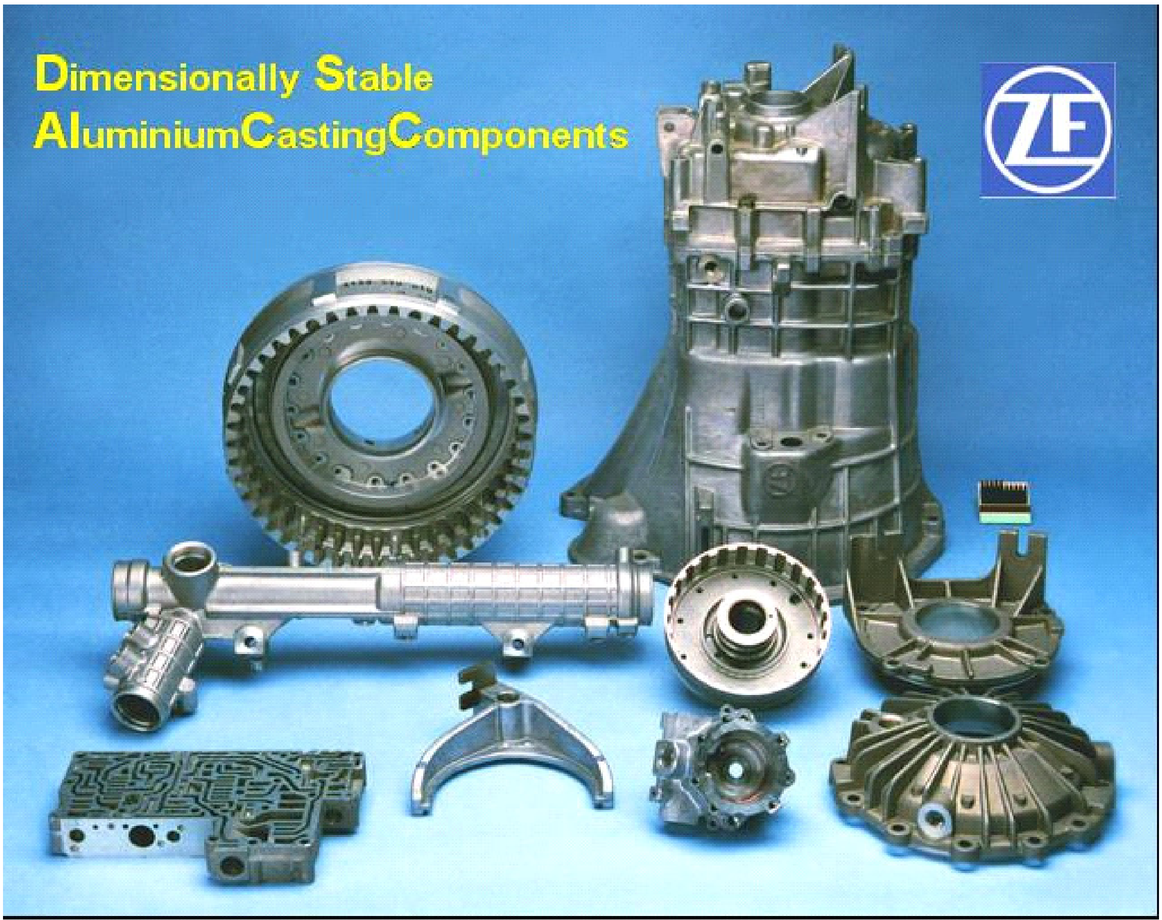

High operating temperatures cause aluminium pressure die casting components to expand dimensionally. The higher the operating temperature, the more damaging this aluminium "growth" can be. In particular, interference fits can be affected. ZF Friedrichshafen AG has developed a process that eliminates this problem.

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Aluminium Pressure Die Casting for High Volume Transmission Production

In car and CV transmission production, housings and components such as gearshift forks, clutch carriers, valve units, flat-top pistons, consoles, and output covers are made of aluminium casting. Pressure die casting is the preferred casting process for high volume production. Pressure die casting provides high strength, the smallest possible wall thicknesses, near net finishing, and low unit cost.

If, as just mentioned, the components primarily require high strength and hardness, the alloy AC-AlSi9Cu3(Fe)DF according to EN 1706 (similar to A380, SAE J452) is mostly used. This alloy cannot be heat-treated if cast using normal pressure die casting technology, because gas entrapped in pores would expand at the temperature of solution annealing and thus warp the part. Metallurgically, however, the process of precipitation of fine particles from a supersaturated solid solution can occur just as in other alloys where this process provides the age-hardening effect.

Aluminium Pressure Die Castings are not Dimensionally Stable

Generally, heat treatment of Al alloys consists of a combination of solution annealing, rapid quench, and an aging treatment. The precipitation sequence for AlSiCu alloys (such as AlSi9Cu3(Fe)) is based upon the formation of AlCu based precipitates. The sequence is described as $\alpha_{ss} \rightarrow$ GP zones $\rightarrow \theta' \rightarrow \theta$ (Al_2Cu). The sequence begins upon aging when the supersaturated AlCu solid solution (α_{ss}) gives way first to small coherent precipitates called GP zones. These particles are invisible in the optical microscope but macroscopically, this change is observed as an increase in the hardness and tensile strength of the alloy. As the process proceeds, the GP zones start to dissolve, and θ´ begins to form, which results in a further increase in the hardness and tensile strength in the alloy. Continued aging causes the θ´ phase to coarsen and the θ (Al_2Cu) precipitate to appear. The θ phase is completely incoherent with the matrix, has a relatively large size, and has a coarse distribution within the aluminium matrix. Macroscopically, this change is observed as an increase in the ductility and a decrease in the hardness and tensile strength of the alloy [1].

If pressure die casting components made of AC-AlSi9Cu3(Fe)DF heat up during operation, they expand not only reversibly as most solid materials do, but they increase irreversibly in dimension [2]. This “thermal growth” is caused by the above mentioned formation and growth of submicroscopic precipitations. Normally, such change is inconsequential. But for example, with interference fits, there is a risk of the originally intended interference fit design being altered by the dimensional increase which may cause a fit connection to work loose.

Well-founded indications [3] were used as arguments in favor of using heat treatment to release the supersaturation and thus anticipate the dimensional changes on the material selected. The aim was to achieve sufficient dimensional stability for a transmission temperature of 110°C.

Compromise Between Dimensional Stability and Strength

A number of stabilization annealing processes were undertaken using different temperatures and annealing times on AC-AlSi9Cu3(Fe)DF alloy components in order to achieve dimensional stability. In addition to the expected effect on the dimensions, the heat treatment also demonstrated an effect on the hardness, 0.2-tensile yield strength $R_{p0.2}$, tensile strength R_m, and elongation A_5 (see figures 1-5). This is because a quasi-heat treatment runs through the material when the pressure die casting process includes immediate quenching and subsequent heating (Regular: Solution annealing, quench, anneal).

A stabilization annealing process has been introduced to volume production at ZF Friedrichshafen AG. This process is a compromise between a high degree of dimensional stability and a considerable gain in hardness and strength. The lower level of elongation associated with this has no influence on component strength. The stabilization annealing process anticipates between approx. 80 % and 90 % of the total change in dimension of which the components are capable (see figure 6).

After casting and water cooling, the components are subjected to stabilization annealing and are then forwarded for transmission production. A further improvement would be a controlled temperature step during cooling the parts after the casting process. Dimensional stabilization by release of supersaturation would thus use the casting heat and become an integrated process. In principle, the aforementioned precipitation process can be run to produce the desired result.

Quality Control

A calorimetrical test (DifferentialScanningCalorimetry) has been developed to monitor the precipitation process. A small volume of material is taken from the pressure die cast component for this purpose. One chip is sufficient for this test. This material sample is placed inside the device on a sample plate. In accordance with DIN 51007 (ASTM E 472), this is a thermo-analytical method during which the difference in heat flows is recorded (in terms of quantity) by measuring the difference in temperature between the sample and reference over a defined heat transfer distance. Here the sample and reference are subjected to the same temperature program (see figure 7). The exothermal reaction shown here accompanies the precipitation process in the material (see figure 8). This test can be used to determine the capability of a die-cast component for any (further) precipitation and thus dimensional change. A batch of parts may thus be checked for correct stabilization heat treatment, or different time-temperature cycles may be assessed with respect to their stabilization effect.

A hardness test can be used to ensure that the component has not been damaged by excessive heat treatment.

Conclusion

AC-AlSi9Cu3(Fe)DF aluminium pressure die casting material is susceptible to a dimensional increase of up to 1 ‰ when operating temperatures increase. This could pose problems, especially for interference fits. Stabilization annealing before machining presents a solution. The optimum process conditions determined (annealing temperature and annealing time) result in a high standard of dimensional stability with the side effect of a considerable increase in strength and hardness. The stabilization annealing process can be tested using differential scanning calorimetry.

by Klaus Daub, Stefan Hock, Frank Thorenz, Artur Berchtold; ZF Friedrichshafen AG

[1]: James M. Boileau, Carla A. Cloutier, Larry A. Godlewski, Paula A. Reeber-Symanski, Christopher Wolverton and John E. Allison
The Dimensional Stability of Cast 319 Aluminum.
SAE "Advances in Lightweight Automotive Castings", SP1734, March 2003, pp 79 – 89

[2]: Aluminium-Taschenbuch, (The Aluminum Pocketbook)
Aluminium-Verlag, Düsseldorf, 1999, 15th printing, vol. 2,
Editor: Aluminium-Zentrale e.V., Düsseldorf

[3]: Wolfgang Schneider und Franz Josef Feikus, Bonn;
Wärmebehandlung von Aluminium-Gusslegierungen für das Vakuum-Druckgießen. (Heat Treating Aluminum Casting Alloy for Vacuum Pressure Die Casting)
Gießerei 83 (1996) 1, pp 20 - 24

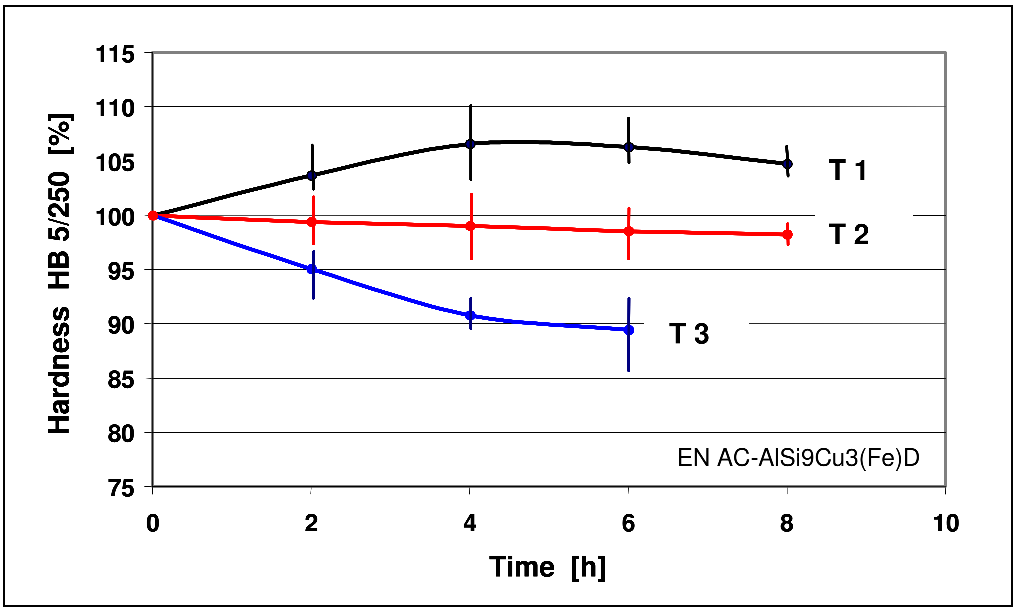

Figure 1:

Influence of heat treatment time on hardness of aluminium pressure die casting EN AC-AlSi9Cu3(Fe)D for three temperatures T 1 < T 2 < T 3.

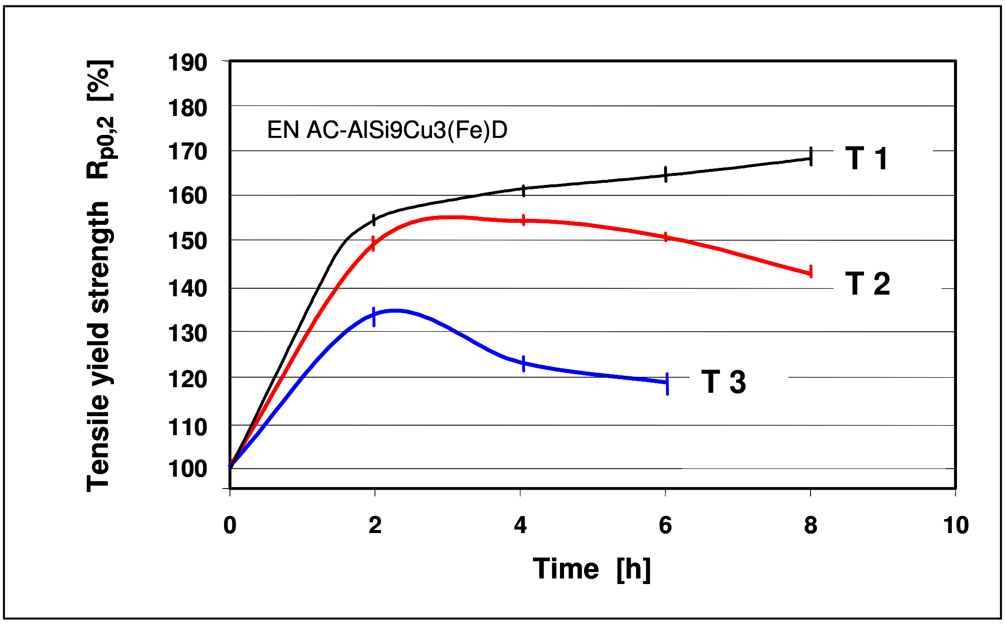

Figure 2:

Influence of heat treatment time on tensile yield strength of aluminium pressure die casting EN AC-AlSi9Cu3(Fe)D for three temperatures T 1 < T 2 < T 3.

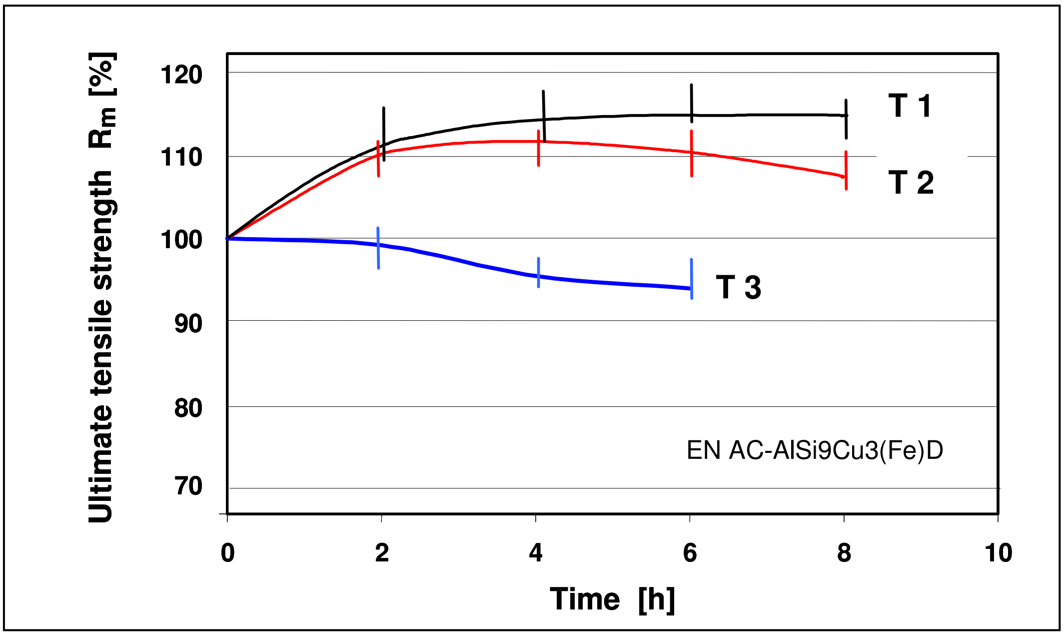

Figure 3:

Influence of heat treatment time on ultimate tensile strength of aluminium pressure die casting EN AC-AlSi9Cu3(Fe)D for three temperatures T 1 < T 2 < T 3.

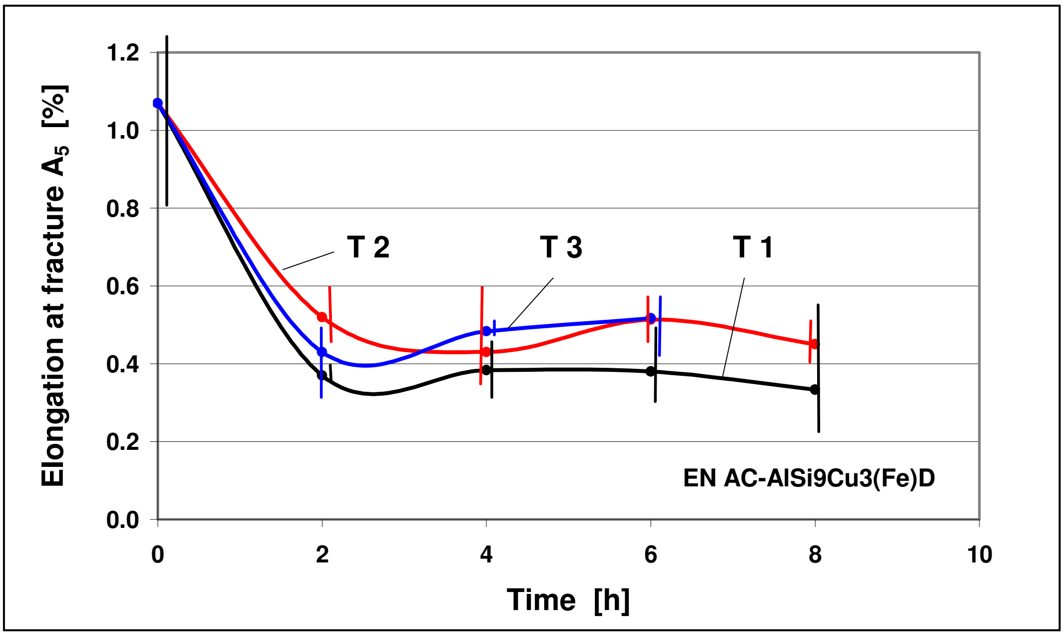

Figure 4:

Influence of heat treatment time on elongation at fracture of aluminium pressure die casting EN AC-AlSi9Cu3(Fe)D for three temperatures T1 < T 2 < T 3.

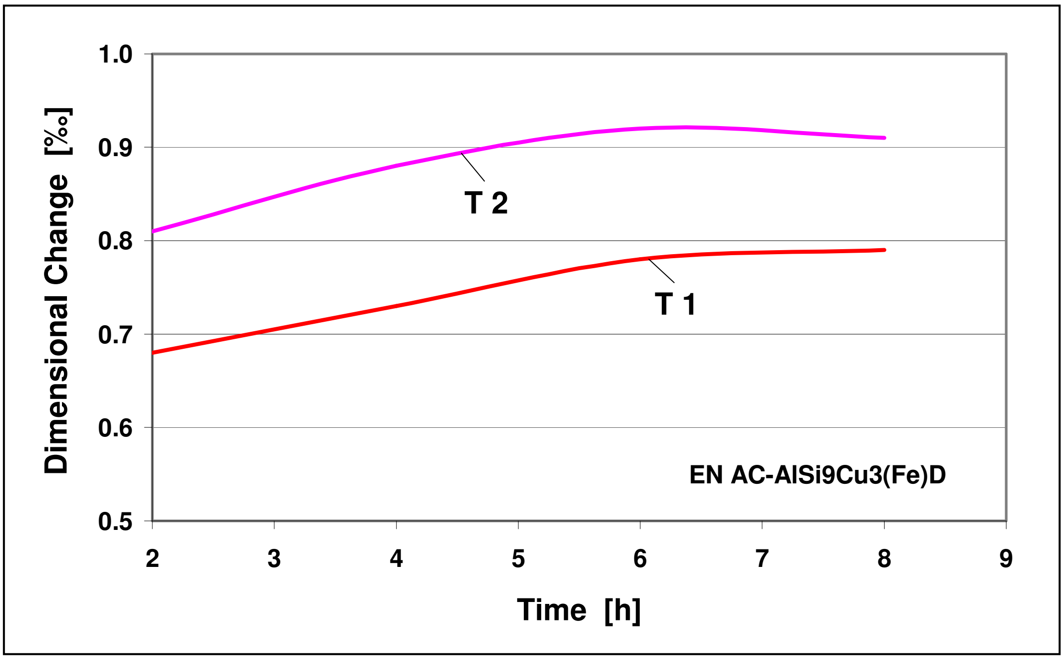

Figure 5:

Influence of heat treatment time on dimensional change of aluminium pressure die casting EN AC-AlSi9Cu3(Fe)D for two temperatures T 1 < T 2.

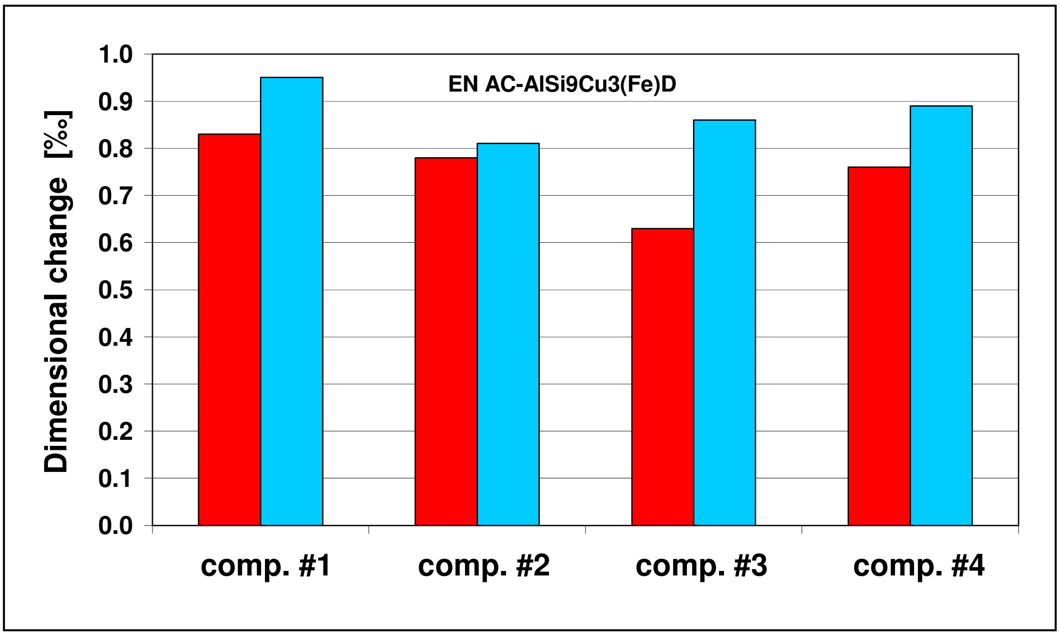

Figure 6:

Influence of short (red) and long (blue) time heat treatment on dimensional changes of 4 components of aluminium pressure die casting EN AC-AlSi9Cu3(Fe)D.

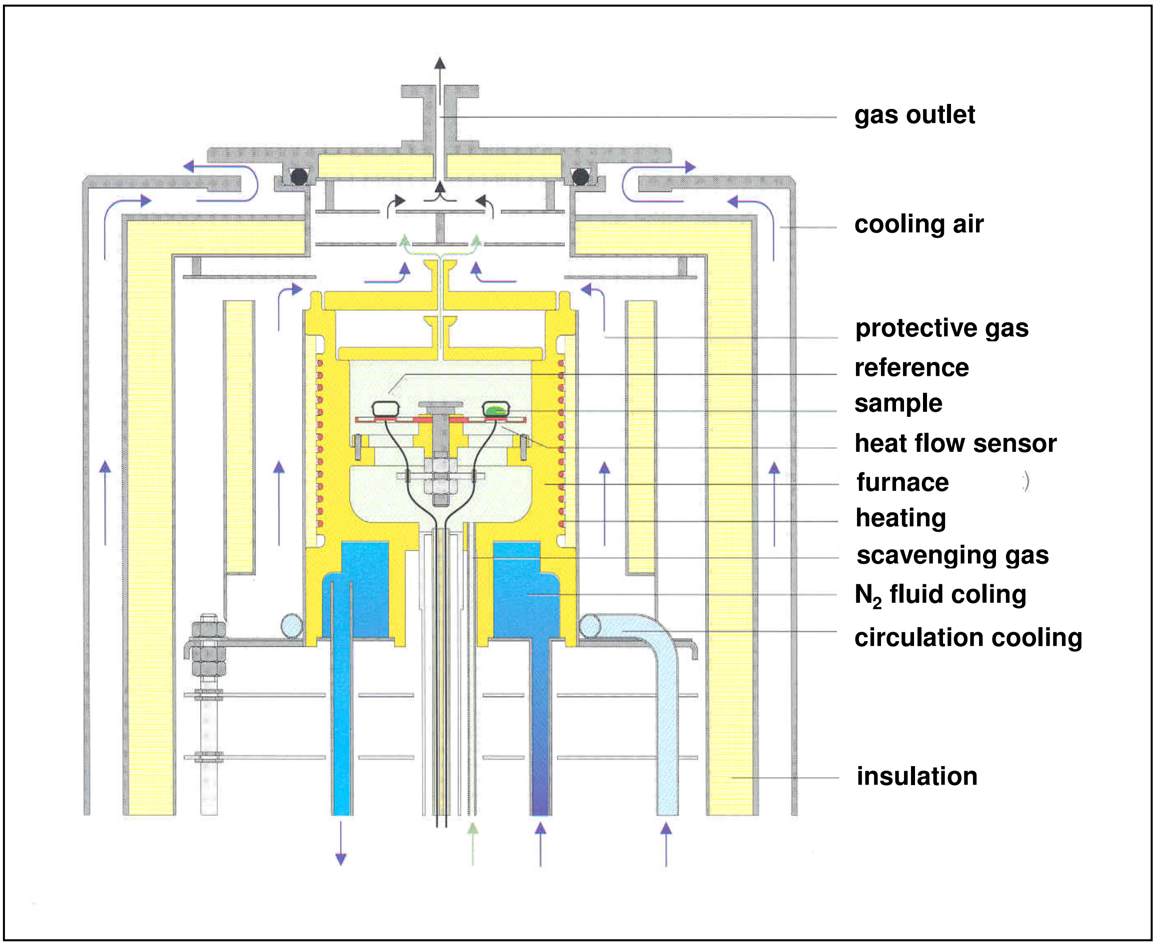

Figure 7: Schema of the measuring cell of the calorimetrical test (DSC).

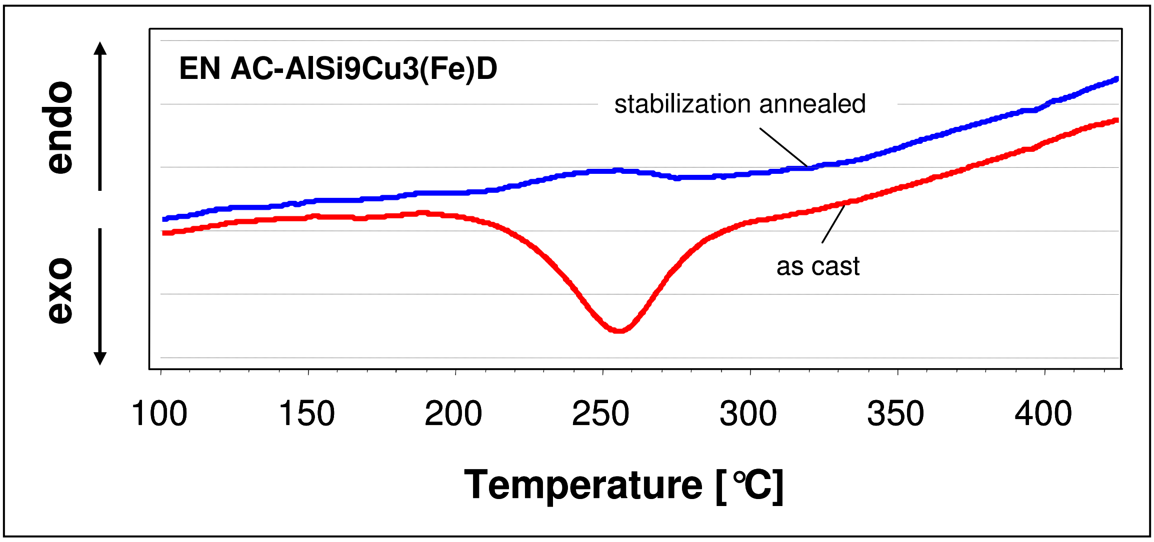

Figure 8:

Calorimetrical test (DSC) of aluminium pressure die casting EN AC-AlSi9Cu3(Fe)D in two conditions: as cast and stabilization annealed. Exothermic reaction shows precipitation from supersaturated solid solution and disappeares after stabilization annealing