal mould under low pressure (typically less than 1 bar above atmospheric pressure) is also referred to as a “low pressure die casting process”.

[SOURCE: EN 12258-1:2012, 3.1.9]

3.4
casting
product at or near finished shape, formed by solidification of the metal in a mould or a die

[SOURCE: EN 12258-1:2012, 2.5.1]

3.5
microstructure
structure of a metal as revealed by microscopic examination of a surface, typically after mechanical and/or chemical preparation, e.g. polishing and micro-etching

[SOURCE: EN 12258-1:2012, 4.5.10]

3.6
defect
quality characteristic is lower with respect to the level or state foreseen (usually specified); it does not allow the product to carry out the function requested

[SOURCE: EN 12258-1:2012, 7.1.2]

3.7
imperfection
quality characteristic is for a some extent lower with respect to the level or state foreseen

Note 1 to entry: This does not mean necessarily that the product is not suitable for use. An imperfection needs to be evaluated by means of a proper scale, based on the related specifications, to decide if the product has a quality level making it suitable for use.

[SOURCE: EN 12258-1:2012, 7.1.1]

3.8
mechanical potential
tensile properties (in terms of Ultimate Tensile Strength, Yield Strength and Elongation) which can be expected by Al-Si based alloys, separately cast in reference dies with state-of-the-art knowledge on die design, process management and alloy treatments correctly applied to minimize defects and imperfections; the mechanical potential can be higher than the mechanical properties evaluated on test pieces taken from real castings

3.9
reference die
permanent die, designed according state-of-the-art methodologies and made of steel or of cast iron, suitable for the evaluation of mechanical potential of Al-Si cast alloys; the geometry of reference dies varies, in dependence of which process is applied (High Pressure, Low Pressure and Gravity Casting)

3.10
reference casting
casting produced using the reference die

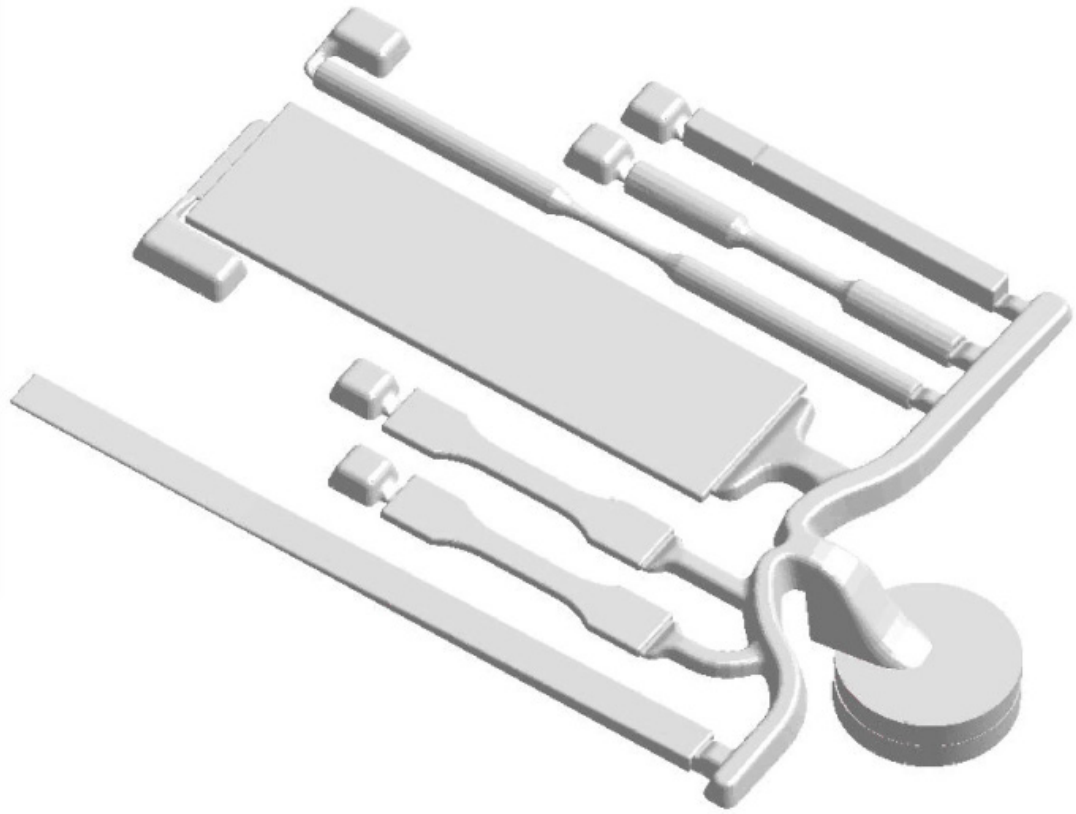
4 Reference dies

4.1 Reference dies for high pressure die cast Al-Si alloys

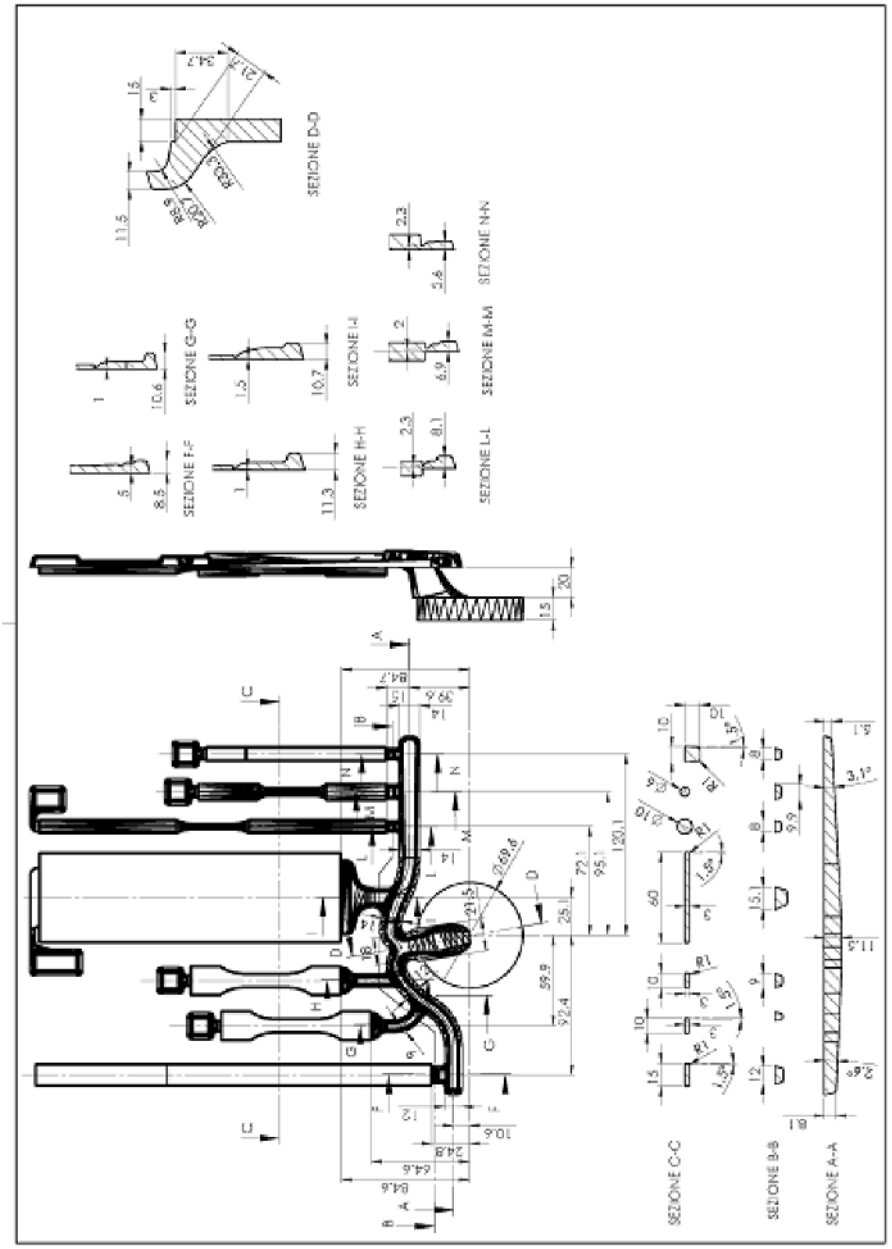
4.1.1 HPDC reference die #1

The mechanical potential of high pressure die cast Al-Si alloys can be evaluated by the reference die designed, built and tested in the frame of NADIA Project (New Automotive components Designed for and manufactured by Intelligent processing of light Alloys, EU IPs-SMEs, Contract n. 026563-2, 2006-2010). The reference casting is also suitable for other kinds of characterizations.

Figure 1 a) and b) shows the configuration of the HPDC reference casting #1.



a) HPDC Reference casting #1 (general drawing)



b) HPDC Reference casting #1 (detailed drawing)

Figure 1

4.1.2 HPDC reference die #2

The mechanical potential of high pressure die cast Al-Si alloys can be evaluated by the reference die, designed, built and tested by HYDRO in cooperation with NTNU (University of Trondheim).

Figure 2 shows the configuration of the HPDC reference casting #2.

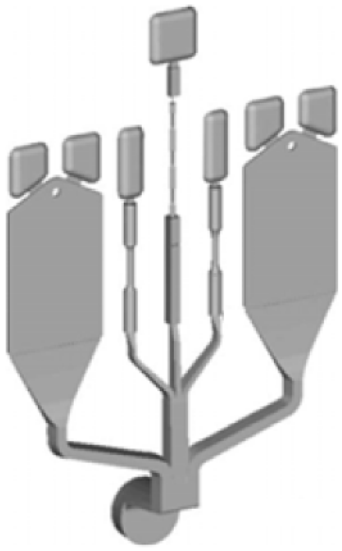


Figure 2 — HPDC Reference casting #2

4.2 Reference dies for low pressure and gravity die cast Al-Si alloys

4.2.1 Gravity casting Reference die #1

The mechanical potential of gravity die cast Al-Si alloys can be evaluated by the Gravity casting Reference die #1, whose details are given in Ref. [1].

Figure 3 shows the configuration of Gravity casting Reference die #1.

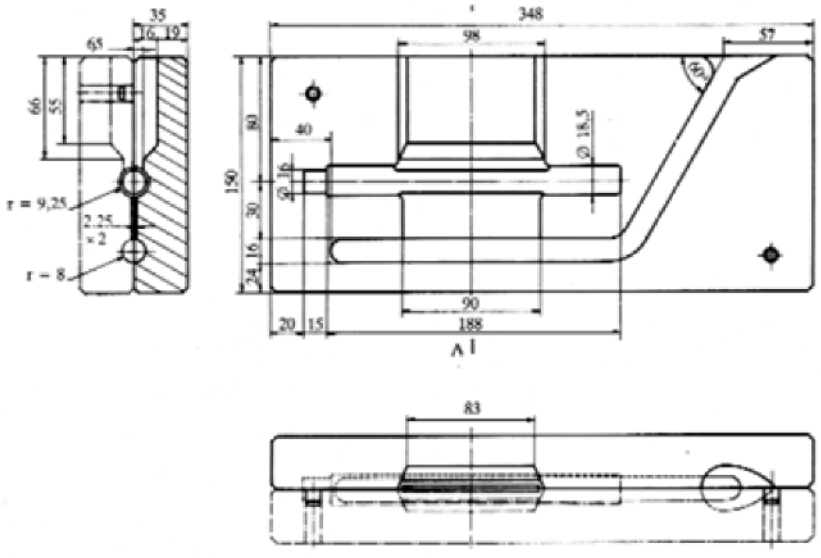


Figure 3 — Gravity casting reference die #1

4.2.2 Gravity casting Reference die #2

The mechanical potential of gravity die cast Al-Si alloys can be evaluated by the Gravity casting Reference die #2, whose details are given in Ref. [1].

Figure 4 shows the configuration of Gravity casting Reference die #2.

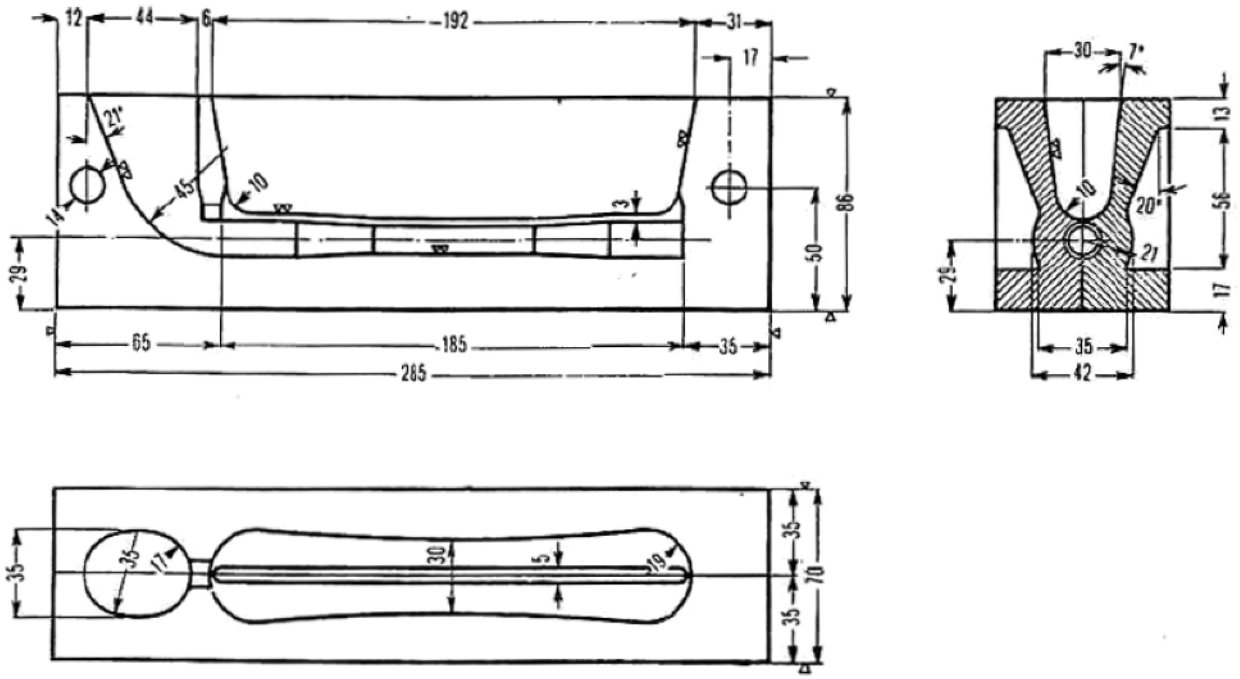


Figure 4 — Gravity casting Reference die #2

4.2.3 Gravity casting Reference die #3

The mechanical potential of gravity die cast Al-Si alloys can be evaluated by the reference die designed, built and tested by NTNU (University of Trondheim) in cooperation with SINTEF (Norway).

Figure 5 shows the configuration of the reference casting obtained Gravity casting Reference die #3.

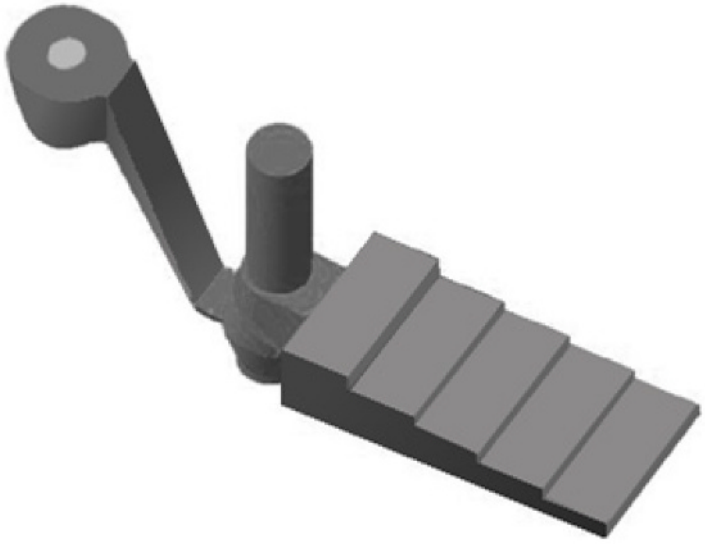


Figure 5 — Reference gravity casting #3

4.2.4 LPDC reference die

The mechanical potential of low pressure die cast Al-Si alloys can be evaluated by the reference die designed, built and tested by NTNU (University of Trondheim) in cooperation with SINTEF (Norway).

Figure 6 shows the configuration of this reference casting.

Figure 6 — LPDC Reference casting

5 Definition of mechanical potential of Al-Si die cast alloys

5.1 General

The mechanical potential of Al-Si alloys shall be evaluated by means of tensile tests performed on specimens cast using the reference dies described in Clause 4. Further information on Reference dies and castings are collected in Annex A. The mechanical properties collected in EN 1706 are referred to minimum values.

Unless otherwise specified in the order document, the production of reference castings shall be left to the discretion of the producer. Unless it is explicitly stated in the order document, no obligation shall be placed on the manufacturer to use the same processes for subsequent and similar orders. However, the supplier should inform the purchaser of any change which may affect the quality of the reference casting.

Tensile tests shall be carried out on as cast specimens (F temper), after holding a few days at room temperature; for other specific tempers, the related details shall be agreed between supplier and purchaser, in accordance with EN 1559-1, EN 1559-4, EN 1676 and EN 1706.

5.2 Tensile tests

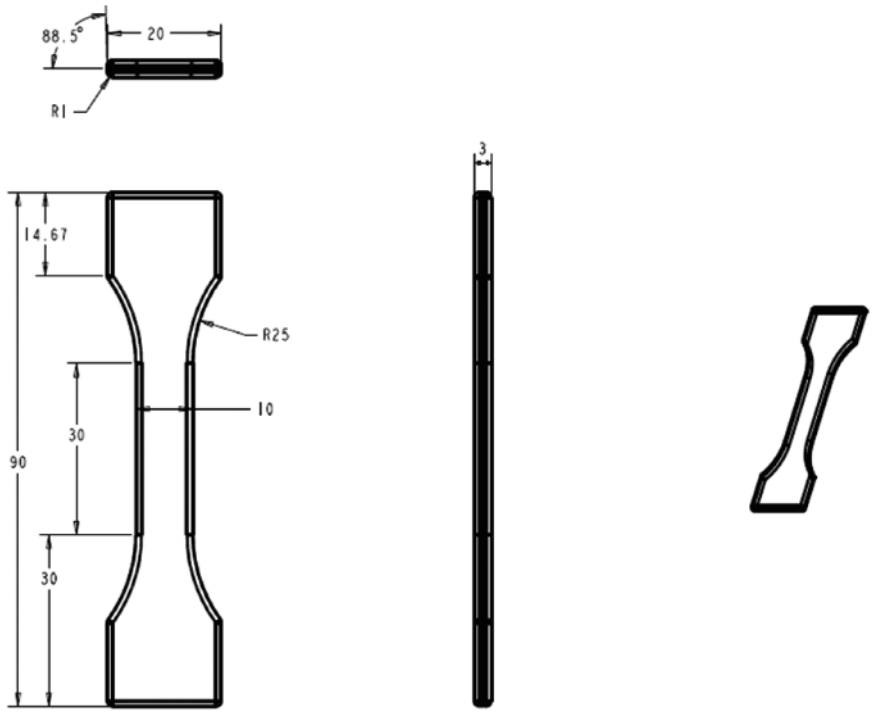
Tensile tests shall be carried out in accordance with EN ISO 6892-1.

5.3 Test pieces

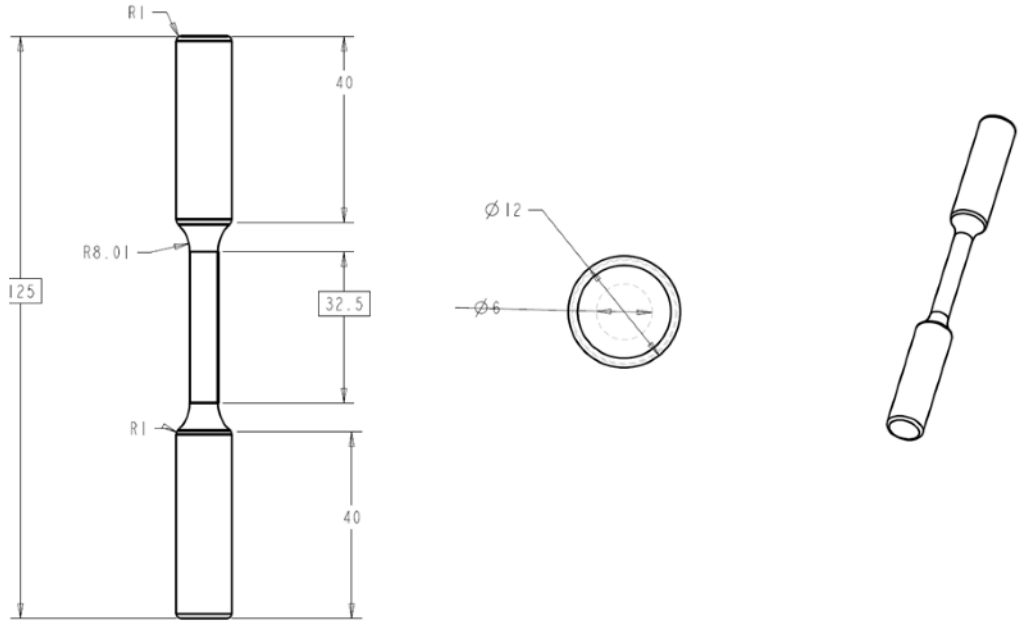
For high pressure die cast alloys, tensile test pieces shall be cut directly from the reference castings, and tested without machining. They shall be conforming to the specifications given in Figure 7 and Figure 8 (Ref. [1]).

For gravity die cast alloys, tensile test pieces may be tested in the machined or un-machined condition. If machined, they shall be conforming to the specifications given in Figure 9 and Figure 10 (Ref. [2]).

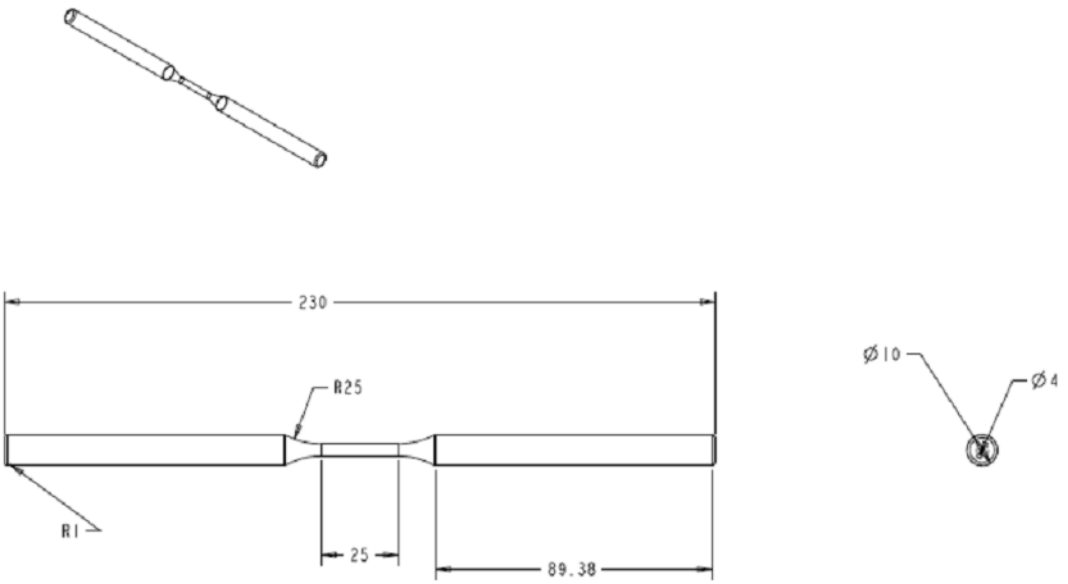
For low pressure die cast alloys, tensile test pieces shall be machined directly from the reference casting, according to EN ISO 6892-1.



a)

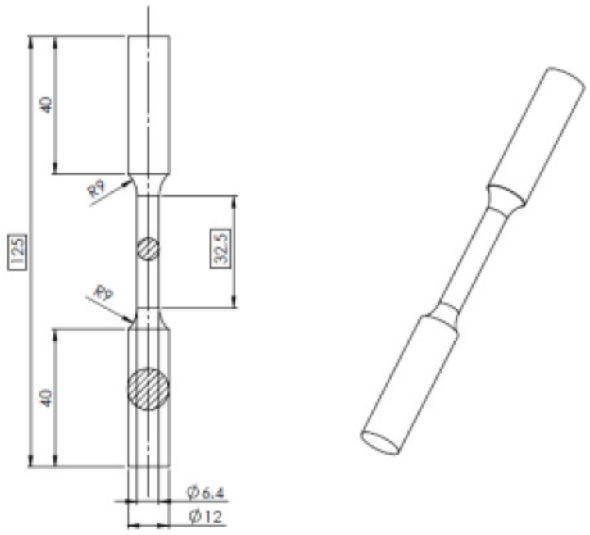


b)

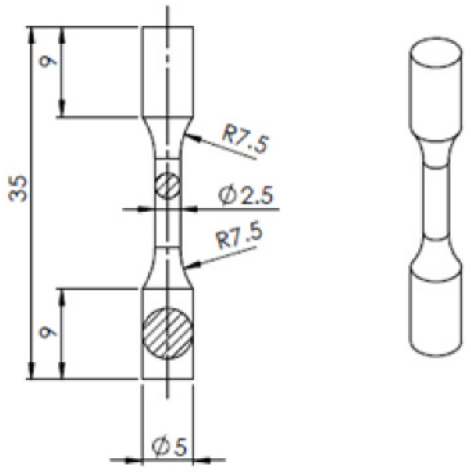


c)

Figure 7 — Specimens cut from high pressure die casting reference casting #1



a)



b)

Figure 8 — Specimens cut from high pressure die casting reference casting #2

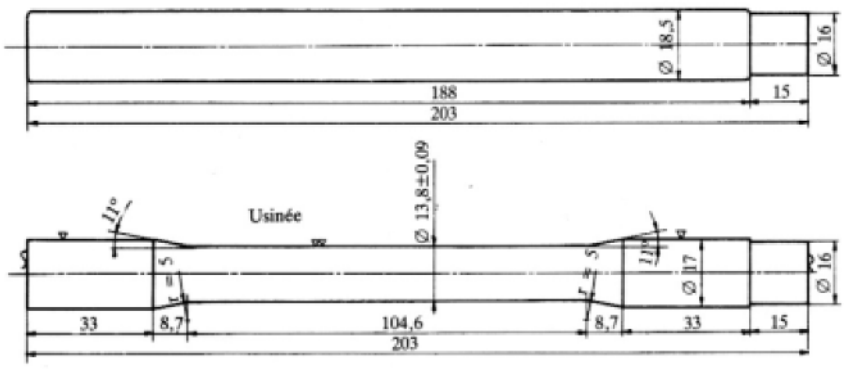


Figure 9 — Specimen drawn from gravity die casting reference casting #1

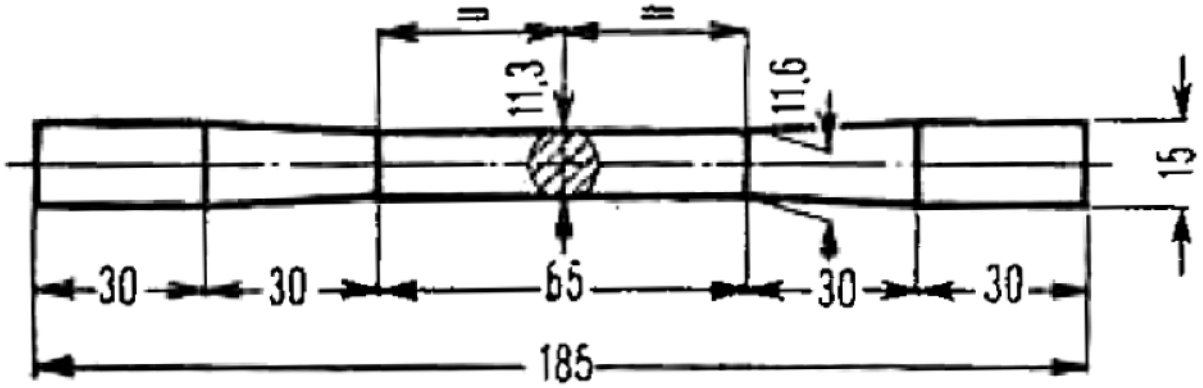


Figure 10 — Specimen drawn from gravity die casting reference casting #2

5.4 Rounding rules for determination of compliance

Rounding rules shall be applied in accordance with EN ISO 6892-1.

5.5 Mechanical potential

The mechanical potential of the alloy shall be directly achieved by the results of tensile tests on test pieces obtained from reference castings. The mechanical potential will be indicated by means of a table (whose template is shown in Table 1), in which R_m, $R_{p0.2}$ and A% values are reported, together with all the available information on alloy composition, casting process parameters and testing procedure.

Annex A reports some examples of the mechanical potential of high pressure die cast Al-Si alloys.

Table 1 — Template for indication of mechanical potential of Al-Si cast alloys

Alloy*	Process: ….. Casting parameters**	Mechanical Potential***		
		R_m MPa	$R_{p0.2}$ MPa	A %

* Information should be supplied on alloy composition<.

** Information should be supplied on casting process parameters (melting and metal treatment procedure, die, HPDC machine, thermo-regulation parameters, pouring procedure, nominal plunger velocity, and intensification pressure).

*** Information should be supplied on mechanical testing procedure (e.g. crosshead speed, kind of extensometer, number of tensile tests conducted for each condition); at least 10 specimens shall be tested; together with average R_m, $R_{p0.2}$ and A% values, the standard deviation shall be reported.

Annex A
(informative)

Mechanical potential of Al-Si based alloys for high pressure and gravity die casting: Examples of reference dies and castings

A.1 High pressure die casting

A.1.1 Reference casting #1 [1]

Figure A.1 shows the geometry of reference casting #1 for high pressure die casting.

a) Alloys evaluated

Table A.1 collects the composition of the alloys tested. The chemical composition of the molten bath is measured on samples separately poured at the beginning and at the end of the casting trials.

Table A.1 — Composition of the alloys evaluated

Alloy	*Si*	*Fe*	*Cu*	*Mn*	*Mg*	*Cr*	*Ni*	*Zn*	*Pb*	*Sn*	*Ti*	*Al*
AlSi9Cu3Fe	8.227	0.799	2.825	0.261	0.252	0.083	0.081	0.895	0.083	0.026	0.041	bal.
AlSi11Cu2(Fe)	10.895	0.889	1.746	0.219	0.224	0.082	0.084	1.274	0.089	0.029	0.047	bal.
Al Si12Cu1(Fe)	10.510	0.721	0.941	0.232	0.242	0.045	0.080	0.354	0.055	0.025	0.038	bal.

b) Experimental procedure and casting conditions

1) *Metal treatment*

The alloy, supplied as commercial ingots, is melted in a 300 kg crucible in a gas-fired furnace set up at (800 ± 10) °C and maintained at this temperature for at least 3 h. The temperature of the melt is then gradually decreased by following the furnace inertia up to (690 ± 5) °C. The molten metal is then degassed with Ar for 15 min. The hydrogen content of the melt in the holding furnace is analysed by hydrogen analyser, and it shows values lower than 0,15 ml/100 g Al during the entire experimental campaign. Periodically, the molten metal is manually skimmed with a coated paddle.

2) *Casting parameters*

Cast-to-shape specimens are produced using HPDC reference casting #1 in a cold chamber die-casting machine with a locking force of 2,9 MN. The reference die is built using X38CrMoV5-1 tool steel. The process parameters can be varied within a range of values, particularly the I phase speed (0,06-0,29) m/s, the II phase speed (2,26-3,40) m/s, the third phase pressure (33,7-40,5) MPa, the melt velocity at in-gates 40-61 m/s and the filling time (8,2-12,3) ms. Cycle time is 45 seconds.

The weight of the Al alloy die casting is 0,9 kg, including the runners, gating and overflow system. About 15 castings are scrapped after the start up, to reach a quasi-steady-state temperature in the shot chamber and die. Oil circulation channels in the die served to stabilize the temperature (at ~230 °C). The melt is transferred in 18 s from the holding furnace and poured into the shot sleeve by means of a coated ladle. The fill fraction of the shot chamber, with a 70 mm inner diameter, is 0,28. The biscuit thickness of the castings is measured to be steady at (31 ± 2) mm.

The nominal plunger velocity is 0,2 m/s for the first phase and 2,7 m/s for the filling phase; a pressure of 40 MPa is applied once the die cavity is full to guarantee high-integrity castings.

c) Optimal conditions and affecting factors

The optimal experimental conditions at steady-state are melt velocity 47 m/s and filling time 10,7 ms. The process parameters influence the defects and microstructure of the casting, such as segregation bands and externally solidified crystals formation.

d) Mechanical testing

The surface finish of samples was considered to be sufficiently accurate to avoid machining, and only some excess flash along the parting line of the die was manually removed. The tensile tests are done on a tensile testing machine. The crosshead speed used is 2 mm/min. The strain is measured using a 25-mm extensometer. Experimental data are collected and processed to provide yield stress ($R_{p0.2}$, actually 0,2 % proof stress), ultimate tensile strength (R_m) and elongation to fracture (A). At least 10 tensile tests are conducted for each condition.

The as-cast tensile bars are:

— flat, with 3 mm thickness, gauge length of 30 mm and gauge width of 10 mm;

— round with 6 mm diameter and gauge length of 32,5 mm.

The samples are maintained at room temperature for 5 months before testing.

e) Mechanical potential

Table A2 summarizes the mechanical potential evaluation of the alloys tested, while Figure A.1 collects the related engineering stress-strain curves. 10 specimens have been tested.

Table A.2 — Mechanical Potential of some Al-Si high pressure die cast alloys (HPDC Reference die #1)

Alloy	**Casting conditions (see above) Process: High Pressure Die Casting**	**Mechanical Potential**		
		R_m MPa	**$R_{p0.2}$ MPa**	**A %**
AlSi9Cu3Fe	Melt velocity at ingates: 51 m/s; filling time: 9,7 ms; pouring temperature: 690 °C FLAT SPECIMENS Thickness: 3 mm	309 ± 6	163 ± 1	3,6 ± 0,3
	ROUND SPECIMENS Diameter: 6 mm	342 ± 8	168 ± 6	5,1 ± 0,4
AlSi11Cu2(Fe)	Melt velocity at ingates: 51 m/s; filling time: 9,7 ms; pouring temperature: 690 °C FLAT SPECIMENS Thickness: 3 mm	312 ± 2	153 ± 1	3,5 ± 0,1
	ROUND SPECIMENS Diameter: 6 mm	342 ± 7	158 ± 3	5.5 ± 0.7
Al Si12Cu1(Fe)	Melt velocity at ingates: 51 m/s; filling time: 9,7 ms; pouring temperature: 690 °C FLAT SPECIMENS Thickness: 3 mm	283 ± 2	137 ± 1	3,5 ± 0,1
	ROUND SPECIMENS Diameter: 6 mm	315 ± 7	131 ± 2	7,1 ± 0,5

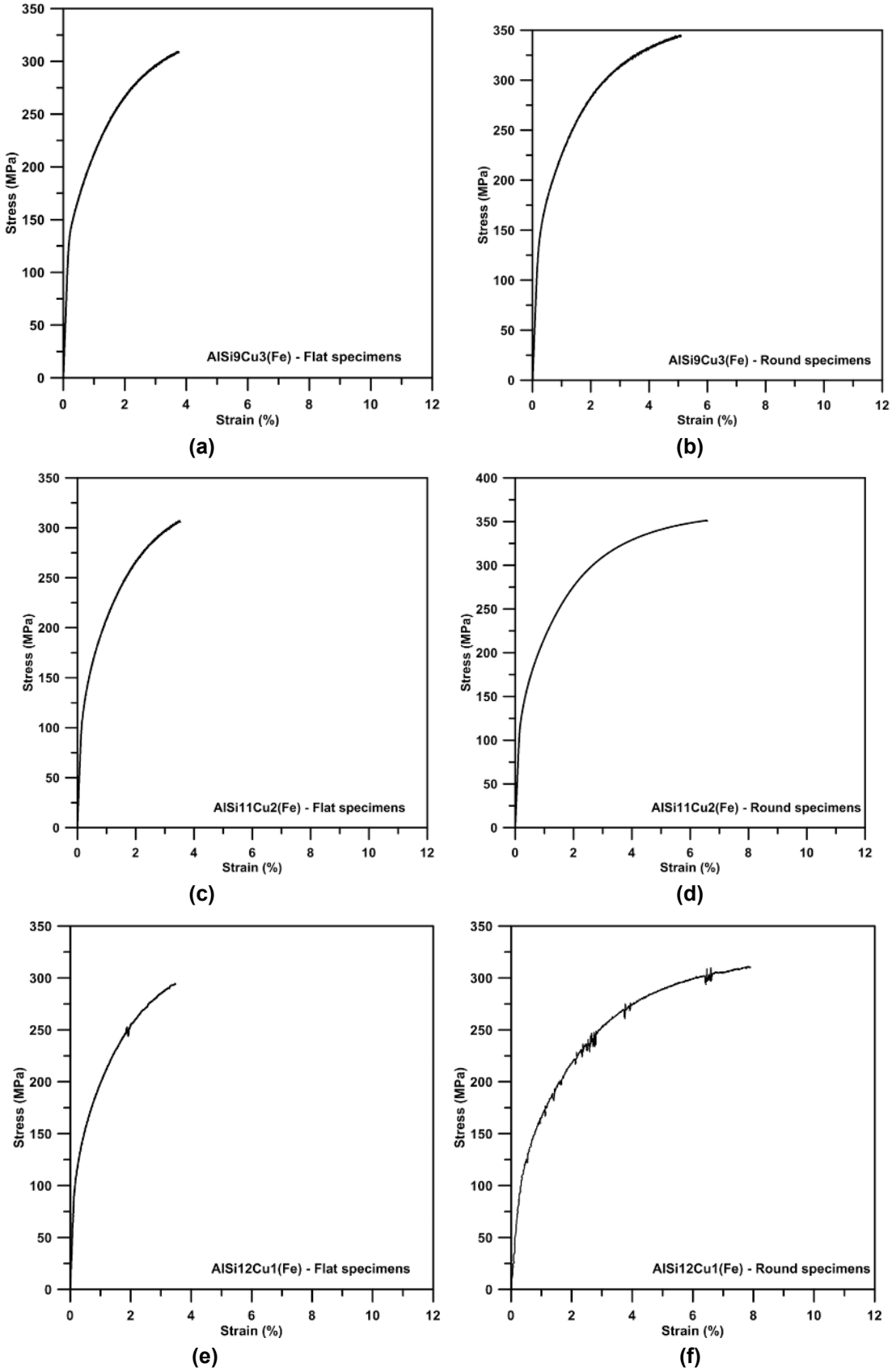


Figure A.1 — Engineering stress-strain curves of diecast (a,b) AlSi9Cu3Fe, (c) AlSi11Cu2(Fe), (d,e) AlSi12Cu1(Fe) (the curves refer to (a,c,e) flat and (b,d,f) round specimens)

A.1.2 Reference casting #2 [3]

Figure 2 shows the geometry of reference casting #2 for high pressure die casting.

a) Alloy evaluated

Table A.3 collects the composition of the alloy tested. The chemical composition of the molten bath is measured on samples separately poured at the beginning and at the end of the casting trials.

Table A.3 — Composition of the alloy evaluated

Alloy	*Si*	*Fe*	*Cu*	*Mn*	*Mg*	*Cr*	*Ni*	*Zn*	*Pb*	*Sn*	*Ti*	*B*	*Sr*	*Al*
AlSi7MgMn	6.97	0.136	-	0.68	0.30	-	-	-	-	-	0.107	0.0004	0.0280	bal.

b) Experimental procedure and casting conditions

1) Metal treatment

The alloy, supplied as commercial ingots, is melted at (780 ± 10) °C. The temperature of the melt is then gradually decreased up to (710 ± 5) °C. The molten metal is degassed with Ar for 15 min and, periodically, it is manually skimmed with a coated paddle. Sr modification has been carried out as well as Ti grain refining; lower mechanical properties can be expected without these metal treatments. The melt was maintained in the holding furnace at 710 ± 5 °C for 30 min before casting.

2) Casting parameters

Cast-to-shape specimens are produced using HPDC reference casting #2 in a cold chamber die-casting machine with a locking force of 4,1 MN. The process parameters are: I phase speed 0.5 m/s, II phase speed 4,2 m/s and the third phase pressure 60 MPa. The shot sleeve diameter is 60 mm, with a fill fraction of 50 %.

The weight of the Al alloy die casting is 1,2 kg, including the runners, gating and overflow system. About 25 castings are scrapped after the start up, to reach a quasi-steady-state temperature in the shot chamber and die. Oil circulation channels in the die served to stabilize the temperature (at ~200 °C).

c) Mechanical testing

The surface finish of samples was considered to be sufficiently accurate to avoid machining, and only some excess flash along the parting line of the die was manually removed. The tensile tests are done on a tensile testing machine. The crosshead speed used is 2 mm/min. The strain is measured using a 25-mm extensometer. Experimental data are collected and processed to provide yield stress ($R_{p0.2}$, actually 0,2 % proof stress), ultimate tensile strength (R_m) and elongation to fracture (A). At least 10 tensile tests are conducted for each condition.

The as-cast tensile bars are round, with 6 mm diameter and gauge length of 30 mm. The samples are maintained at room temperature for 5 months before testing.

d) Mechanical potential

Table A.4 summarizes the mechanical potential evaluation of the alloy tested, while Figure A.2 collects the related engineering stress-strain curve. 10 specimens have been tested.

Table A.4 — Mechanical Potential of AlSi7MgMn high pressure die cast alloy (HPDC Reference die #2)

Alloy	**Casting conditions (see above) Process: High Pressure Die Casting**	**Mechanical Potential**		
		R_m MPa	**$R_{p0.2}$ MPa**	**A %**
AlSi7MgMn	Melt velocity at ingates: 56 m/s; filling time: 8,8 ms; pouring temperature: 710 °C ROUND SPECIMENS Thickness: 6 mm	264 ± 6	130 ± 4	10,5 ± 0,9

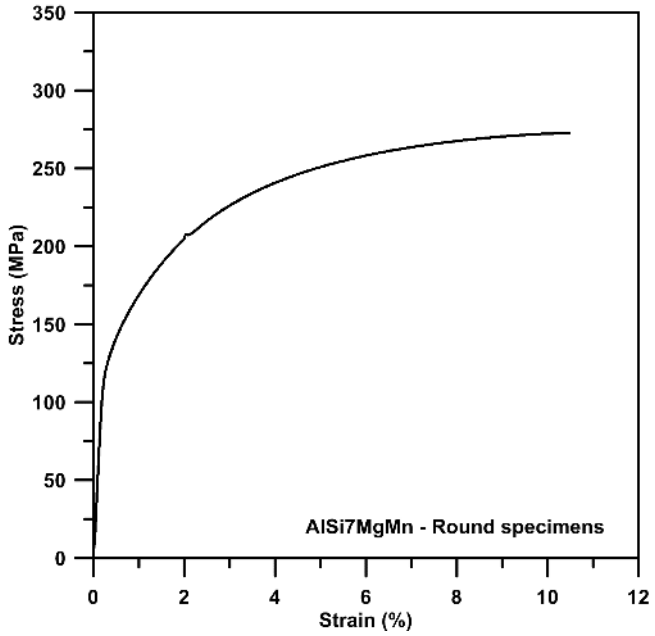


Figure A.2 — Engineering stress-strain curve of diecast AlSi7Mg0.3 alloy

A.2 Gravity die casting

Reference gravity casting #3 [4-5]

Figure 5 shows the geometry of reference casting #3 for gravity casting.

a) Alloy evaluated

Table A.5 collects the composition of the alloy tested. The chemical composition of the molten bath is measured on samples separately poured at the beginning and at the end of the casting trials.

Table A.5 – Composition of the alloy evaluated

Alloy	*Si*	*Fe*	*Cu*	*Mn*	*Mg*	*Cr*	*Ni*	*Zn*	*Pb*	*Sn*	*Ti*	*Al*
Al-Si7-Mg0.3	7.03	0.091	-	0.008	0.41	-	-	0.005	-	-	0.11	bal.

b) Experimental procedure and casting conditions

1) Metal treatment

The alloy, supplied as commercial ingots, is melted in a 70 kg electric resistance furnace set up at (720 ± 10) °C and maintained at this temperature. The molten metal is then degassed with Ar for 15 min. The hydrogen content of the melt in the holding furnace is analysed by hydrogen analyser, and it shows values lower than 0.1 ml/100 g Al during the entire experimental campaign. Periodically, the molten metal is manually skimmed with a coated paddle. Sr modification has been carried out as well as Ti grain refining; lower mechanical properties can be expected without these metal treatments.

2) Casting parameters

Castings are produced using Gravity reference casting #3. Oil circulation channels in the die served to stabilize the temperature (at ~320 °C). About 3 castings are scrapped after the start up, to reach a quasi-steady-state temperature in the die. A ceramic filter with a pore size of 10 ppi was used.

c) Mechanical testing

Flat tensile test bars with rectangular cross section were drawn from each step, in the middle zones of the castings. The tensile specimens were 100-mm long, 20-mm wide, and 3-mm thick, with a gage length of 30 mm and a width of 10 mm.

The tensile tests are done on a tensile testing machine. The crosshead speed used is 1,5 mm/min. The strain is measured using a 25-mm extensometer. Experimental data are collected and processed to provide yield stress ($R_{p0.2}$, actually 0.2 % proof stress), ultimate tensile strength (R_m) and elongation to fracture (A). At least 10 tensile tests are conducted for each condition.

d) Mechanical potential

Table A.6 summarizes the mechanical potential evaluation of the alloy tested. 10 specimens from each step have been tested.

Table A.6 — Mechanical Potential of one Al-Si gravity die cast alloy (Gravity reference die #3)

Alloy*	**Casting conditions** Process: Gravity Die Casting**	**Mechanical Potential***		
		R_m MPa	**$R_{p0.2}$ MPa**	**A %**
	filling time: 5-6 s; pouring temperature: 720 °C FLAT SPECIMENS: Thickness: 4 mm			
Al-Si7-Mg0.3	5 mm step	194 ± 2	-	9,5 ± 1
	10 mm step	182 ± 3	-	7,1 ± 0,5
	15 mm step	174 ± 1	-	5,6 ± 0,3
	20 mm step	166 ± 2	-	4,4 ± 0,2
	30 mm step	161 ± 3	-	3,2 ± 0,6

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