THE ANALYSIS OF EUTECTICAL Al-Si ALLOYS PROPERTIES USED FOR PISTON CAST IN THE INTERNAL COMBUSTION

Mirela POPESCU (DRĂGOIU), Endre FEJÉR, Bela VARGA

TRANSYLVANIA UNIVERSITY of BRASOV, Faculty of Materials Science and Engineering,
e-mail: mireladragoiu1@yahoo.com

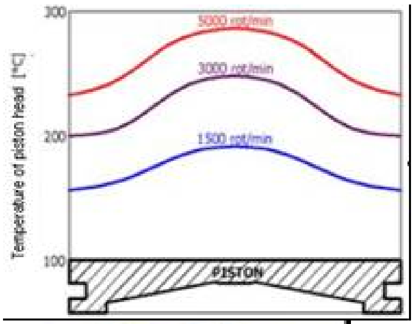
***Abstract**: In this study is analyzed the structure and properties of eutectic aluminum alloys for casting pistons of internal combustion engines. Simple thermal analysis and the presence of eutectical pointed silicon confirmed the modified structure of these alloys. The Dilatometer's analysis draws attention to the necessity of applying heat treatment to stabilize the structure. During the piston's operation there are occured significant structural changes that lead to the reduction of mechanical characteristics*

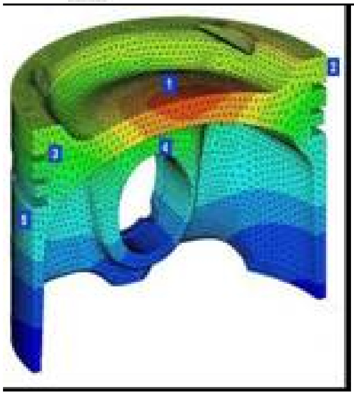
Keywords: *aluminium alloy, piston, structure, cooling curve..*

1. INTRODUCTION

Regarding the internal combustion engines, the piston is designed to ensure the evolution of fluid in the engine cylinder. It is the only cell wall of the combustion chamber. It performs a linear motion during which compresses the fuel mixture [1]

Piston works in extremely hard conditions, high pressures and temperatures, being exposed to some important mechanical and thermal request. Figure 1 presents the temperature distribution of the thermal load and the piston body [5].





Point No.	Tempera ture[^{0}C]
1	267
2	235
3	226
4	218
5	191

Figure 1. Thermal load and temperature distribution in the piston body [5]

The piston must satisfy a series of requirements, like: good tightness through its whole race; good guide provided without jamming both cold and hot; enough strength to take the given effort and gas pressure; small dilatation; lightweight to reduce to a minimum the inertia forces of the dead centers and sufficient lubrication to reduce to a minimum the resistances due to friction.

All these requirements are in good conditions satisfied by aluminum alloys

2. EXPERIMENTAL PROCEDURE

In this paper we analyzed the structure and properties of used pistons against the structure and the properties resulted from remelting and cast-solidified them in various conditions, Table 1.

Table 1. Codification of used pistons and the samples resulted after their remelting

The type of the piston	Cod	Remelt	Molded in:	Cod
U 550 DTC Tractor piston	T-D	Yes	refractory brick	T-D-R-B
			steel	T-M-R-S
Golf petrol piston	G-P	Yes	refractory brick	G-P-R-B
			graphite	G-P-R-Gr
Golf diesel piston	G-D	No		

Figure 2 shown the exposed pistons under analysis

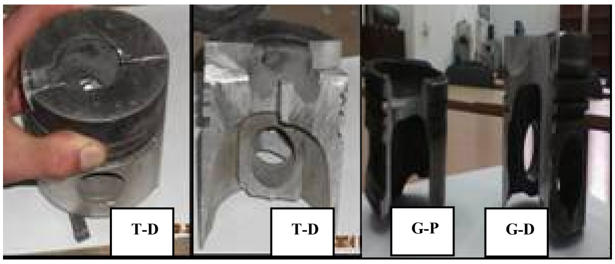


Figure 2. Analized pistons

In section, the T-D piston, figure 2b, we can notice the "special"form of the combustion chamber in order to increase engine power. Can mention that piston G-D has some metal inserts so the ring-shaped upper channel and slabs on the inner surface of the piston skirt, which prevented analysis of this alloy after remelting-casting.

Chemical compositions, determined by spectral analysis, are shown in Table 2.

Table 2. The chemical composition of used pistons on experimental procedure

PISTON	Si	Cu	Mn	Mg	Ni	Al	Fe	Cr	Zn	Pb	Sn	V	Ti
T-D	11,23	1	0,25	0,87	0,73	85,04	0,5	0,01	0,17	0,04	0,04	0,01	0,11
G-P	11,89	1,18	0,14	1,01	0,55	84,21	0,57	0,03	0,25	0,04	0,06	0,01	0,06
G-D	12,73	1,23	0,05	1,12	0,66	83,21	0,41	0,01	0,35	0,06	0,12	0,02	0,03

It is to be note that at T-D and G-P pistons have an easily hypoeutectical compositions, while the composition of G-D piston easily hypereutectical.

The melting was performed into a furnace with the crucible heated by electric resistors, figure 3a, under a flow bed to prevent oxidation of the metal melt. Cast temperature was 789 ^{0}C, figure 3a. The alloy was castied in refractory brick shapes, graphite and metallic forms (steel), figure 3b. The recording temperature was achieved using coaxial thermocouple type K-TPN-101 with an outer diameter of 0.6 mm protected with refractory slurry. Plotting cooling curves was performed using the program WIN-log EBI 2000 using arrangement of figure 3c.

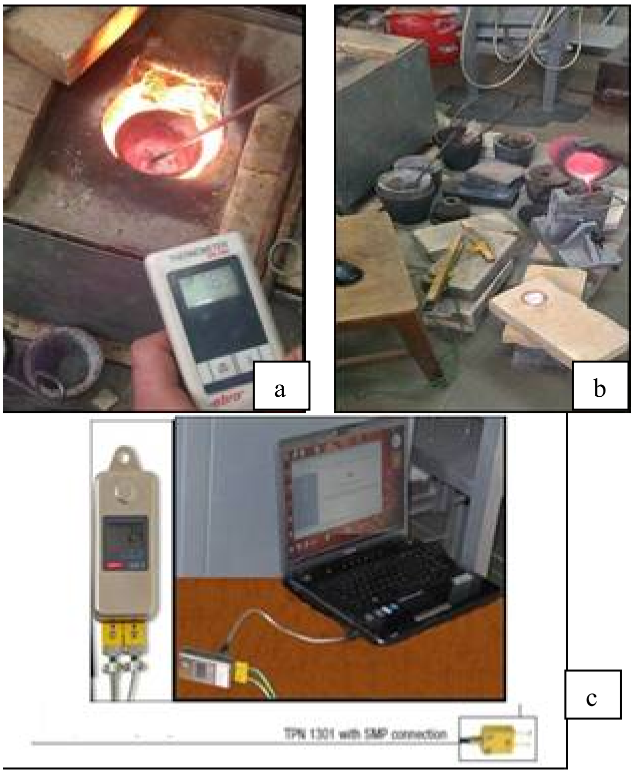
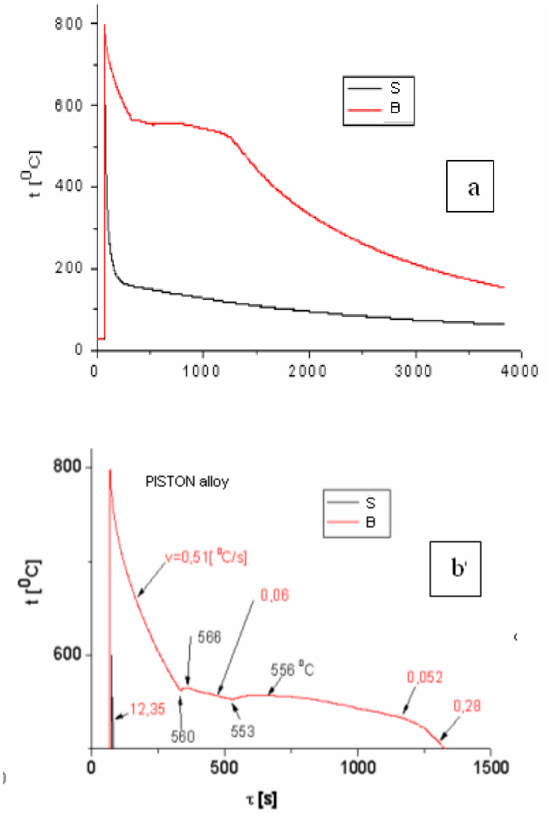


Figure 3. Stages of development and casting piston alloy - ATCSi12CuMgNi

The recorded solidification curves is given in figure. 4 and 5.

In figure 4b, there are shown the cooling curves with the solidification parameter: the temperature of processing point and the cooling rates of transformation periods, depending on the material form.

Refering at casting in brick is apparent the phenomenon of undercooling in crystallization of both primary and eutectic transformation. In case of casting in metalic chill, due to the high cooling rate, the eutectic conversion occurs at 541^{0}C, figure 4.c.



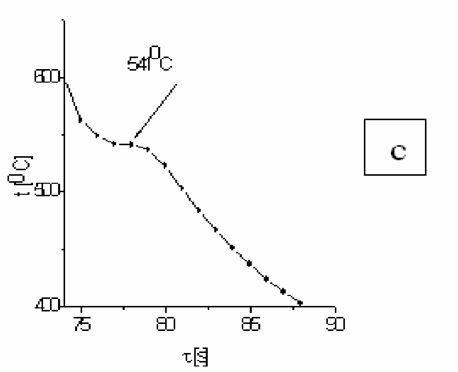


**Figure 4. Curves registered to alloy.
The solidification in brick and shell of T-D cast**

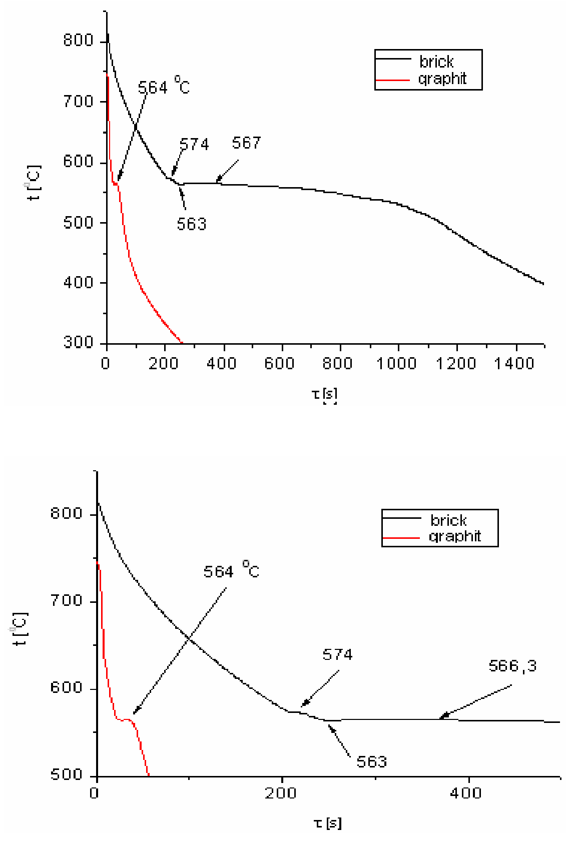
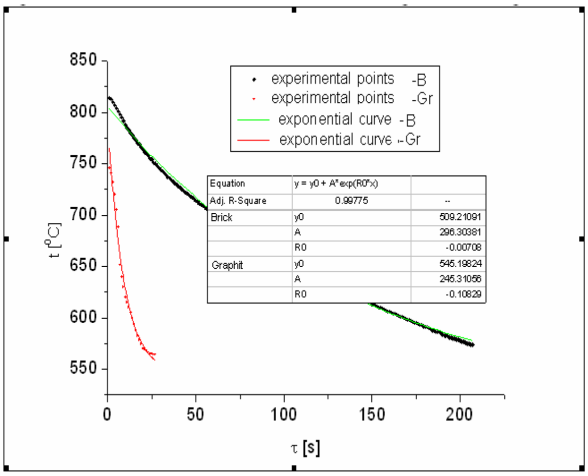


Figure 5. The solidification curves registered to T-D alloy cast in brick and shell

Considering that the structure of casting is determined by the cooling rate applied to the melt, we switched to determine proper equations of cooling curves for the four conditions of solidification, using ORIGIN-8, figure 6.



Equation	y = y0 + A*exp(R0*x)	
Adj. R-Square	0.99775	--
Brick	y0	509.21091
	A	296.30381
	R0	-0.00708
Graphit	y0	545.19824
	A	245.31056
	R0	-0.10829

Figure 6. Cooling curves for G-P alloy in a liquid state

As it is known, the cooling curves are described by an exponential function like:

$$t = t_0 + (t_k - t_0)\, e^{-w\tau} \qquad (1)$$

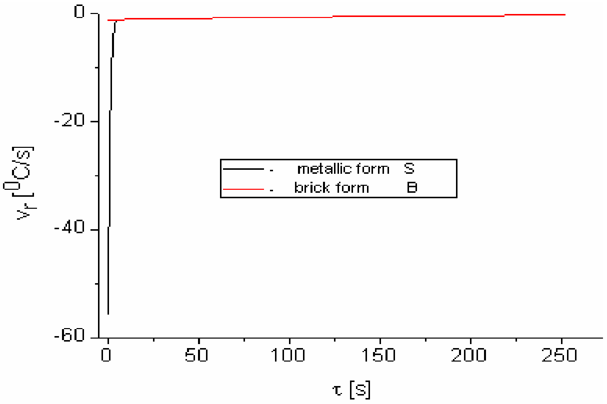
where:

t_0- is the initial temperature of the melt;
t_k- minimum temperature on cooling curve,
factor **w= - k.A/m.c,**

where:

m- the alloy mass of the casting sample;
c- specific heat alloy;
A- the area where is performed cooling of sample
k- the global factor of heat transfer between casting sample and form.

In equations there are described the cooling rates obtained by differentiating cooling curves.



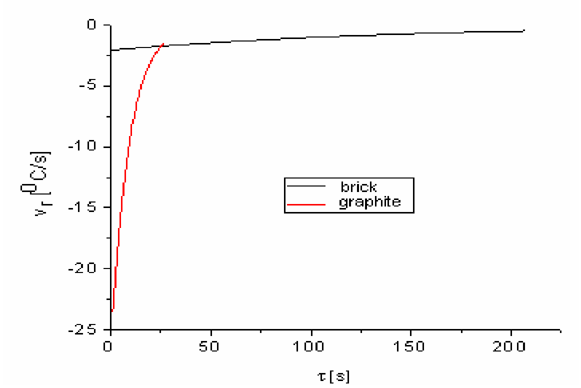


Figure 7. The cooling rate variation of the liquid state based on time and solidification conditions for T-D and G-P

Considering the castings specimens size and the specific heat alloy analyzed, can be calculate the global heat transfer factor. The results are centralized in table 3.

Table 3. The constants of the equation (1) to the samples cast

Sample cod	t_0 [^{0}C]	t_k [^{0}C]	w [1/s]	K [cal/m^2.s.^{0}C]
T-D-R-B	482,5	744,5	0,0046	27,4
T-D-R-S	539	600	0,93	2760
G-P-R-B	509	805	0,007	41,7
G-P-R-Gr	545	790	0,11	705

For structural analysis and dilatometer we collected samples (specimens) on brick and chill cast and on used pistons (for remelting).

The results of structural studies are presented in figure 8, 9 and 10.

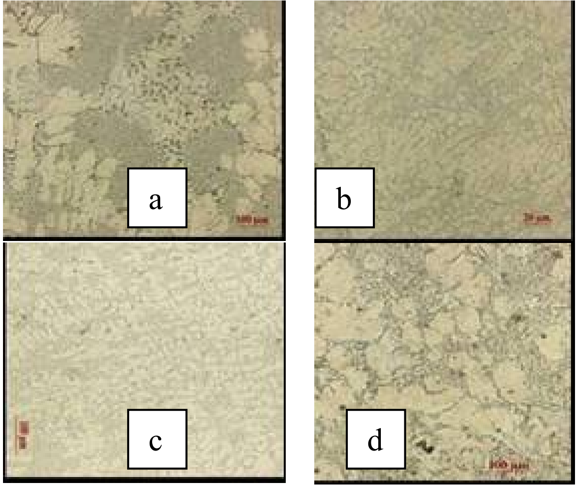
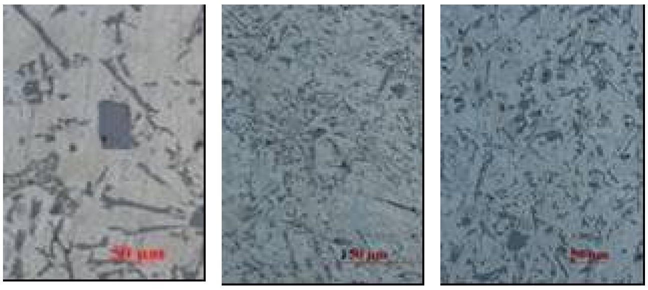


Figure 8. The structure of T-M alloy,in casting state and the used piston a)- cast in brick; b)- in chill; c)- piston skirt; d) - the combustion chamber



a) b) c)

Figure 9. The structure of G-P alloy, a)- cast in brick; b) combustion chamber-core and c) the combustion chamber-surface

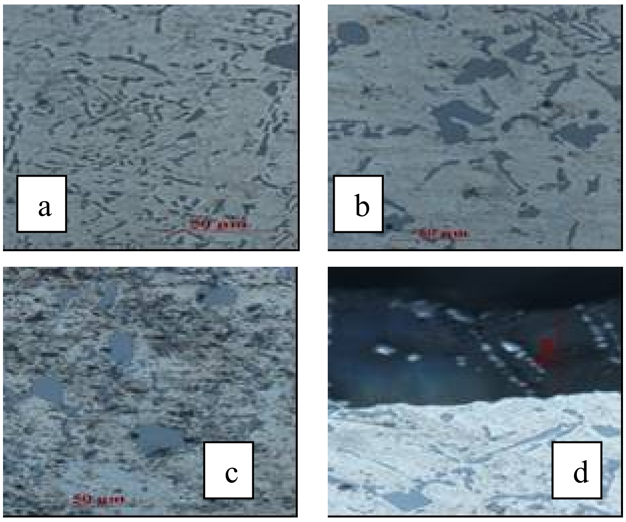


Figure 10. The structure of G-D piston (used) a)piston skirt; b) the combustion chamber- central; c) the combustion chamber -upper part d) the combustion chamber -upper layer

Based on the shown microstructures result that in case of T-D alloy, irrespective of the solidification conditions and the alloy state, eutectical silicon is modified. The modification status is evidenced by the presence of globular eutectic silicon separations and that all the structures are strongly hypoeutectice although the concentration comes close to that proper eutectical silicon point. The effect of modification was maintained after remelting, which means that the change was made with strontium.

For G-P and G-D alloys, irrespective of the solidification conditions and the alloy state, eutectical silicon is unchanged, it occurs in acicular separation form.

The status of structure: changed or unchanged is confirmed by the difference(Δt), between the corresponding values by eutectic temperature of balance (t_{Ecalc} - calculated by Mondolfo relation [2, 3]), and the eutectic temperature registered during solidification ($t_{Emodified-measured}$).

$$\Delta t = t_{Ecalc} - t_{Emodificed-measured} = 4\ldots 12\ ^oC - modify\ structure \qquad (2)$$

Sample cod	Analized area	Conditions ‘ determination [F/τ]-[gf/s]	Hardness recorded
G-D Diesel piston (used)	the combustion head, -in core	100/15	77,7/69,2/71,5
		50/15	54,2/51/55,8
	the combustion head, -upper layer	50/15	247/141-intercrystalline area 514/598-inside crystals-figure 11.a
G-P Petrol piston (remelted)	- cast in graphite	50/15	82,8/109,8/127,3/105,4
	- cast in brick		54,3/58,6- alpha-solid solution figure. 11.b 287 – Si (crushed crystal)
		10/15	962 -Si separation, figure 11.c 97.2 - in vicinity of –Si separations figure 11.c 49 -inside alfa solid solution - figure. 11.c

$$t_{Ecalc}= t_{E0} - 12,5/[Si]\ \{(4,43[Mg]+1,43[Fe]+ 1,93[Cu]+ +1,7[Zn]+3[Mn]+4[Ni])\} =563,36\ ^{\circ}C \qquad (3)$$

The results of the calculations to both alloys are presented in Table 4.

Table 4. Dates to assess the state of change

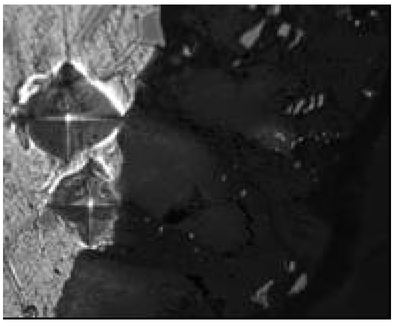
Sample code	t_{Ecalc} [^{0}C]	$t_{Emodified-measured}$ [^{0}C]	Δt [^{0}C]	The state of alloy
T-D-R-C	563,4	556	7,4	modified
G-P-R-C	565,8	566,3	0,5	unmodified

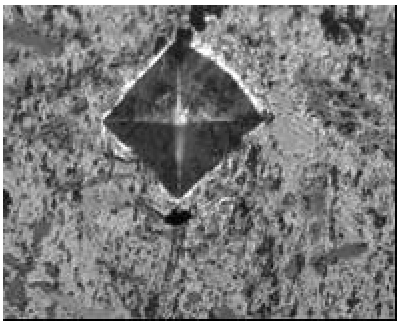
It should be mentioned that in case of G-D used pistons, there are occuring major structural changes on combustion head, figure 10d, to a depth of 50 µm.

Taking into consideration the slightly hypereutectical composition for the pison it can be assumed that, due to thermal conditions during operation,the structure comes close to that to balance, that means it forms solid solution crystal of large size, wherein all the alloying elements are dissolved and the excess silicon is separated at the limits.

Microstructural observations was completed by microhardness analysis phases present in the structure of studied alloys. The results of these analyzes are listed in table 5 and figure 11.

Tabel 5. The microhardness of studied alloys


a)


b)

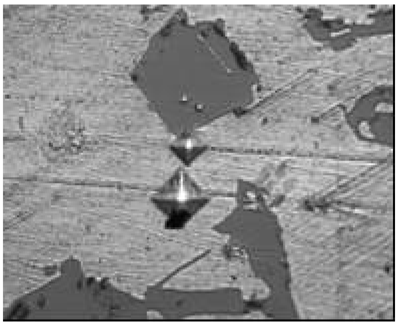

c)

Figure 11. The microhardness of alloys studied: a) piston G-D; b) solid solution alloy G-P-R-C and c) alloy G-P-R-C

The results of dilatometrical analysis on piston alloy T-D are shown in figure 12. The heating rate in all determinations was 10 ^{0}C /min.

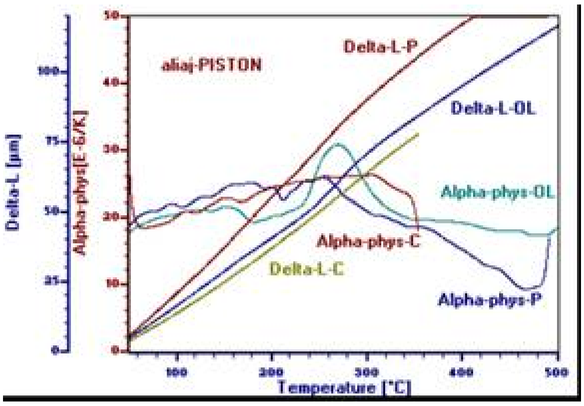


Figure 12. The curves and coefficients of dilation T-D Silumin piston

Due to the high cool speed of casted alloy for molding in chill, the structural transformations during heating leads to significant dimensional changes which requires the application of heat treatment of dimensional stability for castings pistons. As is known, in the casting piston is applied, mostly, the technology of molding in chill.

CONCLUSION

The simple thermal analyzes allowed both the local cooling rates appreciation and the values of global heat transfer coefficient for different solidification conditions. Quantifying global heat transfer factor presents a special importance for modeling programs of solidification processes.

Analyzing the cooling curves can be appreciate if the elaboration was done properly in order to obtain a modified structure, which is necessarily required for some parts that operate under hard thermal condition.

Some alloys used for casting pistons have not a modified structure, as confirmed both by structural analysis and either by calculation.

During operation, because of thermal conditions in piston, it occurs significant structural changes on diesel cars piston: the structure becomes one of large crystals and a biphasic in the upper layer of the combustion head.

Also because of thermal conditions during the operation it changes the value of thermal expansion coefficient, which underscores the importance of conducting heat treatment on dimensional stability.

ACKNOWLEDGEMENT:

This paper is supported by the Sectoral Operational Programme Human Resources Development POSDRU/159/1.5/S/137516 financed from the European Social Fund and by the Romanian Government

REFERENCES:

Books:

[1] Domşa Al., Chişu al., Trebonius I. (1961) **Pistons**, Editura Tehnică Bucureşti

Reports:

[2] Varga B.: (1996) **Basic of non-ferrous alloys elaboration, lithographed course,** Transylvania University of Brasov

[3] Varga B.: (1992) **Development and casting non-ferrous alloys, laboratory guide,** Transilvania University of Brasov

[4] Varga B.: **The Science of Metallic Materials**, course notes, lab [3]

References sourced via the world wide web:

[5] piston group http://www.e-automobile.ro/categorie-motor/20-general/31-grup-piston.html, downloaded in 04.04. 2014