Mass Production of Fuel Rails by Die Casting in the Semi-Liquid State from Flow-Cast Alluminum Alloys

Dr. Moschini R. Weber - Magneti Marelli (Engine Control Division)

Abstract

Semi-liquid forming process, applied to pressure die casting, can achieve low - cost components of high - quality and adequate mechanical performances. The technology is based on the employment of material with a globular microstructure (flow-cast alloys) which permits the use of conventional forming processes at temperatures in the solidification range. The particular fluid-dynamic properties of the semi-liquid slurry and the lower injection temperature can result in castings with improved soundness, without the need of impregnation, and to extend die life.
The present work describes the WEBER (MAGNETI MARELLI) activity for the industrialization of the process and mass-production of fuel rails.

Riassunto

Il processo di formatura in semi-liquido, applicato alla pressocolata, permette l'ottenimento di componenti a basso costo, di alta qualità e di elevate caratteristiche meccaniche. La tecnologia è basata sull'impiego di materiale a struttura globulare (leghe reocolate) che permette l'esecuzione di processi di formatura convenzionali a temperature comprese nell'intervallo di solidificazione. Le peculiari proprietà fluidodinamiche dello "slurry" semi-liquido e le basse temperature di iniezione permettono l'ottenimento di getti di elevata sanità, senza necessità di impregnazione consentendo nel contempo di allungare la vita degli stampi.
Il presente lavoro descrive l'attività WEBER (MAGNETI MARELLI) per l'industrializzazione del processo e la produzione di massa dei collettori benzina.

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Introduction

Today it is well known (1-6) that semi-liquid forming process, based on the employment of material with a globular microstructure processed at temperatures in the solidification range, can achieve low-cost, high-quality components.
Sounder castings, elimination of impregnation, less machining, lower injection temperatures, extending die life, power saving are some of obtainable advantages by this technology which moreover permits to design parts of complex geometry not manufacturable by conventional forming processes.
The present work describes the WEBER activity for the process industrialization and its application for the manufacture of fuel rails by die casting in semi-liquid state

Weber Technology

Semi-liquid forming process, carried out according to WEBER's patents (7-9), is sketched in fig. 1. The process consists of two phases: 1) microstructural transformation of raw material; 2) preheating and die casting of flow-cast slugs.

Production of flow - cast material

A great variety of techniques can be employed to produce a flow-cast material (that is characterised by a globular morphology of primary solid), in any case all based on the stirring of a metal alloy during solidification. A method, patented by CENTRO RICERCHE FIAT (4) for generating elevated shear rates, causes the alloy in the solidification phase to pass through a static mixer device. The geometrical configuration of

the mixer is arranged so as to generate high shear forces in the alloy and also to make it an excellent heat exchanger capable of efficient dissipation of the heat of solidification with a significant increase of the intrinsic productivity of the process (1500 Kg/h per static mixer).
Pilot plant for applying this mixing device in industrial conditions was designed and patented by WEBER (7) and was then built and installed at its own foundry. The system is based on the use of a pressurized melting furnace (Civardi) by means of which, through the mechanical action of an inert gas or compressed air, the solidifying metal alloy is transported through the static mixing device. A second plant (Fergal), capable of producing up to 5000 kg/day, is productive since September'93. The system for collecting the semi-liquid material consists of an ingot-casting unit in the case of the pilot plant, but is of the "continuous bar casting" type in the case of the plant for large capacity production (9).
The production unit consists of:

- Melting furnace
- Degassing unit (FDU)
- Pressurized furnace
- Bar collection system
- Ingots/bars cutting unit

Plants for die cast components

The essential conditions for successful diecasting in the semi-liquid state are determined by the availability of flow-cast material characterised by a high-quality microstructure and the use of suitable equipments to ensure accurate temperature control and a fast feeding of the die casting machine.
WEBER' s die casting production plants (3 installations) principally consist of:

- a plant for preheating and handling of the slugs;
- a die casting machine.

The presses are IDRA 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 and are equipped with external units for electrical temperature control of the dies and a set of transducers which interface an analyser to permit measurement and recording of injection parameters. The dies are lubricated automatically by means of a robot which gives selective deposition of a Kluber lubricant for use at high temperature. The preheating and handling plant (SIA) comprises a resistance furnace with automatic feed of slugs and an unloading manipulator to feed the die casting machine.
The flow-cast slugs are held in individual sample holders in such a way as to work either like a semi-solid or like a semi-liquid condition ($\Delta T = 15°C$),therefore with wide process reliability.

Productive Activity

After a long period of research of ten years at CENTRO RICERCHE FIAT (1979 ÷ 1988) the activity was transferred to WEBER for a technological development. The industrialization's stage was completed positively and now the technology is an industrial reality. At present, WEBER possesses 8 patents as regards "semi-liquid forming process" and, as above - mentioned, at its own foundry are installed two plants to produce flow-cast material and three plants to manufacture automotive components. The technological knowledge acquired in the course of development stage was directly trasferred to productive activity, allowing an effective mass production start.

Mass-production of fuel rails

The main aim of die casting in the semi-liquid state is to manufacture parts "actually not die cast" and manufactured with other more expensive technologies or with other materials. With these motives in mind, expe-

rimentation was focused on automotive components which highlight these expectations, particularly on parts for fuel injection systems: "fuel rail" may be considered the most significant example.
The fuel rail is a component not in fact die cast since the quality resulting from the traditional process cannot cope with the severe conditions envisaged at the design stage, particularly the metallurgical characteristics in terms of soundness and tensile strength.
The manufacture of the component by die casting in the semi-liquid state permits to realize large profits compared with conventional productive methods (steel, chill cast or die forged aluminium). The saving is attainable by high productivity rate (tipical of die casting) and by the possibility of reducing tooling (near - net - shape parts): for example it's possible to obtain directly (as cast) a dead hole using a steel core 32 cm long, draft angle 0°24' (fig. 2).
Mass-production of fuel rails, started in the month of October 1992 limitedly to applications on new Lancia cars (< 100 parts /day) has been progressively extended during the 1993 to other FIAT cars including the engine 1242 cm^3 assembled on new model "PUNTO" (fig. 3). At present (March'94) the output amounts to 1500 parts/day (fig. 4) and, within two year, it will be doubled owing to the production of fuel rails for 4 new engines with multi-point injection systems.
Production start of fuel rails meant for WEBER a phase of important technological innovation in addition to the acquisition of a business on a new product previously bought (steel made) from a third party and assembled with other WEBER components (pressure regulators, injectors, ...).

Qualification tests

A period of two years preceding the beginning of production of fuel rails was required to setting-up the whole process (installations and productive methodologies). Several thousand of components for fuel injection systems were manufactured using different kinds of aluminum alloys (Al - Si, Al - Si- Cu, Al - Mg) in order to consider all aspects relating to machinability, corrosion resistance, mechanical tests, and so on.
On account of strategical and business aspects, particular attention was given to the fuel rail for which MAGMA software to simulate the die filling was used.
Moreover, as regards fuel rails, tests were carried out in relation to:

TABLE 1 - Fuel Rail: Functional Tests

1) Pressure tightness (t > 30s, air bar)
2) Equalisation test (head/flow at the entrance of injectors)
3) Tensile strength of additional elements (F_{min}= 200 Kg)
4) Overpressure strength (1200 k Pa)
5) Low/high temperature vibrations (50 < v < 500 Hz, a_{min}= 30g, T = -40, T = (130 C)
6) Fast thermal cycles (T = -30 ÷ 130 C, 20 consecutive cycles)
7) Low temperature resistance (16h, T = -40 ± 2C)
8) High temperature resistance (16h, T = 130 ± 2C)
9) Inner surface fuel corrosion (336h with Water gas, 720h with Sour gas)
10) Humid-statical test (200h, T = 40C, 95% relative humidity)
11) Outer surface corrosion (96h in saline mist according to ASTM B 117)
12) Engine compartment liquids compatibility (1h, immersion in oils/detergents)
13) Inner cleanliness (solvent circulation⇒colation⇒residuals < 2mg)

- Design validation:	Table 1 shows a series of validity tests;
- Bursting test:	by high-pressure oil was pointed out a bursting pressure > 280 bar (28 MPa), (wall thickness: 0,25 cm)
- Density:	the difference between the density measured before and after heat treatment (T 6) gives an indication of the soundness of parts. Experimental values result < 0.3%.
- Tensile tests:	Fuel rails were submitted to heat treatment (T 6) and tensile bars were taken directly out of the parts. The results are summarised in fig. 5 .

Conclusions

Industralization of the "die casting in semi-liquid state process"under taken by WEBER is yielding very positive results. WEBER is able to produce flow-cast material and to use it to manufacture automotive components. At present, the whole production is intended to fuel rails (> 1500 parts/day), regarding which is scheduled a progressive productive increase.

References

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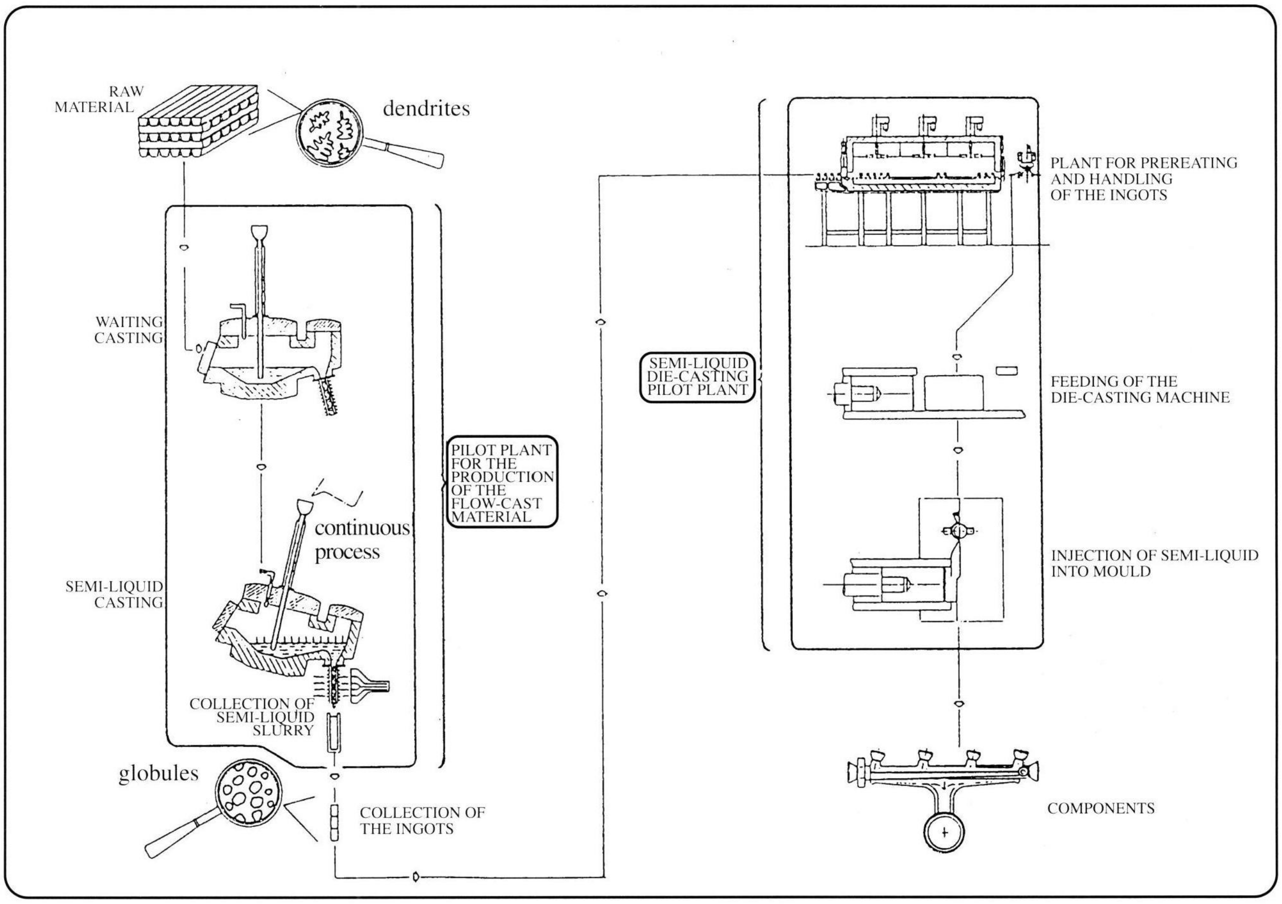


Fig. 1:
Semi-liquid forming process

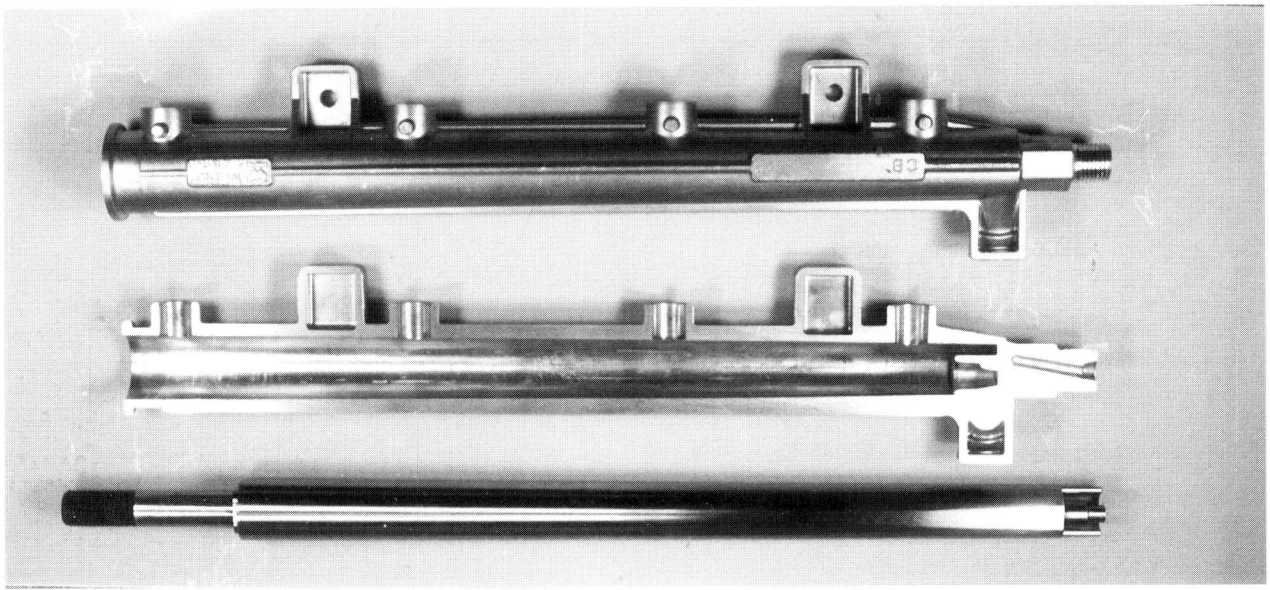


Fig. 2:
Fuel rail for "nuova Lancia DELTA 1750 cc".
middle: longitudinal section; bottom:steel core (notice the terminal zone to obtain directly (without machining) the O-ring housing for the internal circuit of fuel recirculation.

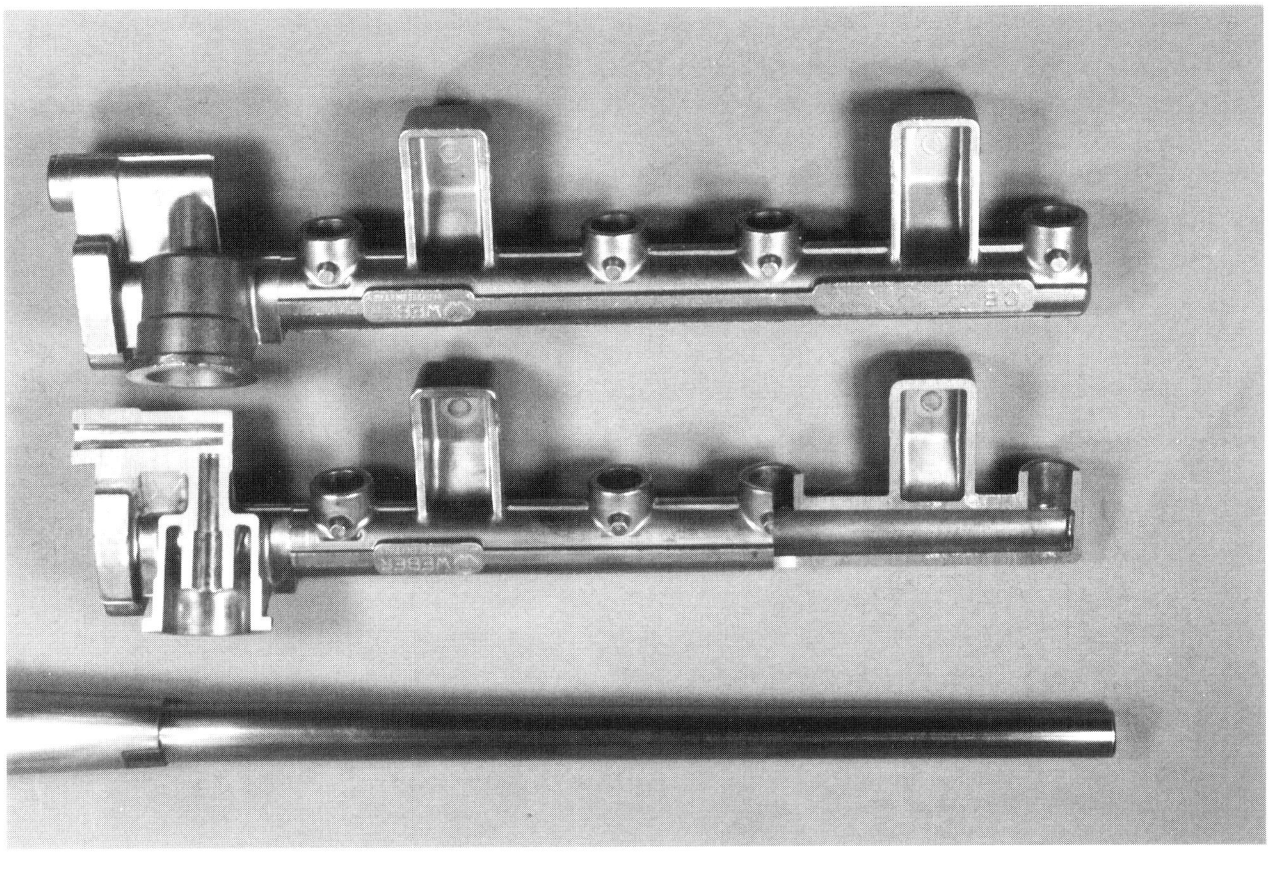
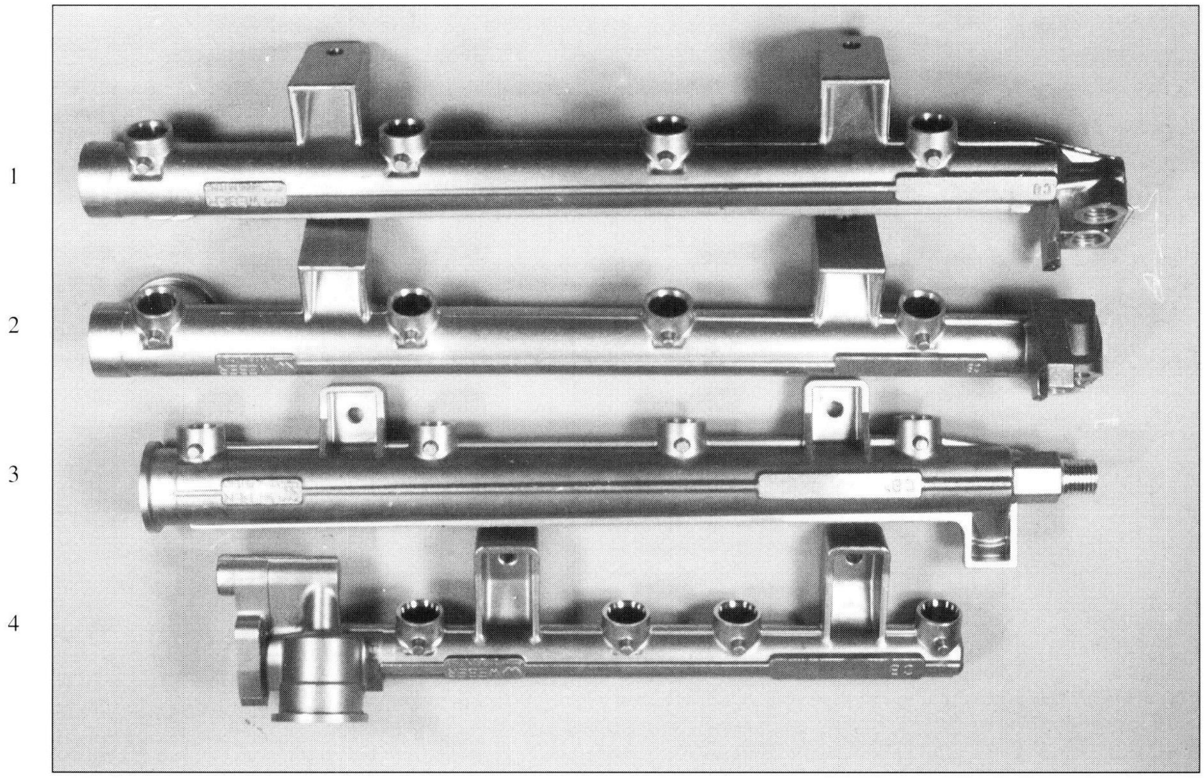


Fig. 3:
fuel rail for Fiat "PUNTO".
middle: dissected areas; bottom: steel core.



	APPLICATIONS
1 - "2000 16V":	FIAT "TIPO - TEMPRA - COUPE ESSE" LANCIA "NUOVA DELTA"
2 - "2000 16V TC":	FIAT "COUPE ESSE" LANCIA "NUOVA DELTA"
3 - "1750 8V":	LANCIA "DEDRA - NUOVA DELTA"
"2000 8V":	FIAT "TIPO - TEMPRA - TEMPRA S.W." LANCIA "DEDRA"
4 - "1242 cm^3":	FIAT "PUNTO"

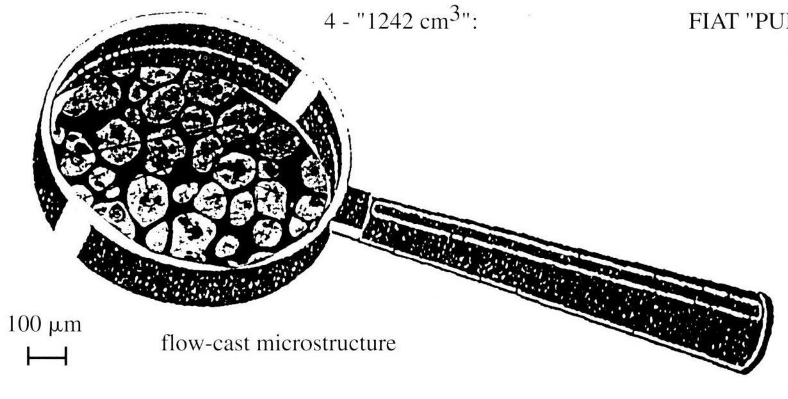


Fig. 4:
Fuel rails die cast in semi-liquid state

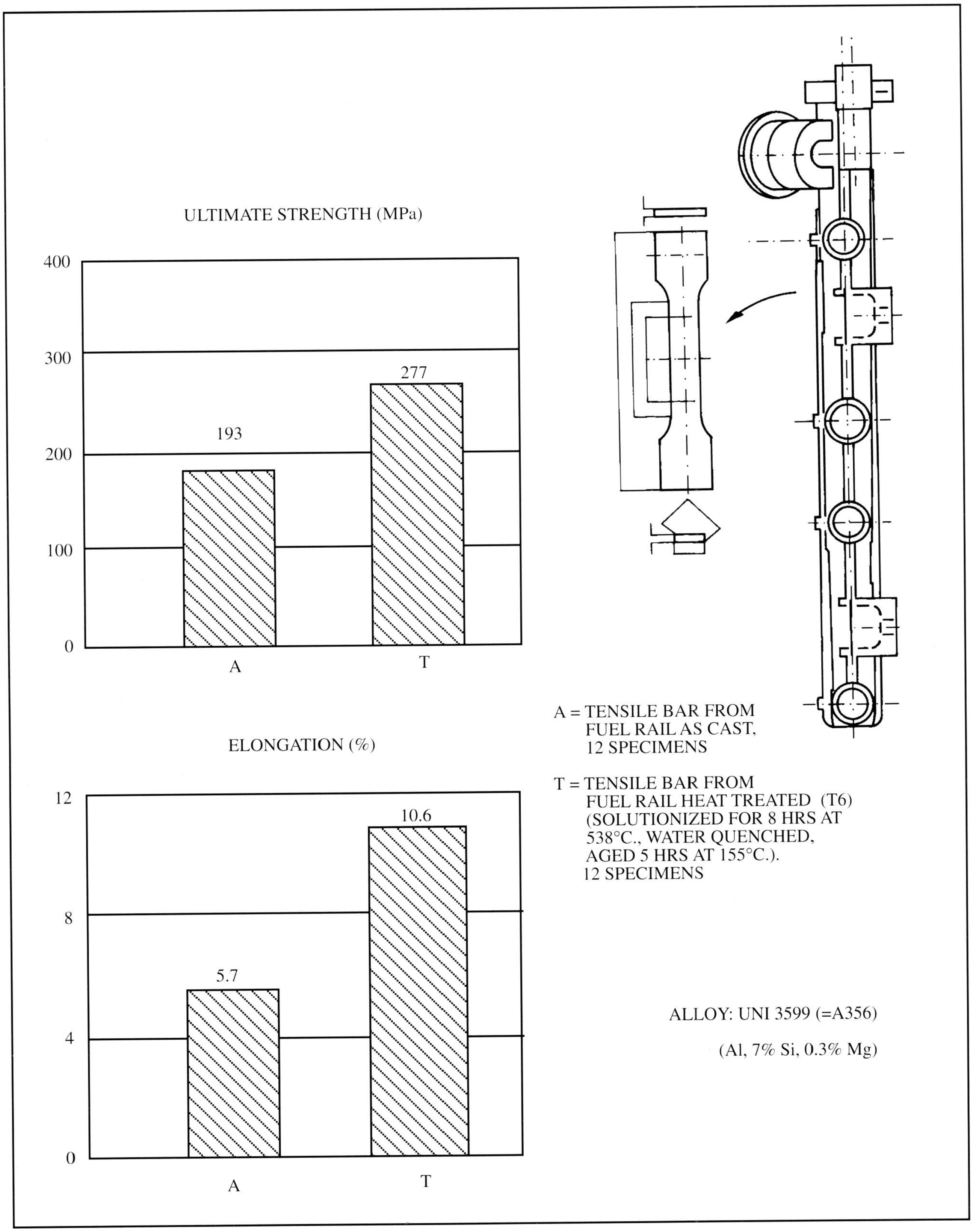


Fig. 5:
Tensile tests