

CAST STEEL IN THE COMPETITION OF MATERIALS

Alfred R. Buberl
Reinhold Hanus

VOEST-ALPINE STAHL LINZ GmbH Steel Foundry, Linz, Austria

Abstracts

The globalisation of trade, environment and technology requires a continuous improvement of all products in functionality and exact adaptation of materials to the conditions of use. Therefore the range of materials was increased and the race of the designers as well as the material suppliers in finding the best solution for new challenges is also a challenge for the steel foundries. This paper shows two examples of new cast steel types and points out the aspects which are considered for research, development and for the introduction of newly developed cast steel grades into commercial production. It also shows the technical and commercial issues that are very often denied for the benefit of the final product from the very beginning. One example is a cast steel for offshore structures with high yield strength in low temperature application and good weldability. The second example is a new creep resistant cast steel grade used in advanced steam power plants at higher temperatures and pressures for increase of efficiency and decrease of environmental pollution. No company or even industrial sector can afford the expensive development of new processes and materials. Therefore operators, manufacturers and material suppliers have to work together in a network of international projects which make the contribution of a single company effective for the benefit of all partners involved, also for competitors on the market. The role of steel foundries and the cast steel materials within this new type of competition of materials is an important part for being successful with the development of new or advanced processes and technologies.

1 Introduction

In the past the technology of cast steel was developed rapidly on base of classical methods for foundry technology like solidification technique, sand systems, coating processes, melting and pouring technique, and many other processes of steel foundries.

A lot of new methods were introduced, to improve the technology, quality and competition of cast steel materials, methods like simulation of solidification, floating methods for coating moulds, simulation of heat treatment and microstructure, etc.

Latest techniques which were introduced in foundries are rapid prototyping or robotics.

Parallel to these attainments and changes in steel foundry technology also the organisation and management systems in industrial branches had to change, nevertheless due to a dramatic change in market- and price policy [1].

New cast steel materials were developed and well known materials were modified for improvement in properties and enlargement of their application.

But not only technologies developed, also standards for materials, non destructive testing, and a lot of other applications changed or new standards were introduced.

Therefore the range of cast steel grades increased and there is a lot of new possibilities for applications and variations.

One big change in standardisation is the introduction of international standards like CEN and ISO in all fields of technology. We are right now within this process of change and foundry experts are involved too less in the important discussions of the technical standardisation committees.

As the results of these discussions will be content of new standards and requirements and these requirements are a matter of costs for the foundries, the involvement of the steel foundry experts is most important.

2 Steel foundry in wrap

2.1 Market and Costs

The economic situation, the existence of over capacities and struggles for market shares of those industrial branches which need cast steel products, led to a drastic slump of the market prices for foundry products. In Europe this trend was enhanced by the opening up to former COMECON-Countries, on the one hand and by change of parity in currencies on the other hand. The chance of survival of the foundry industry lies with the adjustment of the cost structure to the international market situation. Total operating performance (TOP), including defined targets in quality-, time- and cost-improvement, is one possibility to meet the new challenges [1]. The installation of a lean organisation in combination with permanent reengineering- and continuous improvement-programmes are modern management tools to keep the price-cost-shear closed (see figure 1).

2.2 Competition

The old attitude towards development and know how is no longer valid. In the past for example patterns and casting technology was always the secret of a foundry. In times when simulation of solidification is a well known tool in foundry technology, but not every single foundry installs the extensive equipment and specialists for programming, there are institutes and also some foundries which offer their expertise in engineering and also patterns are offered by pattern shops which are out sourced from former foundries.

The competition today takes place on price and delivery, quality and technology is specified and assumed by the customers. Today it is important to concentrate on the core business and not to cover as many competencies as possible.

2.3 Quality Management (TQM)

ISO 9000 is not the only interest today. It is one brick of the wall and shows only the qualification of the defined processes. What is not covered by ISO 9000-series are the quality of the product, the benefit for the customer, quality of the employees and quality of the management. Continuous improvement should be installed as a systematic tool by the management. Reengineering for business to make the processes customer orientated and for the management to make the organisation lean, is the actual catchword which will not stop before the gates of the foundries.

2.4 Technology

The steel foundry development is no longer limited on the well known fields of simulation of solidification, moulding- and sand technology, melting metallurgy, etc.. It also has to influence developments from the customer and consumer side. The presence of foundry representatives in all technical developments where cast steel components are involved is highly important, to avoid solutions which are not applicable in foundry practice. Innovation for application of steel cast components replacing other manufacturing technologies will open new markets. An example, where welding fabrications of gas turbine casings were replaced by cast steel components, with workout of casting design by the foundry, is shown in figure 2.

2.5 Materials

The competition of materials takes place on development of new materials for new fields of application of steel castings, as well as the modification of well known materials, for improvement of processes where steel cast components are used.

The range of cast steel grades sharply increased in the last decade, due to many modifications of standard materials, but also revision of norms and standards, e.g. the many new European standards.

Two examples of cast steel development are shown in paragraph 3.

2.6 Globalisation

Globalisation is the magic formula which drives all developments in trade, politics, communication, environment, research, technology, etc.

Also the producing industries, like the foundry industry, are influenced and have to change their attitude towards development, know how and competition.

3 Examples for development of cast steel materials

Two examples should make the wrap in the development and competition of materials visible. Not the technical details should be aim of this paragraph, but the way how materials are developed and what has changed in the global system of research and development of materials where foundries are only one part in between customers and other suppliers like manufacturers of plate, tube, welding consumable, etc.

3.1 High yield cast steel for offshore structures

Cast steels with high yield strength in low temperature application and good weldability are used for offshore structures. An example, a universal joint, which is used on ships for oil production, is shown in figure 3. It is important that the cast components are fully compatible to the quenched and tempered plate materials to which they have to be welded on. Therefore weldability, mechanical properties in field conditions (sea water, low temperature, dynamic loads), fracture mechanics characteristics are demands on these materials and everyone dealing with offshore-technology knows how extensive qualifications of materials, designs and processes are.

Many steel foundries tried to get access to the offshore market and each of these foundries developed their own modified materials, designs, finite element analysis and invested in the extensive qualification demands without having guarantee for getting an order. Some examples of successful developments and qualifications are reported in [2], [3], [4] and [5]. All these cast steel developments have main common issues: improvement of toughness, strength and weldability by modification of chemical composition (low Carbon-equivalent, low range of embrittling elements, micro alloys for grain refinement and rapid cooling from austenitisation temperature to meet the required high yield and tensile strengths. Some typical chemical compositions of weldable steel castings and plates are summarised in table 1 ([2], [5], [6], [7], [8], [9]).

The boundary conditions are defined by the customers: design loads, main dimensions, type of finite elements, material properties, requirements for non destructive testing. The suppliers have to consider how to fulfil the requirements and propose exact design, finite element calculation, chemical analysis, heat treatment, welding procedure, NDE-procedure. The material and all procedures have to be qualified with very high effort in the status of inquiry. The effort for development and qualification has to be taken over by the supplier.

3.2 Highly creep resistant cast steel for coal fired power plants

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. An example, a very high pressure casing, with valve casings to be welded on both sides of the outer casing is shown in figure 4. 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. [10], [11] and [12] report the contribution of steel foundries to the European COST-programme for the development of a new 10%Cr steel grade. [11] and [12] also show the introduction of the new 9-10%Cr cast steels G-X 12 CrMoWVNbN 10 1 1 and G-X 12 CrMoVNbN 9 1 into commercial production of heavy steel castings.

The principal idea is, to cover all suppliers of power plant components within one project with a defined, common goal: increase the efficiency and decrease environmental pollution by higher temperatures and pressures in the steam process. The proper materials to stand these requirements should be developed. The demands and considerations of the individual branches could be co-ordinated from the very beginning and the results could be exploited very effectively, due to the participation of representatives of the involved branches, namely power plant manufacturers, producers of pipe steels for boilers, forgings for rotors castings for casings and valves, welding consumable. The metallographic investigations and modelling activities were investigated by universities. Issues like high temperature corrosion were worked out by institutes or specialist companies in form of study contracts. The working group "Castings" consisted of representatives of 7 manufacturers for power plants, 3 suppliers for steel castings, 3 suppliers for welding consumable and 4 universities and research centres from 6 different countries within Europe. All member countries of the participating companies have to sign their intention for participation in a memorandum of understanding and the companies were supported by founding from the national bodies.

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. 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. Welding consumables were developed parallel to that of the base metals for boilers and castings.

The introduction of the new 9-12 % Cr-steel castings into commercial production could be performed parallel to the ongoing research work. 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.

4 The role of the foundry organisations

Due to the wrap in technology, research and development, standardisation, management and marketing, as a matter of globalisation also the organisations, representing the foundries have to change from administration to uncomplicated work. As the dynamics of the circumstances drive the changes, we all are in the middle of the wrap and a lot of work has already been done.

Foundry organisations co-operate with institutes and industry, to use the synergy's, and the topics of work come from the requirements of industry.

4.1 CIATF and the national foundry organisations

The commissions of CIATF would be the appropriate platform for international work packages and the support from the committee to make their work effective is highly essential. The big problem is that the initiative for topics to work on and the workforce have to come from the member foundries. Nowadays, in a time of lean production and lean management, the resources, to send out representatives for meetings and to spend time on projects with unclear benefit for the own company, are very limited. Therefore the work of the commissions has to be success oriented, like the work of service companies. Defined goals with measurable results are highly important. This means, that the work of the commissions should be systematic (topic, goal, milestones, report system, benefits for the participants). If a manager can not realise the benefit of a project for his own company, he will not spend time and effort on it. Also the financial support for meetings and the used services is important.

4.2 Introduction of Commission 7.2

With respect to the above one commission of CIATF will be presented.

The commission 7.2, "Steel Casting" was set up in October 1991. Today the commission consists of 10 members from 8 different countries (see figure 5).

As a first topic the implication of specified quality requirements on the cost structure of the manufacturing stages of steel castings was investigated. The results, reported in [13] and [14], can be used as a basis for a better understanding by all parties involved in the manufacture, purchase, specification and use of steel castings.

Currently the standards for process and acceptance levels (e.g. of non-destructive testing - standards) as well as definition of quality classes are being reviewed in working groups at ISO, ECISS and CEN. This will result in technical and economic consequences for the steel foundries.

The work of the commission tries to point out that quality is the result of equipment, materials (raw and additional materials, ...) R&D, services, etc.. According to the demands of the final product the quality grades are of different level and so are the expenditures.

Criteria and expenditures were established, to ensure a specific quality for the individual phases of production.

4.2.1 First topic "Cost influence - quality grades of steel castings"

By means of a model for cost relativisation the relation between quality and costs was illustrated. Criteria which influence quality have been listed and each criterion sub divided into 5 quality grades from the lowest realistic quality up to highest quality according the latest state of engineering. 11 main groups of criteria (see figure 6) with detailed lists of sub criteria were worked out.

For each criterion the 5 quality grades were described either by means of limits (e.g. for chemical composition, mechanical properties) or reference pictures (e.g. for surface

condition, NDT), tolerances or factors (e.g. for dimensional accuracy) or other characteristics (example see table 3).

The relative importance of each criterion to the overall quality is graded by a valuation factor between 0 (not important) and 1 (most important).

Any operations, required to meet the appropriate quality grade were listed in an expenditure reference list (main groups of expenditures see figure 7). Every expenditure was factored with regard to costs to the foundry with factors between 0 (no extra costs, nothing special required, no difficulties) and 10 (highest extra costs, highest requirements, highest difficulties). A degree of difficulty (calculated from the expenditure factors) shows how difficult a single expenditure is, relative to another expenditure.

Finally the cost influence grade was calculated from all the factors, which should show the relative relationship between quality grades and costs (see figure 8).

Following conclusions are possible:

- A relationship exists between quality and costs for the production of steel castings. The costs of steel castings rise with increasing demands on quality (i.e. a higher quality grade) because of increasing expenditures for equipment, materials, R&D, services, etc. that ensure the required quality grade.
- Comparison of a customer's specification to the criteria list, what quality grade comes nearest to this specification. On the basis of this identified quality grade, it is possible to evaluate the different efforts for achieving the different quality standards. Similarly the percentage difference in cost between quality grades can be evaluated.

4.2.2 Second topic "UT-Standards for Steel Castings"

As the first topic was a general concern, covering all foundry processes, we looked for a actual application of the ideas, we learned from our previous work: how can we avoid unnecessary high efforts, resulting from specifications, which try to reach the newest state of technology, but are hardly applicable in daily manufacturing.

The discussions and negotiations for a new European standard for ultrasonic testing of steel castings took already 7 years from the very beginning in the technical committee TC 190 of CEN and the content of the draft prEN 190/411-1 was confusing. The original proposal consisted of one brand new method, which had its origin in a company specification of turbine manufacturer. The aim was, to test very critical highly loaded steel casting components of steam turbines with a new method of recording and evaluation for acceptance of indications. This complicated method with dramatically increasing efforts for testing, recording and upgrading should replace all well known standards, like DIN 1690/SEP 1922 , or BS 6208 and be used as general standard for all steel castings.

After a rejection in the first inquiry, especially from Great Britain, the main content of BS 6208 was added into the paper and the new draft consisted of 2 methods, the new one (method 1) and a bad extract of BS 6208 (method 2). These methods were not separated, but main parts and also figures were valid for both methods. The decision which method should be applied was to be taken by the customer. The proposal was sent out for CEN inquiry as prEN 12680-1. This draft should apply for all kinds of steel castings (from uncritical parts for general application to critical, highly loaded components).

The commission 7.2 members agreed to the following working programme:

1. national rejection of prEN 12680-1 by the foundries via the national standardisation institutes
2. official letter from CIATF-secretariat to CEN secretariat with main concerns from the foundrymen and the offer to work within the technical committee of CEN/TC190
3. workout of an alternative proposal, which should try to harmonise the actual national standards (see figure 9) and present this to the technical committee of CEN/TC190

All mentioned activities were performed in a very expendable, but effective work. Many meetings, within commission 7.2, with representatives of TC190 as well as other working groups involved (see figure 10).

A special co-operation was organised between commission 7.2 and members of a research project of the German foundrymen's association VDG and German turbine manufacturers. This projects (Aif. 8338) works on "behaviour of defects in heat resistant cast steel under loads similar to operation" and ultrasonic testing is a main issue within this project. Following results were achieved by the work of commission 7.2:

1. the proposal of commission 7.2 for a new draft of prEN 12680-1 was taken as a basis for the international negotiations within CEN/TC 190, on September 23, 1997 in Düsseldorf. The results off the discussions with the main content of our proposal was sent for CEN-inquiry.
2. the methods were separated into two independent papers with the proposal of commission 7.2 as a general standard for ultrasonic testing of steel castings and a second proposal from the German research group Aif 8338 as a standard for "ultrasonic testing of steel castings for critical turbine components"
3. the applicability of both standards in foundry praxis is guaranteed, due to the presence of foundrymen in all working groups and discussions

The final report of this second topic will be issued by the end of 1998 and the next topic will be started.

5 Conclusion and outlook

The "Steel Foundry 2000" will be included in networks of technology, quality management, standardisation, research and commerce.

The competition of materials is part of a general development and the foundries play their important role within the race for new technologies with new and modified cast steel materials. The steel foundries have to participate in many projects and working groups to resist in a development of globalisation of technology. The foundry associations and especially CIATF are the best institutions for distribution of information, installations of working groups and official appearance in common concerns for foundries.

Some single examples from material and standardisation developments should show that this new way is possible, it is only a matter of organisation and management on basis of technology.

6 References

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7 Tables and Figures

Steel grade	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	Nb	V	N	Al	CE	Pcm
GS-20 Mn 5 [6]	0,17 0,23	max. 0,60	1,00 1,50	max. 0,020	max. 0,015	max. 0,30	max. 0,40	max. 0,15	-	-	-	-	-	-	-
GS-8 Mn 7 [5]	0,11	0,53	1,64	0,013	0,001	-	0,19	0,07	-	0,035	0,01	0,008	0,038	0,40	0,22
GS-13 Mn Ni 6 4 [6]	0,08 0,15	max. 0,60	1,00 1,70	max. 0,020	max. 0,010	max. 0,30	0,80 1,20	max. 0,20	-	max. 0,05	max. 0,10	max. 0,020	-	-	-
GS-13 MnNi 6 4 mod. [2]	0,10	0,53	1,45	0,014	0,003	0,04	0,89	0,10	0,17	0,03	0,03	0,008	0,035	0,44	0,22
Fe E 450 EM [7]	max. 0,16	0,25 0,60	1,00 1,65	max. 0,025	max. 0,015	max 0,30	max. 0,65	max. 0,25	max. 0,30	max. 0,03	max. 0,08	max. 0,010	max. 0,055	-	-
FW RX 0002 [8]	0,11	0,42	1,39	0,010	0,0011	0,11	0,52	0,016	0,16	0,019	-	0,006	0,036	0,41	0,22
XAB0 500 [9]	0,10	0,39	1,48	0,006	0,0015	-	0,52	0,27	0,30	0,02	-	0,005	0,038	0,45	0,23
$CE(IIV) = C + \frac{Mn}{6} + \frac{Cr+Mo+V}{5} + \frac{Cu+Ni}{15} [\%]$						$Pcm = C + \frac{Si}{30} + \frac{Mn+Cu+Cr}{20} + \frac{Ni}{60} + \frac{Mo}{15} + \frac{V}{10} + 5B [\%]$									

table 1: typical chemical analysis of high strength steel

wall thickness [mm]	Location of Specimen	Yiel Point [N/mm ²]	Tensile Strength [N/mm ²]	Elon-gation l=5d ₀ [%]	ISO-V Mean Value -40°C, Joule
50	T/2	461	586	26,6	106
		465	588	26,0	
100	T/2	465	590	25,6	85
		467	590	25,8	
200	T/2	458	576	24,8	80
		460	576	27,4	
500	n.s.	474	582	26,2	55
	T/4	416	533	20,0	
	T/2	403	510	20,4	

table 2: mechanical properties of GS-13 MnNi 6 4 mod.

Criterion		Quality Grades				
No.	Description	1	2	3	4	5
A10	Ranges	precise "point analysis" (reach the aim, no ange) ELC, Cr-, Ni- equivalent, C- equivalent	according to specification of customers	according to national and international standards	according to internal specification	only max. values of P and S are specified (e.g. S<0,05%, P<0,04%)
A20	Sulphur	< 0,003 %	< 0,010 %	< 0,020 %	< 0,030 %	< 0,050 %
A30	Phosphorus in non-alloy and low-alloy materials	< 0,010 %	< 0,015 %	< 0,020 %	< 0,025 %	< 0,040 %
A31	Phosphorus in high-alloy materials	< 0,010 %	< 0,015 %	< 0,025 %	< 0,030 %	< 0,040 %
A40	Hydrogen before pouring	< 3 ppm	3 - 5 ppm	5 - 7 ppm	> 7 ppm	not determined

table 3: criteria list with description of quality grades, examples for main group chemical composition

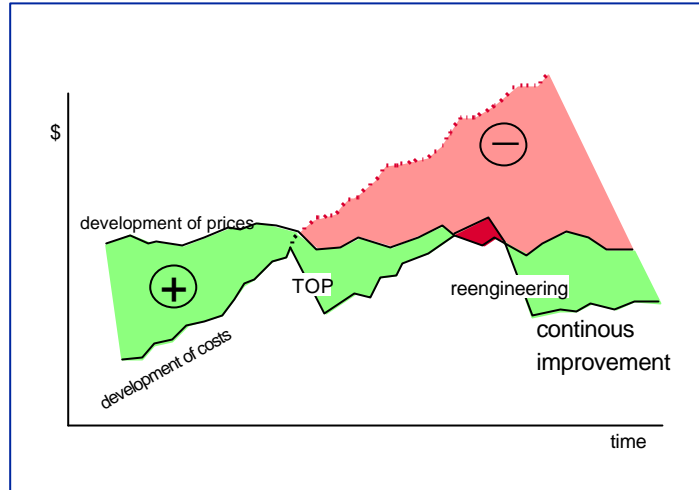


figure 1: close the price-cost-shear



figure 2: gasturbine components, made of creep resistant cast steel replaced a former welding fabrication



figure 3: steel castings for offshore structures universal joint for a oil production ship



figure 4 steel casting for steam turbine processes made of 9-10% Cr cast steel

- **AUSTRIA**
 - VOEST ALPINE STAHL LINZ
- **CANADA**
 - CANADIAN STEEL FOUNDRIES
- **CZECH REPUBLIK**
 - SLATINA SLEVARNA
 - SKODA-TURBINY
- **FINLAND**
 - LOKOMO OY
- **FRANCE**
 - CREUSOT-LOIRE INDUSTRIE
- **GERMANY**
 - PHB STAHLGUSS
 - SANDE STAHLGIUSS
- **NORWAY**
 - SCANA STAAL A
- **UNITED KINGDOM**
 - RIVER DON CASTINGS



figure 5: CIATF, Commission 7.2 - participants

- Chemical composition
- Mechanical properties
- Surface condition
- Surface defects
- Internal soundness
- Dimensional accuracy
- Qualifications
- Quality management
- Third party
- Documentation
- Inquiry

figure 6: main criteria groups for definition of quality grades

- Melting
- Testing
- Foundry engineering
- Surface preparation
- Surface testing
- Ultrasonic and radiographic testing
- Dimensional control
- Upgrading and welding
- Qualification
- Quality management
- Third party inspection
- Certification
- Commercial

figure 7: main expenditure groups for description of required expenditures, to meet the appropriate quality grade

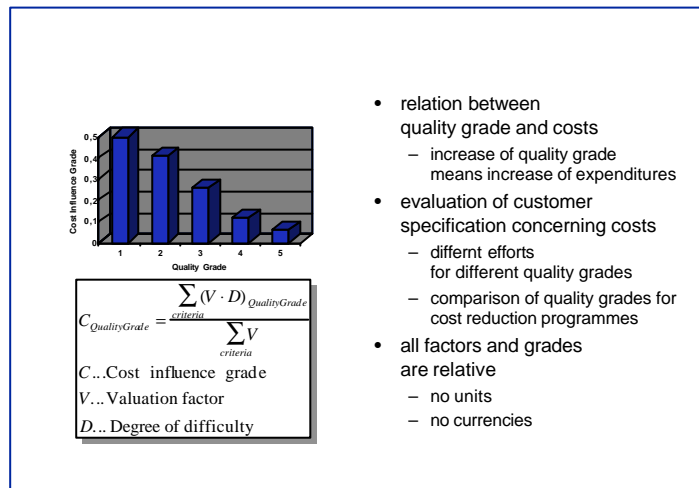


figure 8: relation between costs and quality grade

- prEN 190/411-1
prEN 12680-1
- DIN 1690
SEP 1922
- BS 6208
- ASTM A 609, ASME SA-609
- CCH 70-3

figure 9: important standards for ultrasonic testing of steel castings

- GEC-Alsthom Energie, Nürnberg
(former MAN) company specification
- CEN/TC 190, WG 4.10 working group "Inner Defects"
- FES AA-11, standardisation committee iron and steel
within DIN, working group "Cast Steel"
- GINA, common committee of VDEh and VDG
[AIF-No. 8338](#) (VDG research-project)
"Behaviour of defects in heat resistant cast steel under
loads similar to operation"
[CIATF Commission 7.2](#) "Steel Casting"

**figure 10: parties involved in the discussions of
EN for ultrasonic testing of steel castings**