# Mass production of fuel rails by pressure die casting in the semi-liquid state

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***Abstract***

*The present paper describes the advantages in term of industrial reliability and production versatily of the semi-liquid pressure die casting technology developed by MM/ECD.*
*The points summarized are the progress of the production activity concerning fuel rails for multi-point injection systems, the setting up of anodizing treatment on parts and, in conclusion, the prospect for the development of the technology for diversified applications.*

**Riassunto**

Il presente lavoro descrive i vantaggi in termini di affidabilità industriale e versatilità produttiva della tecnologia di pressocolata in semi-liquido sviluppata da MM/DCM.
Vengono illustrati l'avanzamento dell'attività produttiva riguardante i collettori benzina per sistemi di iniezione multi-point, la messa a punto del processo di ossidazione anodica sui pezzi e, in conclusione, le prospettive per lo sviluppo della tecnologia per applicazioni diversificate.

## SEMI-LIQUID PRESSURE DIE CASTING ACCORDING TO MM/ECD TECHNOLOGY: SEMI-LIQUID (S.L.) VERSUS SEMI-SOLID (S.S.)

With the term "pressure die casting in the semi-liquid state" we are referring to the process of pressure die casting of alloys with a globular microstructure (1-4) making use of a forced convection preheating furnace (MM process).
According to this technology (5-7) the flow-cast slugs are held in individual holders and pass through the preheating furnace (scheduled in terms of working temperatures, transit times and stand-by temperatures) in condition to feed the pressure die casting machine with the required production out put (60-90) parts/hour).
The advantages of S.L. technology compared to the "conventional" one making use of inductive preheating system (S.S.) can be summarised as follows.

### 1.1 Conditions of high reliability

S.L. technology permits to use a wide range of working temperatures (584-600 °C for the alloy UNI 3599, Al-7%Si) which allows the stage concerning the preheating of slugs to be made industrially very reliable.

At the top of the range (600 °C), as you can see from the solidification curve of the alloy above mentioned (fig. 1), the fraction of solid in the slug is about 45% and, therefore, such us to permit, from a metallurgical point of view, the production of parts characterized by their high level of soundness. On the other hand, at this temperature, from a technological point of view, the slugs possess a relatively low viscosity and therefore, for their manipulation and transfer to the pressure die casting machine, a suitable holder is required wich will ensure not the slightest loss of eutectic liquid.
Evidently with a preheating system which does not necessarily have this type of holder, it will not be at all possible to work at these high temperatures and, consequently, it will limit significantly the range of admissible temperatures for carrying out the process.

## 1.2 Optimum temperature for each kind of parts

At the present (Dec '96) MM produces 10 different kinds of fuel rails in alloy UNI 3599 (8).
Within the admissable range of temperature for this alloy (16°C) it has been observed that each kind of die, owing to the geometric configuration of the cavity, runners and ingates, requires an optimum value of viscosity to carry out the filling in a complete manner.
These conditions can be easily realized with S.L., technology taking into consideration the elevated range of working temperature which allows choise of optinum viscosity according to parts to be produced.
It is therefore possible to affirm that the S.S. technology is a subset of S.L. technology: with the S.L. technology it is possible to produce any kind of parts obtainable using S.S. technology but this does not work vice versa.

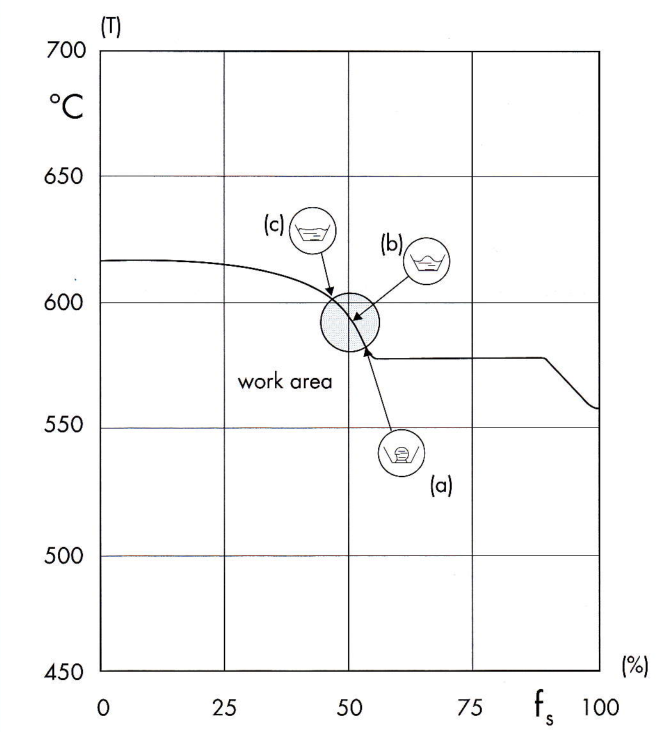


*Figure 1: solidification curve of the alloy UNI 3599 (Al 7% Si); solid fraction versus temperature*

## PRODUCTIVE ACTIVITY

At present MM is working with 6 installations for semi-liquid pressure die casting. Each installation is equipped mainly with a preheating furnace and a die casting machine as well as the auxiliary equipments and control devices.

The presses are IDRA (Italy) cold chamber horizontal die casting machines (3450 kN and 4510 kN locking force) suitably modified to ease semi-liquid material feeding and injection; the machines are interfaced with the preheating furnaces

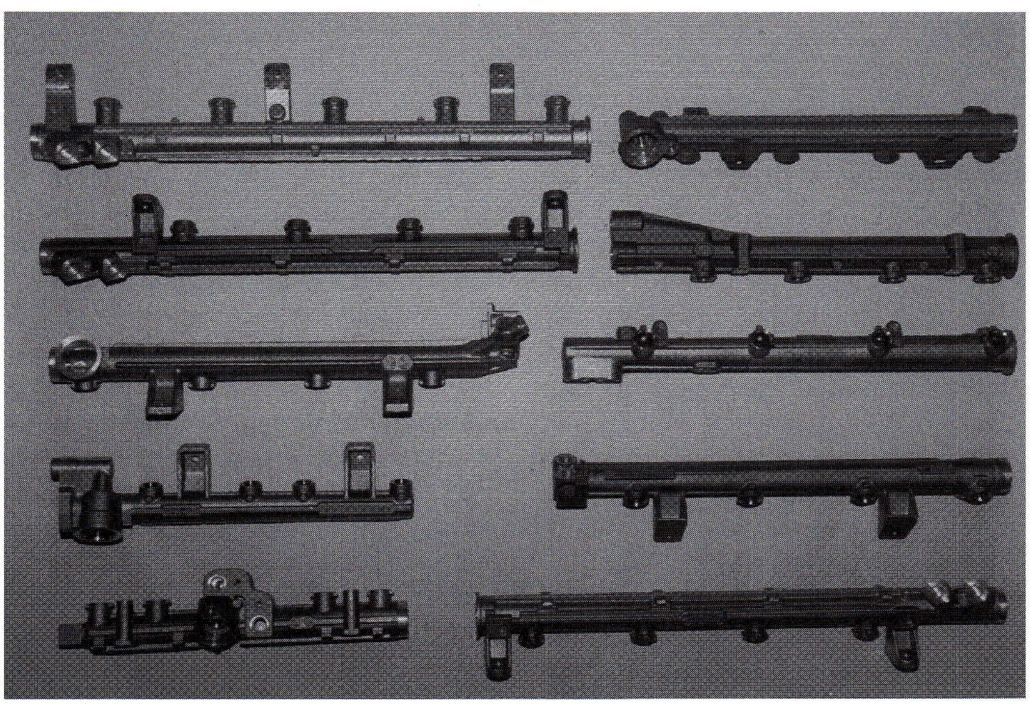

*Figure 2: fuel rails pressure die cast in the serrs-liquid state*

and are equipped with external units for die thermoregulation and a set of transducers which interface an analyser to permit measurement and recording of injection parameters.
The preheating and handling plant (SIA, ITALY) comprises a resistance furnace with automatic feeding of slugs and a manipulator to feed the die casting machine. SPC procedures are applied both for monitoring the injection parameters and the temperatures of preheated slugs.
Mass production of fuel rails (10 kinds as shown in fig. 2), started in Oct '92, at present amounts to about 5500 parts/day with a minimum scrap level (<1% at leakage test). The technology is confirming high reliability levels which allowed a robust industrialization.
Production programs foresee >7500 parts/day being reached by the year 2000, and together with a series of actions able to reduce further the industrial cost of parts (2 cavity dies, near net shape, cycle time optimisation), consequently making the S.L. technology economically competitive even in comparison to plastic injection moulding.

## SETTING-UP OF PROTECTIVE COATINGS

UNI 3599 alloy used to produce fuel rails is characterized by an adequate corrosion resistance with regard to European petrol, saline mist (>200 h), water gas (>336 h) and sour gas (> 720 h). However it is necessary, for some automotive markets (eg. Brasil), to have a superficial coating which is able to resist the corrosive action carried out by fuels at a high alcoholic percentage (> 20%).
Different kinds of protective treatments were considered and in particular organic coatings, nickel-plating and anodizing: only this last type of treatment was capable of overcoming severe validation corrosion tests.
Due to the intensive experimental activity carried out at DUROX (Italy), it was possible to set up a process which must consider particularly the problems encountered in two-phase alloys.
In fact it is well-known that the thickness of anodic oxide increases with different rates depending on the percentage of Si in the substrate: the superficial substrate in "as cast" parts is eutectic (12% Si, fig. 3a) but in tool-machined areas the globules of solid solution α (2% Si) appear at the surface; as a consequence of anodizing, therefore, within the two-phase areas, the superficial roughness is destined to increase owing to the differential growth of oxide (fig. 3b).
The improvement of the process allowed one to obtain "minimum local thicknesses" (ISO 2064) >5μm maintaining the roughness below the limit required by an O-ring (1.6μm) to ensure sealing.

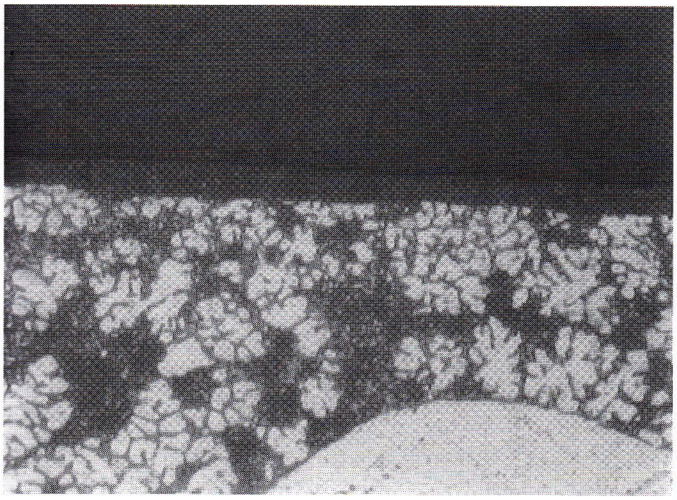

*Figure 3: microstructure of fuel rail anodized: (a) as cast*

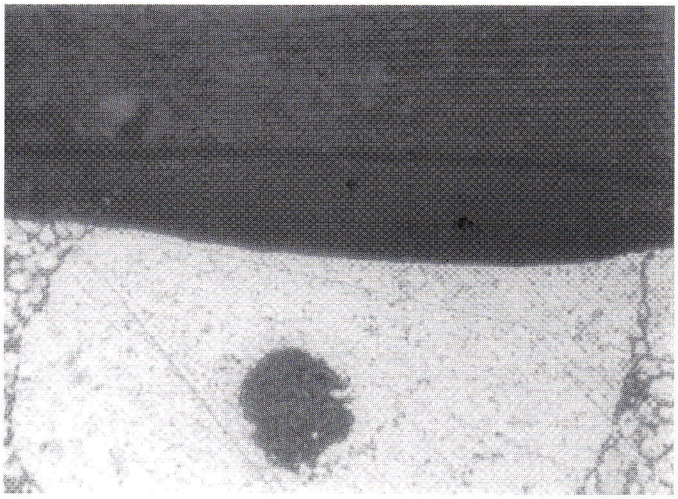

*Figure 3: microstructure of fuel rail anodized: (b) tooled area*

## CONCLUSIONS

The high industrial reliability and productive versatility of the S.L. forming process permits the potential for production of various components which require high performance and safety characteristics.

Also from the economic point of view the technology is competitive compared with conventional processes and the investments made by MM/ECD can prove this. Nevertheless the MM/ECD business is presently limited to applications in the car field and particularly to injection systems.

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