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Low Pressure Casting Micro-Foundry – Investigation of the Car Wheels

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Abstract
The paper presents technological experiments and optimized casting process parameters in a low pressure casting machine such as an open thermodynamic system (OTS). The basic information is: technological parameters for casting of 7Jx15H2 wheel/(alloy A356); the polycrystalline structure by macro- and micro-grinds with DAS analysis; the local crystallization time LCT; the mechanical properties obtained in the different zones of the casting. Obtained scale and LCT basic data for 3D tasks Stephan and Stephan-Schwartz.

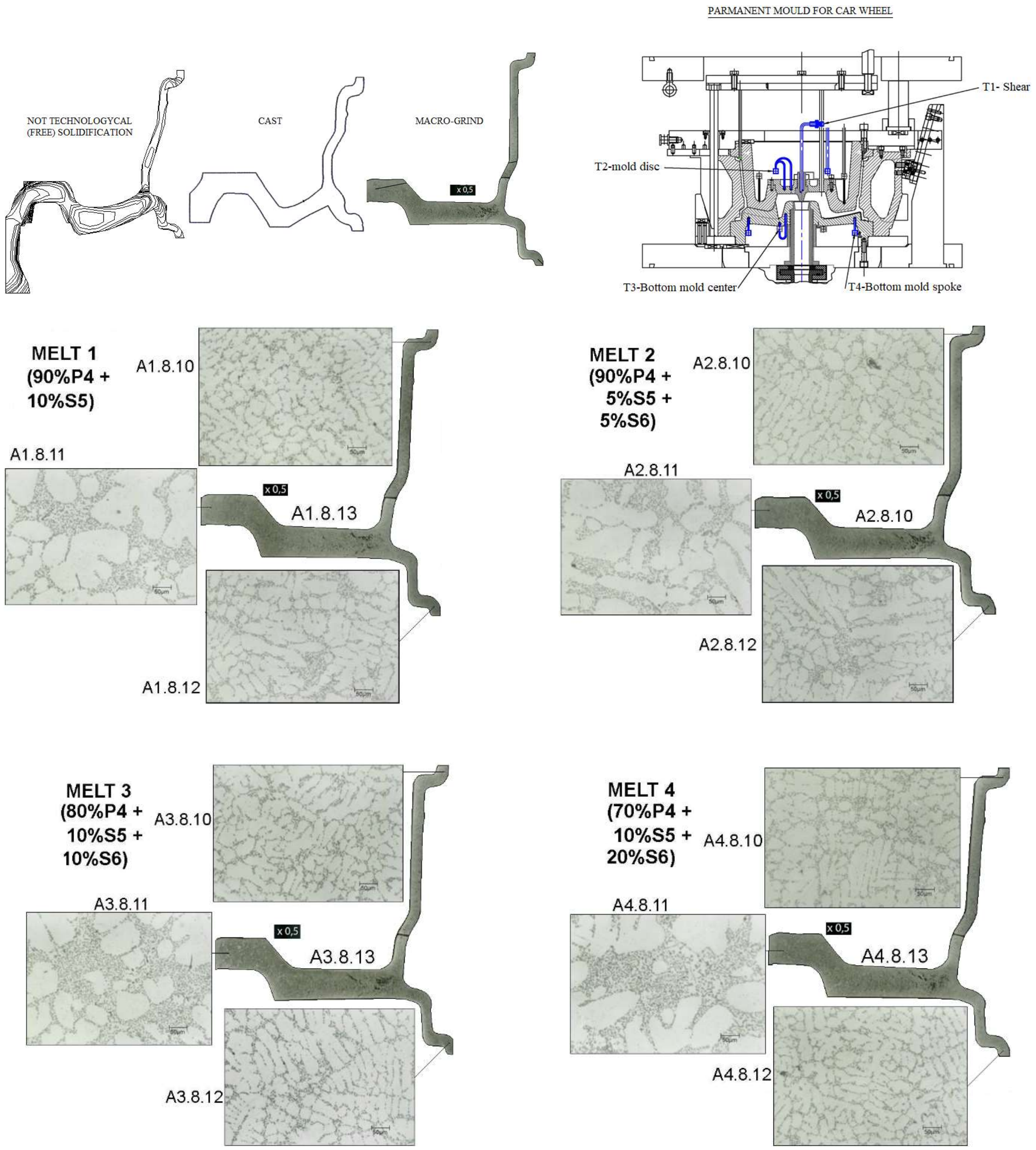
Keywords: car wheel, low pressure casting and technological casting dates: structures, DAS analysis, LCT and scale.

1. Introduction – test results cast car wheels

The theory of heat conduction through Stefan Schwarz's task is the mathematical description of the process of creating the structure of the flying material – the phase transition of the first genus. The mathematical scheme of Stephen-Schwarz's task is: thermal conductivity equation, initial conditions and boundary conditions

$$
\begin{aligned}
c_i \rho_i \frac{\partial T_i}{\partial t} &= \lambda_i \Delta T_i + Q_m, \text{ in } V_C \cup B_{C|M} \cup V_M \cup B_M \\
T_C(x,y,z,t) &= f_C(x,y,z), \\
T_M(x,y,z,t) &= f_M(x,y,z), \\
\nabla T_{BC}(x,y,z,t) &= \nabla T_{BM}(x,y,z), \\
\nabla T_{BM}(x,y,z,t) &= \alpha(T_{BM|Ar.M.}(x,y,z) - T_{Ar.M.},
\end{aligned}
\qquad (1)
$$

where $\Delta = \partial^2/\partial x^2 + \partial^2/\partial y^2 + \partial^2/\partial z^2$; T, c, ρ and λ are nonstationary temperature of solidification of OTS heat capacity, density, heat conductivity with index i = C for cast and i = M for mold; V_C, $B_{C|M}$, V_M and $B_{M|Ar.M.}$ are volume of cast, boundary between cast and mold, volume of mold and boundary between mold and around medium (Ar.M.) and $T_{Ar.M.}$ is temperature around medium; Q_m is latent heat of melting; f(x, y, z) is initial temperature of the parts of OTS; $\nabla = \partial/\partial x + \partial/\partial y + \partial/\partial z$. Fundamental information from Stephen-Schwarz's task is nonstationary behavior of isothermal surface (T_M – temperature of melt). This has been a description for thousands of years of the phase transition of first order.



The technological obtained polycrystalline macro- and micro-structures;

Fig. 1 Basic scheme – OTS for low pressure casting on a car wheel with technological obtain of macro- and micro- structures

Fig. 1 shows the basic idea of this article through six consecutive figures as follows: **First picture:** not technological solidification (Free) solidification with close volume of melt (numerical result) [9 and 10]; the cast; the technological macro-structure obtained in different volumes of the cast; **Second picture:** Assembly drawing Open Thermodynamics System (OTS) mold-machine; and with next very important **Four consecutive pictures**: we introduce the statistics of measurement of the structures in the volume of casts with inscriptions. Full characterization in this investigation of the care wheels is AX.YY.Z, where A is care wheel; X is melt number (1÷end); YY is casting number (1÷end); Z is zone. On each figure there is: the Melt Number (%P4 + %S5 + %S6), where %P4 is the percent the designation primary alloy of

composition 4, %S5 is the percent of the secondary alloy (turnover), %S6 is the percent of the secondary alloy (turnings) + macro-grind, where Z is the full area + micro-grinds is of three local zones Z:
Melt 1 (90%P4 + 10%S5) + A1.8.13 + A1.810 + A1.811 + A1.8.12;
Melt 2 (90%P4+5%S5 + 5%S6) + A2.8.10 + A2.8.10 + A2.8.11 + A2.8.12;
Melt 3 (80%P4 + 10%S5 + 10%S6) + A3.8.13 + A3.8.10 + A3.8.11 + A3.8.12;
Melt 4 (70%P4 + 10%S5 + 20%S6) + A4.8.13 + A4.8.10 + A4.8.11 + A4.8.12.
The technological process of the first-order phase transition is determined by the initial, boundary conditions, the heat-physical coefficients of the casting material with the mold, the complex geometry of the casting and the mold construction.

Technological results of casting conditions from experiments for 7Jx15H2 wheel/(alloy A356).

Technological parameters

- Low pressure casting.
- Melt temperature TMe – 720 ± 5 ^{O} C
- Pressure in the machine furnace Pmax – 0,05 MPa
- Initial mold temperature:
  - top mold – 320-330 ^{O}C
  - bottom mold – 330-360 ^{O}C
  - lateral mold parts – 280-300 ^{O}C
- Technological casting times:

Technological casting times during different procedures [s]: τ_1 – time for achieving of P; τ_2 – crystallization under P; τ_3 – cooling of the casting under P = 0 MPa. For τ_1, τ_2 and τ_3 are obtained initial casting times [s] as follows τ_1(35; 35; 35), τ_2(0; 20; 70) τ_3(180; 150; 120) and optimal casting times [s] τ_1(35), τ_2(130) τ_3(80). Mold cooling regime: Cooling circuit zone T_1 – shear, T_2 – top mold disk, T_3 – bottom mold center, T_4 – bottom mold spoke and results Cooling circuit time in [s]: T_1 – Pause 100 [s] Air cooling 90 [s]; T_2 – Pause 50 [s] Air cooling 100 [s]; T_3 – Pause 100 [s] Air cooling 60 [s]; T_4 – Pause 50 [s] Air cooling 40 [s].
It is well known, that the polycrystalline structure carrying the working properties of the castings (see Fig.1). The structure is introduced by *DAS* analyses with showing *scales* on the macro- and micro-pictures we name **statics properties** and the *local crystallization times* are **dynamical properties of OTS**. The connection between DAS and LCT is

$$LCT[s] = (DAS[\mu m]/10)^3. \tag{2}$$

Some data of static and dynamic properties are in Table 1 (see Fig. 1)

Table 1: Secondary dendrite arm spacings (DAS, µm) and Local Crystallization Times (LCT, s) for the investigated cast car wheels

Car wheel	DAS [µm]	LCT [s]
A1.8.12	23.4	12.8
A1.8.10	22.8	11.8
A1.8.11	50.4	128.0
A1.8.12	23.4	12.8
A2.8.10	19.8	7.8
A2.8.11	48.0	110.6
A2.8.12	21.6	10.1

A3.8.10	21.6	10.1
A3.8.11	50.4	128.0
A3.8.12	24.0	13.8
A4.8.10	21.6	10.1
A4.8.11	58.8	203.3
A4.8.12	24.6	14.9

The working properties of castings are achieved in the technological casting process and most often after heat treatment. The working mechanical properties are test: 1. Hardness test $R_p0,2$ [Mpa], R_m [Mpa], A%; 2. Fatique test; 3. Impact test; 4. Microstructure. The obtained from specific castings and in specific local locations are presented in the following Tables 2, 3, 4:

Table 2: Mechanical test of the car wheel-Center after statistical calculating

Code	Rp02 [MPa]	Rm [MPa]	A5 [%]
A1.1	236	291	10
A2.1	227	291	9
A3.1	234	290	8
A4.1	218	282	8

Table 3: Mechanical test of the car wheel – Spoke after statistical calculating

Code	Rp02 [MPa]	Rm [MPa]	A5 [%]
A1.2	240	297	11
A2.2	235	290	10
A3.2	229	282	9
A4.2	226	281	10

Table 4: Hardness HB 2,5/62,5/30 in different zones of wheels

Zone	Code	A1	A2	A3	A4
Center	AX.Y.7	92	91	91	93
Spoke	AX.Y.8	92	88	96	85
Front flange	AX.Y.9	89	95	93	84

The optimal mechanical properties for alloy A356 with composition AlSi7Mg are (Rp02 = 90; Rm = 160; A5 = 2; HB = 60). We choose criteria for mechanical properties

$$\delta \geq (\text{Rp02}=90\text{ MPa; Rm}=160\text{ MPa; A5}=2\%\text{; HB}=60\text{ MPa}). \quad (3)$$

The aim of this article is to present a methodology for micro-foundry based on technological experiments to evaluate the optimal parameters of the non-stationary temperature field of first order phase transition.

2. Industry 4.0 – Material Science

The Big Industry 4.0 Change [4] is based on the development of science and industry in the 20th century, presented here by keywords from the ten principles of materials processing as follows [5]: 1. Planning principle; 2. Standardization principle; 3. Work principle; 4. Ergonomic principle; 5. Unit low principle; 6. Space utilization principle; 7. System principle; 8. Automation principle; 9. Environmental principle; 10. Live cycle cost principle. The set of many large and very small things in the material science and engineering (LSTMSE) is represented in [8] by the principles:

$$\text{Processing} \rightarrow \text{Structure} \rightarrow \text{Properties} \rightarrow \text{Performance.} \tag{LSTMSE}$$

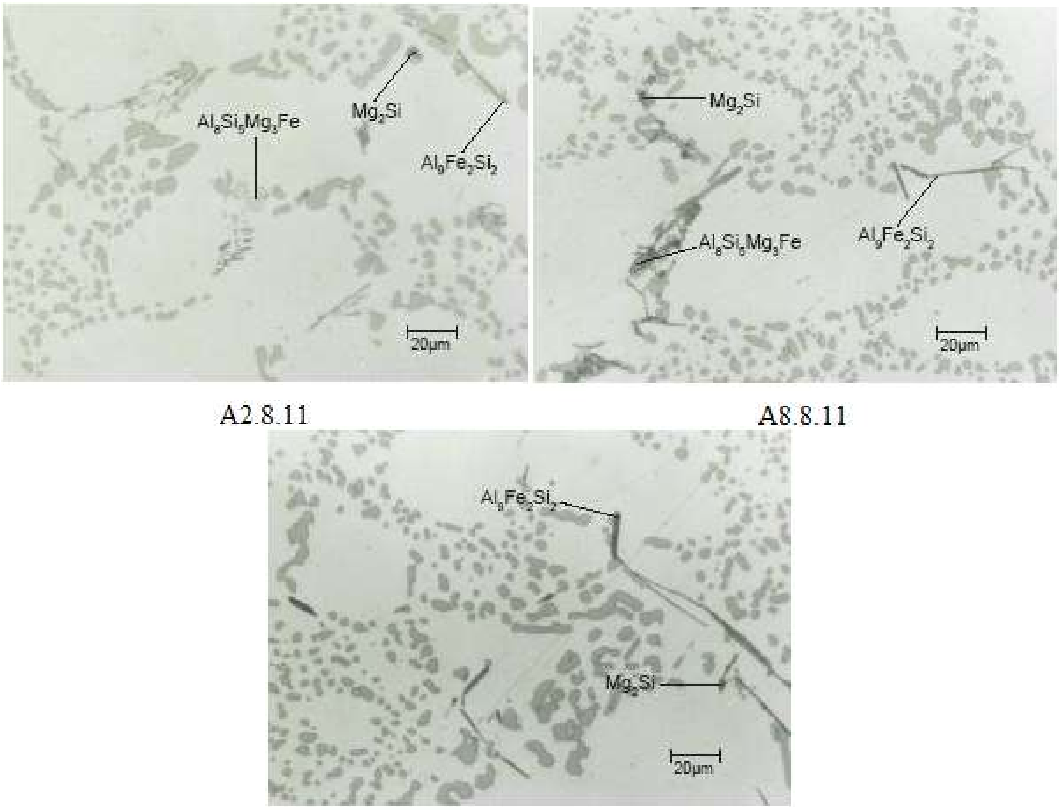
Generalization on the base of [1÷3], the ten principles [5] and (LSTMSE) [8] of the finished casting technology to us is the following scheme A, Technology Casting (ATC):

Phase transition of first order (eq.(1)) in every cast's local volume crystallization time (LCT) (eq.(2)) → Polycrystalline structure (DAS) (eq.(2)) → Work properties (eq.(3)).
(ATC)

General mathematical scheme (ATC) is (A, Mathematical Casting) or (AMC):

Stephan-Schwartz's problem → Polycrystalline structure → Work properties.
(AMC)

Each crystalline structure is observed with precision equipment for its own time [1, 3]. The crystalline structure observation and investigation equipment constantly refine to an example comparison of [6] and [7]. On Fig.2 is shown the micro-structures for the same area of different casts.



A9.7.11

Fig. 2 Statistical results of the micro- structures of different casts

From Figure 2, we select a scale for geometric representation of a cube-shaped local volume whose edge is of a length l = 20 μm. Here we use only data from photo A2.8.11 to define a measurement scale.
In Fig. 3, three microstructures with their respective compositions are shown as follows: $Al_8Si_5Mg_3Fe$, Mg_3Si и $Al_9Fe_2Si_2$:

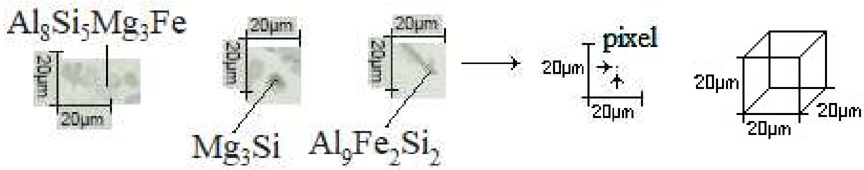


Fig. 3 Scale selection and possible volume of description with 1 pixel.

From Fig. 3 the scale represented by one pixel is:

$$l_{scale} = 20\mu m \to 28 \text{ pixels} \Leftrightarrow 1 \text{ pixel} = 0{,}714285714\ \mu m. \quad (4)$$

The local crystallization time LCT of eq.(2) is LCT =8 s with and along with the scale we are prepared to use a numerical network to solve the Stefan-Schwarz problem in 3D space. Thus, we can use developed non-commercial software products in our institute [9] and interaction with commercial software products MAGMASOFT [10].
The modern methodology of material science and engineering application is continually enriched and develops on the basis of development the fundamental scientific knowledge [8]. The structure and properties of the materials are the relationship between the two principles of "processing" and "performance" [8]. The historical development of material science is presented with work [1, 2, 3, 5, 6, 7 and 8]. For the sustainability of micro-foundries on the market under the conditions of Industry 4.0 [4], the acute need for their database is put in place. In the database for a micro-foundry it is necessary: 1. Casting method; 2. Technology – a desirable structure with working properties; 3. Future benefits for the manufacturer: product lifetime with service and easy modification for next application; 4. New product i.e. the need for fundamental scientific knowledge.
We assume that infrastructure is needed through branch research. The modern micro-foundry is highly robotic and computerized. Scientific assurance is based on:

- macro- and micro-tasks of the Stephan type;
- data from technological experiments;
- a description of the polycrystalline structure through mathematics and mathematical physics based on the obtained correlation scale eq.(4).

3. Conclusions

The resulting scale of technological experiments along with the local crystallization time are important physics data for a mathematical description of the first-order phase transition and the obtaining polycrystalline structures and work properties.

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