

# INVESTIGATIONS ON LARGE TURBINE CASINGS AND VALVE BODIES MADE OF NEW 9-10%CR-CAST STEELS AND IMPROVEMENT OF CASTING TECHNIQUE AND QUALITY PERFORMANCE

Hanus R., Voest Alpine Stahl Linz GmbH, Foundry, Linz, Austria

Schuster F.A., Voest Alpine Stahl Linz GmbH, Foundry, Linz, Austria

Buberl A., Voest Alpine Stahl Linz GmbH, Foundry, Linz, Austria

Cerjak H., Technical University Graz, Graz, Austria

## Abstract

Steel castings made of creep resistant steels play a key role in fossil fuel fired power plants, for highly loaded components in the high and intermediate pressure sections of a turbine. Inner, outer and valve casings, inlet pipes and elbows are examples for these critical components. In the development for higher efficiencies of the power plants and the improvement of creep resistance for the involved materials, also the casting steel grades have to be adapted to the increased demands on material properties. This paper shows the contribution of a steel foundry to the European COST-programme for the development of a new 10%Cr steel grade. It also shows the introduction of the new 9-10%Cr casting steels G-X 12 CrMoWVNbN 10 1 1 and G-X 12 CrMoVNbN 9 1 into commercial production of heavy castings.

**Keywords:** steel castings, 9-10%Cr cast steel, turbine components, manufacturing, foundry

## 1 Introduction

Parallel to the continuing R & D activities within the scope of COST 501, as early as 1992 the commercial production of castings using the new 9-10% Cr steels, both with and without tungsten additions, was commenced at the Voest Alpine Stahl Linz Foundry. This paper reports on various aspects of the full-scale manufacture of such castings for steam turbines in the 1-60 t weight range. The report is based on the production within the last 6 years. During this period the results of the European research work within the frame of COST 501 were introduced into the foundry practice. Some details are also reported in [2].

The welding tests free of cracks demonstrated the good weldability of the new 9-10% Cr steels. The analysis of typical defects in the castings made an adjustment of the casting and feeding techniques to the solidification behaviour of the new 9-10% Cr steels necessary. These measures led to a reduction in feeding defects (shrinkage cavities) in the later production castings. Through the experience gathered in the course of extensive non-destructive material testing, it was proved that the new 9-10% Cr casting steel grades are excellent for testing and that the smallest casting irregularities according the applicable specifications can be located. The production of 80 steel castings of modified 9-10% Cr-steels in a weight range from 1 to 60 tons demonstrates that quality performance is as good as for 1% CrMoV steel castings traditionally used for steam turbines.

## **2 COST 501 Programme**

### *2.1 Casting Programme*

After evaluation of the most promising alloy from laboratory melts and production of cast plates from this alloy, these plates were welded with a matching electrode, to perform a welding procedure qualification, and to start a testing programme for mechanical properties, microstructure and creep rupture strength [1].

Based on these screening programmes, for selection of chemical composition and heat treatment, a pilot valve body was cast, to verify castability, non-destructive testability and weldability.

The details of these COST 501, Round II and III programmes are reported in [2].

### *2.2 Welding Programme*

As welding is an important step in the manufacturing process of steel castings, the welding programme within COST 501 and the development of welding consumables is an important issue for the foundry. The investigations and results of the welding group of COST 501 Round II are reported in [3] and [4].

## **3 Production of Heavy Steel Castings, Manufacturing Process**

Figure 1 shows the main sequences in the flow of production of heavy steel castings for power engineering.

After design of casting technology, pattern making and moulding, the existence of the product starts with the melting and pouring process.

As castings in such dimensions must not have defects which result in scrap, the pouring and solidification process is simulated on the computer during the design phase, in order to locate critical sections for shrinkage (see Figure 2).

After the time of solidification (approx. 2 weeks) has passed, the casting is shaken out. The handling of the casting in this condition is absolutely critical, because the as cast microstructure is highly brittle. Therefore an annealing treatment is necessary for the casting, to stand the high thermal stresses during riser burning. The temperature range in which riser burning is performed, is also critical, as the stresses from the different temperature gradients and the changes in wall thickness in different sections should not be added to the stresses from transformation of the microstructure.

The quality heat treatment is the most important sequence besides the chemical composition, to obtain the required microstructure and mechanical properties, as a basis for creep strength.

After pre machining, the casting is examined by non destructive testing methods (magnetic particle, ultrasonic and radiographic). All indications which do not meet the applied acceptance standard, have to be removed by grinding and arc air burning. After magnetic particle testing of the excavations, these are welded, followed by a stress-relief cycle.

Many dimension control sequences are performed between the main production phases, in order to determine whether the dimensions will become critical for final machining or function.

Final non destructive testing is the last sequence in the foundry, before the casting is sent for final machining.

## 4 Introduction of 9-10%Cr Steel Grades into Commercial Production of Heavy Steel Castings

### 4.1 Considerations for Manufacturing

The main issues to be considered for commercial production of new casting steel grades, designed by R&D programmes are:

- *Casting Design and Simulation of Solidification*

The reasonable design of casting and feeding technology is one of the main demands for obtaining sound castings. As the parameters for solidification of 9-10%Cr cast steels are different from those of 1CrMo(V) steels, the shrinkage behaviour is more complicated, especially in heavy cross-sections

- *Melting and Pouring*

High quality raw materials, proper steelmaking and correct pouring practice are needed to achieve the chemical composition exactly to the specified point and to minimise endogenous and exogenous inclusions. Secondary refining using a ladle furnace can be helpful in this respect. Figure 3 shows the melting process applied within VOEST-ALPINE STAHL LINZ GmbH steel foundry.

The main issues for melting and pouring of the new 9-10%Cr cast steel grades are described in [2].

- *Microstructure*

Some of the considerations for microstructure, especially in heavy sections of steel castings, namely segregations of C and Delta Ferrite, and the necessary adjustments of chemical composition for the new 9-10%Cr steel grades, are described in [2].

- *Heat Treatment and Mechanical Properties*

Figure 4 shows the main production phases in a time/temperature diagram, beginning with cooling in the casting mould and ending with final stress relieving.

Due to the fact that severe differences in wall thickness are typical for turbine casings, the temperature distribution in the different sections is highly critical in the temperature range of martensite transformation. Therefore the logistics of handling the casting during production has to be planned dependent on the microstructural condition of the different sections.

Castings in such dimensions usually have a long history of heat treatment cycles, due to more cycles of repair and construction welds with intermediate stress-relief-treatments and long required holding times for thick sections.

In order to show the influence of long holding times and more stress-relief-cycles a special investigation was performed, where we applied several tempering cycles to cast test plates with a wall thickness of 100 mm. Figure 5 shows the heat treatments and holding times applied to the test plates of 9-10%Cr cast plates with and without tungsten and the results of the mechanical properties. Multiple tempering and long holding times cause a reduction in yield strength, which must be taken into consideration in the specification of minimum requirements.

On the basis of the available results, a minimum yield strength of 520 MPa is advised for the tungsten-alloyed G-X 12 CrMoWVNbN 10 1 1. As tungsten has a strengthening effect, it could be proved that the yield and tensile strength was higher than that of 9% Cr cast steel without tungsten at the same tempering temperature of 730 °C. For the G-X 12 CrMoVNbN 91 cast steel without tungsten, the minimum yield strength shall be specified within the 480-500 MPa range.

- *NDT and Casting Defects*

One of the advantages of steel castings for complex designed structures such as turbine components is that defects can be repaired by welding. Fabrication welding is one of the main cycles in the manufacturing plan of a steel casting (see Figure 1). The amount of welding volume is a matter of costs and is dependent on type and complexity of design and material.

A detailed description of the comparison of defect type and repair volume for the new 9-10% Cr cast steels is given in [2].

- *Welding*

Due to the high residual stresses of the 9-10% Cr steels, resulting from the martensite micro-structure, major process and construction welds are performed in partial stages with intermediate stress relieving. Corrective welding is then occasionally required when only partially healed hot tears have not been completely removed. In closing, we can confirm that the welding behaviour of the new steel grades is satisfactory, providing that the specific stipulations for martensite, high Cr alloyed steels are applied and strict quality controls are carried out during the welding process.

- *Cycle Time and Costs*

As opposed to the 1% CrMoV cast steel generally employed, the production period for castings using the new 9-10% Cr steel grades is 2-4 weeks longer, depending on the size and complexity of the casting.

The main aspects which cause the increase in costs and cycle time for 9-10% Cr-steels are:

- Material costs.
- Different casting technology, resulting in decrease of output, especially for heavy and complex designed castings. The left chart of Figure 6 shows the difference in output between 1%CrMo(V) steels, 9-10%Cr steels and all produced steels on average. The right chart of Figure 6 shows the increase of the necessary liquid steel for feeding purposes and the appropriate decrease of output for the new 9-10%Cr steels, when the design weight of the castings increases.
- Difficult handling for shake-out, cleaning and riser burning resulting in additional heat treatment cycles and intermediate reheating.
- Complex and longer cycles of heat treatments during foundry production (see Figure 4)
- Intermediate stress-relief cycles for fabrication welds and construction welds with large wall thickness.
- New formation of well known defect types, resulting in higher volumes of excavations and fabrication welding.
- High-Cr scrap, alloyed with W, Nb, N is very difficult to sell, even for prices, lower than that of low and unalloyed scrap, therefore the internal costs for circulate material increases.

At this point of production experience we have to discuss the cost aspect. On the one hand we all profit from the effort to improve power plant efficiency and to participate in the reduction of CO<sub>2</sub> emissions and other important positive effects on the environment. On the other hand we have to accept the higher costs for higher alloyed materials which can resist the elevated temperatures and ultra super critical steam conditions of advanced power plants.

The cost increase from 1 % Cr Mo V steel castings to 10 % Cr Mo W V Nb N material was shown to be 20 to 40 % depending on size and complexity of steel castings.

Due to the characteristics of the modified 9-10 % Cr-steels the expenditures are higher for larger steel castings as expected.

The experiences of the last five years production of modified 9-10 % Cr-steel castings for new power plants in Europe and overseas have shown that the 10 % Cr-cast steels are quite compatible in general.

#### *4.2 Realised Projects with Examples of Produced Steel Castings of 9-10%Cr Steels*

The transition of development work into practical casting took place in stages, whereby the increase in weight from 3.5 t (test valve casing) to 14 t (first inner casing for project Schkopau) was fraught with considerable risks. However, in the end, perfect castings with weights of 60 t were successfully manufactured using G-X 12 CrMoWVNbN 10 1 1.

Detailed information, with an overview of the power stations in which the new tungsten alloyed and tungsten-free 9-10% Cr cast steels have been employed up to now, is given in [2].

Some examples should give an impression of such castings.

Figure 7 shows the first projects realised, namely IP Inner Casings for power plant SCHKOPAU (14 tons) and MERI PORI (19 tons). The initial increase in weight and complexity was the IP Inner Casing for SCHWARZE PUMPE (40 tons) with welded-on cast pipes (see Figure 8). The HP/IP Inner Casing for the Danish power plants SKÆRBÆK and NORJYLLAND was a further challenge especially for casting technology and melting practice (see Figure 9). The biggest valve casing ever produced of the new steels was for power plant LIPPENDORF (see Figure 10).

An absolute challenge in all aspects of steel foundry technology were the casings for the project BOXBERG:

An IP Inner Casing weighing 60 tons with 113 tons of liquid steel necessary, which we believe is the biggest casting ever made of 10%CrMoWVNbN steel (see Figure 11).

Also a VHP Casing (31 tons) with welded-on valve casings (18 tons each), with a 185 mm welding seam (see Figure 12).

### **5 Conclusion and Outlook**

Figure 13 shows the development of production volume in rough weight and liquid steel since the beginning of production of the new 9-10%Cr steels at VOEST ALPINE STAHL LINZ - Foundry, in 1992. The amount in 1997 has reached 15% of total production volume. This fact and the mentioned examples show that the technical introduction of R&D-designed steel grades within COST 501 into commercial production was done most successfully and in the quickest possible way.

The new challenge, with even higher goals and more complex materials in COST 522, will also be a challenge for the steel foundry industry.

### **6 Acknowledgements**

The difficult, but successful, technical transfer of the R&D work into operational practice was achieved in an excellent co-operation with our customers and the friendly assistance of the COST 501 working group, for which we would like to express our thanks.

We also thank the Austrian Research Foundation for their support of the Austrian contribution to COST 501.

## 7 References

- [1] Gysel W., Trautwein A., Mayer K.H., "10 % CrMoWVNbN Cast Steel for Casings for advanced Steam Cycles - A Collaborate European Effort in COST 501/II", Third International Conference on Improved Coal Fired Power Plants, 1991 held in San Francisco.
- [2] Mayer K.H., Hanus R., Kern T., Staubli M., Thornton D.V., " High temperature cast components for advance steam power plant", 6<sup>th</sup> Liege Conference „Materials for Advanced Power Engineering“, 5-7 October 1998, Liege, Belgium
- [3] Cerjak H., Schuster F.A., „Weldability and behaviour of weldings in newly developed creep-resistant 9-10% Cr steels“, Second European Conference on Joining Technology - Eurojoin 2, Florence, Revista Italiana della Saldatura 4/94, pp.467 - 473.
- [4] Cerjak H., Letofsky E., Staubli M., „The role of welding for components made from advanced 9-12% Cr steels“, 6<sup>th</sup> Liege Conference „Materials for advanced Power Engineering“, 5-7 October 1998, Liege, Belgium

## 8 Figures

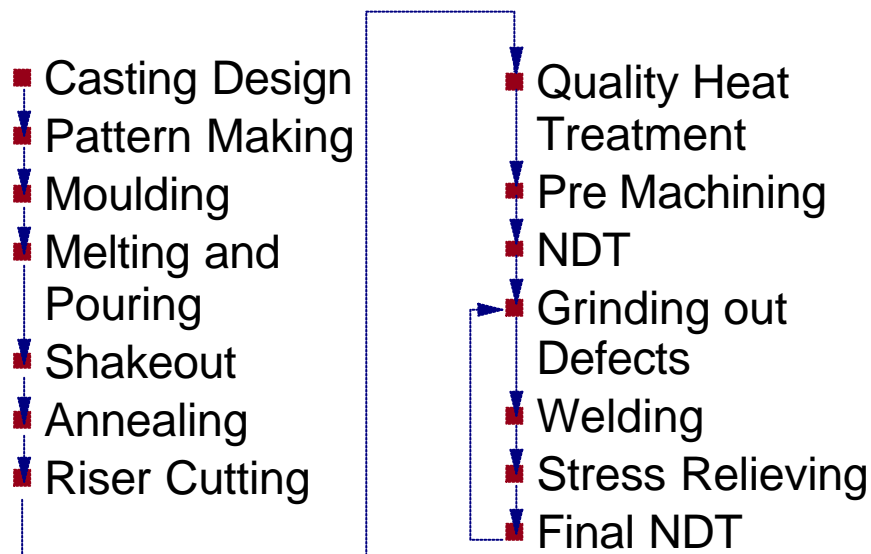


Figure 1: Typical manufacturing plan for heavy steel castings



Temperature [°C]

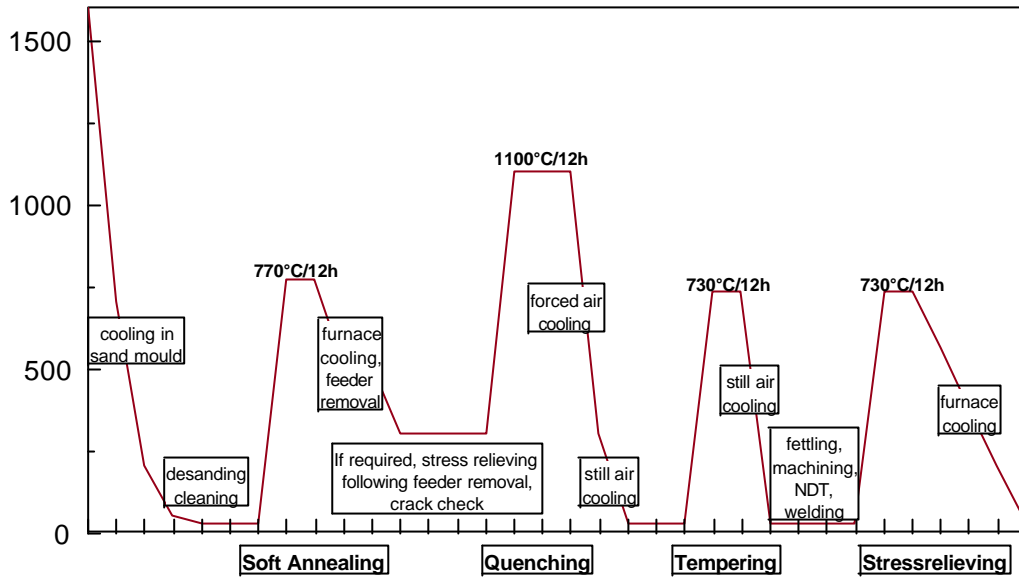


Figure 4: 9-10%Cr steel castings – time/temperature history: minimum cycles of heat treatments during production in the foundry

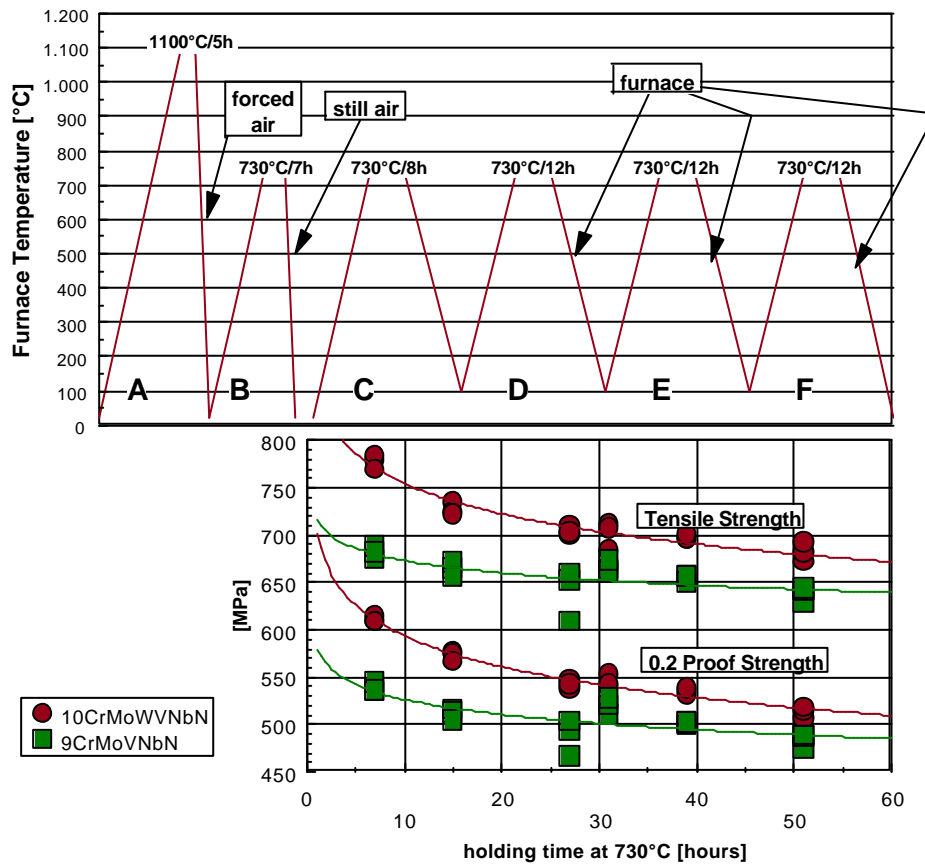


Figure 5: Temperature cycles for investigation programme: influence of multiple heat treatments on mechanical properties of new 9-10%Cr cast steels

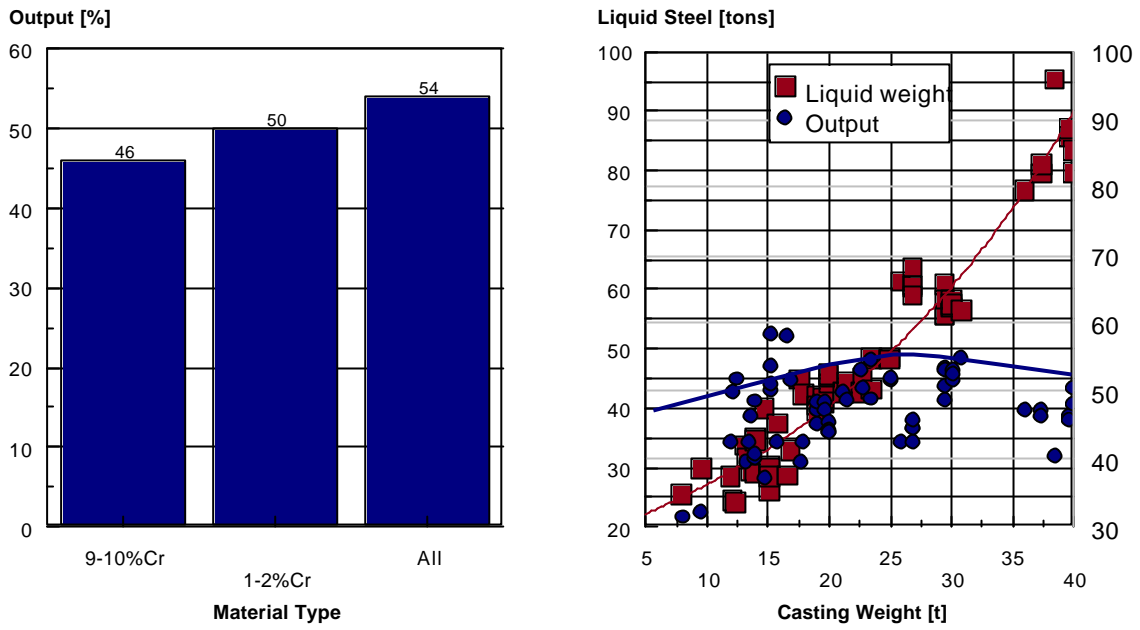


Figure 6: Comparison of output: 9-10%Cr steels, 1-2%Cr steels, all steels in average;  
Liquid steel and output versus rough weight for 9-10%Cr steel castings

Figure 7: Projects Schkopau and Meri Pori IP inner casings,  
14 t and 19 t (G-X 12 CrMoWVNbN 10 1 1)

Figure 8: Project Schwarze Pumpe, IP inner casing, 40 t  
with welded on cast-pipes (G-X 12 CrMoWVNbN 10 1 1)

Figure 9: Projects Skærbæk and Nordjylland, HP/IP-inner casing  
20 t, (G-X 12 CrMoVNbN 9 1)

Figure 10: Project Lippendorf, valve casing  
27 t (G-X 12 CrMoWVNbN 10 1 1)

Figure 11: Project Boxberg, IP inner casing  
60 t (G-X 12 CrMoWVNbN 10 1 1)

Figure 12: Project Boxberg, VHP casing, 31 t and valve casing, 2x18 t)  
later welded together (G-X 12 CrMoWVNbN 10 1 1)

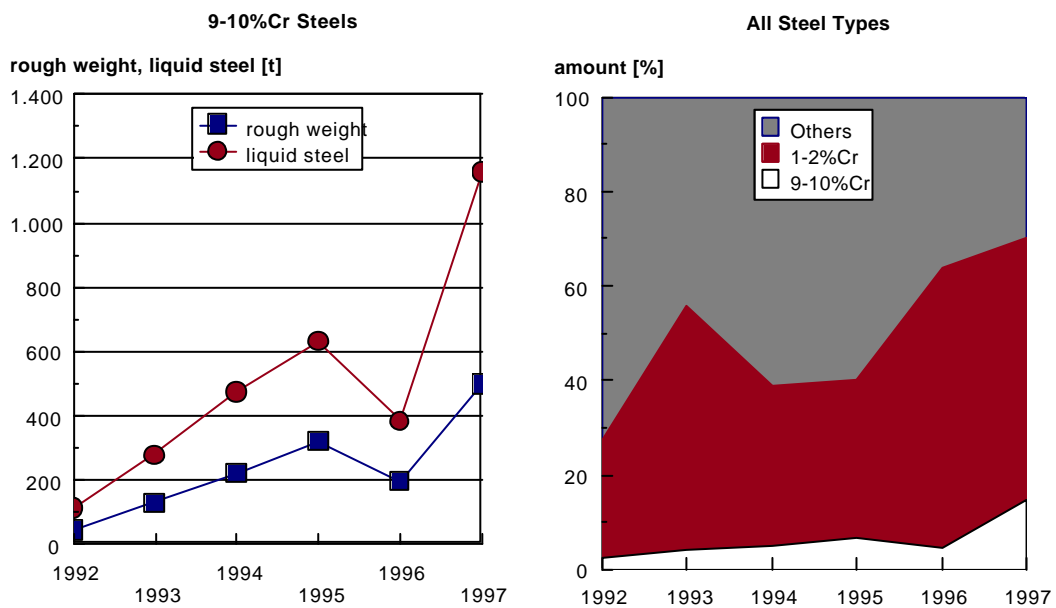


Figure 13: 9-10%Cr-cast steel – development of production in rough weight and liquid steel weight- development of proportionate amount