NEW CC MOULD SYSTEMS FOR LONG PRODUCTS [1]

Adrian Stilli [2]

Abstract
Continuous casting of steel is basically a process in which liquid metal starts its solidification at the meniscus of the so called mould. Here at the very first process step the heat extraction is a multiple of any other heat exchanging process and the mould material suffers from temperatures which is at the limit for copper. Because of the large range of steel grades cast with carbon contents of 0.03 % - 1.00 %, the steel shrinkage factor varies substantially. Therefore the mould shape, taper and other design features need to be carefully chosen and may be calculated with finite element method (FEM). Mould-Systems can incorporate electromagnetic stirring and the like in order to distribute the hot liquid steel over a longer length. Mould level control and powder detection systems are also available. This paper describes cartridge mould systems, state of art CONVEX moulds, integrated moulds, ALL-CONVEX moulds and looks into the future designs. Productivity figures and mould optimizing- and refurbishing processes are mentioned.
Keywords: Long products; Mould systems; Quality.

1 *Tecnhical contribution to XXXVIII Steelmaking Seminar – International, May 20th to 23rd, 2007, Belo Horizonte, MG, Brazil.*
2 *Director Mould Division, Concast AG Zurich, Switzerland*

1 INTRODUCTION

The mould is the heart of the continous caster.
Concast AG, founded 53 years ago, has always been the frontrunner of the best performing mould systems and we still continue to develop better systems. The challenge in this “work field” lies in the combination of the best suitable designs for the particular needs of each individual steel plant.
Firstly basic parameters like steel grades cast, end application, section size and the planned annual production will define a certain mould system.
Secondly, the philosophy of service, replacement, refurbishing is to be considered before a decision is made e.g. plate mould, tube mould or the newly developed integrated mould system.

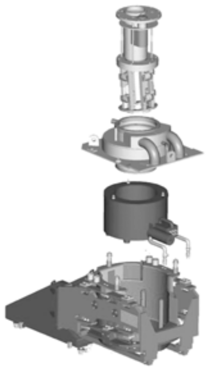


Fig. 1 – The mould components

A state of art mould system (Fig.1) is a combination of 3-4 parts which need to be maintenance and operation friendly. The only changeable part is the cartridge insert. All other items remain permanently in place and include the mould level control system. This paper will also introduce the benefits and give reference data of the renowned CONVEX-Mould.

Integrated mould (Fig.2) consists of a stainless back-up construction which provides the required rigidity and stiffness to support and hold the Cu moulds liner at the inner (steel) face. The water cooling channels are placed between the two materials

Integrated mould which combines a copper liner with a rigid back-up structure made from stainless steel.

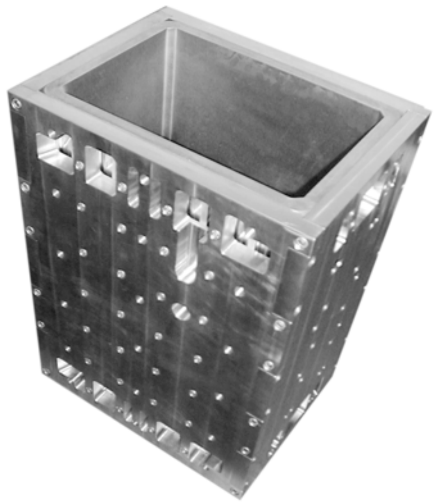


Fig. 2 – Integrated mould – “One piece Mould”

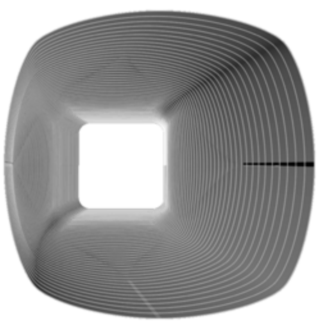


Fig. 3 – ALL CONVEX shape

The ALL CONVEX-“Four round” mould (Fig.3), is based on the FEM calculation method and provides uniform surface temperature of the solidified shell at its entire circumference. It means that the casting powder can melt with same conditions at faces and corners. The result is a crack free product with favorable large radius corners for the rolling process.

2 STEEL SHELL FORMATION - OBSERVATION

When the steel solidifies in a mould, there is an initial area of perfect contact, where the strand shell is still thin with temperature of 1400°C and low tensile strength. Below this area, air gaps are forming, especially near the corners.(Fig 4) The air gaps reduce the local heat transfer and lead to a slower shell growth in the affected areas. These weak areas increase the risk of breakout. These weak points that normally occur in square or rectangular sections, can led to bulging and rhombic deformation eventually producing "hinge cracks". The risk of thermal induced tension is imminent. Moreover the solidified material is at that point within the zero-ductility zone. The already grown shell acts as a great barrier for the heat transfer and further shell growth rate is substantially reduced.

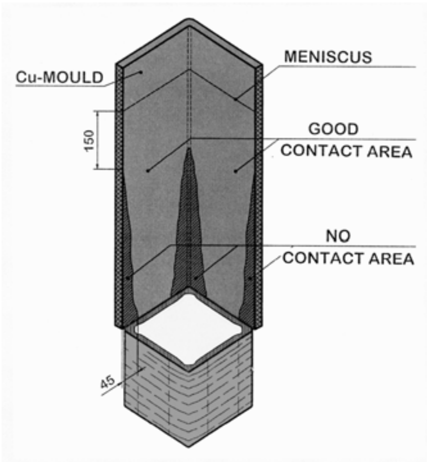


Fig. 4 – Contact in mould

Billets, Blooms at mould exit as cast with over cooled and dark color at corners. i.e. heat flux occurred in two directions (x,y) at the same time. Fig. 4 shows the early loss of contact at all four corners. The faces keep in contact with the copper mould, heat flux only in one direction.(x) These faces of semi-products (billets, blooms) are defect free but corners, in particular: off-corner parts can show subsurface cracks.

.

Round sections typically suffer from longitudinal face depressions and/ or longitudal cracking.
The absence of a "guiding face" such as existent with square or rectangular shapes gives the possibility to contract totally uncontrollable and contact with the copper cooling face is therefore nonuniform i.e. incidental. Contrary to the logical theory, shell growth is very irregular and tension in the steel shell is unavoidable. (Fig.5)

Fig. 5 – shell of round section

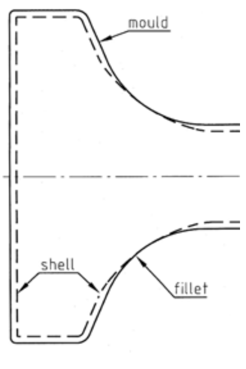


Fig. 6 – Mould/ Shell

Fig. 7 – Shell formation

Beam blanks moulds (BBL)
The initially formed shell can shrink freely from all mould faces except in the four fillet parts where it "clamps" onto the faces. (Fig.6) The result may be longitudinal cracks in the web area.
Another phenomena (Fig.7) is a "wash-out" where the open steel stream was not centered, too close to the fillet and prevented shell growth.

3 CONVEX TECHNOLOGY

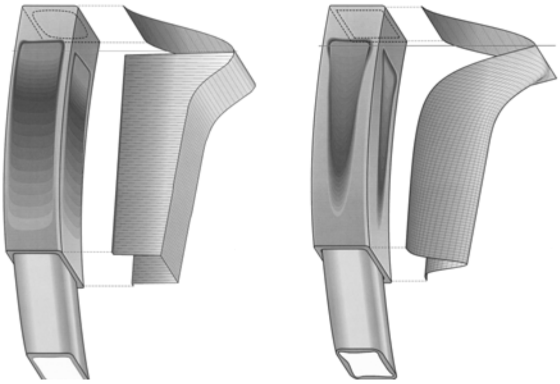
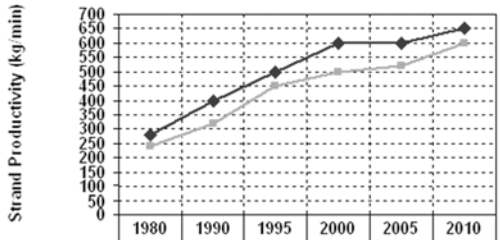


Fig. 8 – Heat extraction



	1980	1990	1995	2000	2005	2010
Commercial grades	280	400	500	600	600	650
Special bar grades	240	320	450	500	520	600

Fig. 9 – Productivity increase

CONVEX moulds: Introduced to the steel plants twelve years ago, shows some remarkable performance: Installed at 400 Strands or 70 CC-machines these moulds cast some 50 – 60 Mio tons p.a! This success based on the versatile use and practical application of this unique mould geometry.

For the first time it combines a (known) vertical taper with a horizontal taper at the first portion of the mould cavity resulting in an increase of contact area strand/mould (Fig. 8) where the heatflux area of the two different mould tubes is shown.

Therefore productivity increase (Fig.9) has been substantial in the last 25 years

Convex moulds with its unique shape (Fig.10), allow to cast a large variety of steel grades with 0.02 % C (soft wire) up to 1.00 % C (bearing steel: 100 Cr 6) with the very same mould geometry. Understandably, this universal use is greatly appreciated by the production staff.

Example of world record plant: ICDAS Turkey, BIGA Steel plant: EAF 185 t, 30 taps daily, 6 strands CCM CONVEX-CONCAST, Section 180 sq, 650 kg/min or 38 t/h, casting speed 3 m/min reaches 5’000 – 5’500 tons/day i.e. actually cast 1.6 Mio t of good billets in the year 2006.

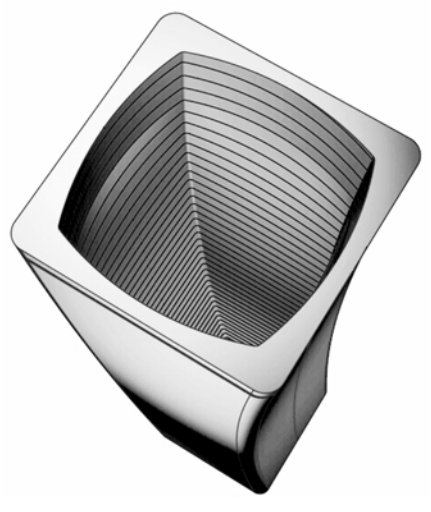


Fig. 10 – Convex shape

Production distribution of an automotive supplier in Germany

Commercial grades	7 %
Drawing/ welding wire	13 %
PC and wire rope	12 %
Tire Cord	12 %
Alloyed SBQ	20 %
Unalloyed SBQ	9 %
Cold heading	9 %
Free cutting	18 %

3.1 Convex for Rounds

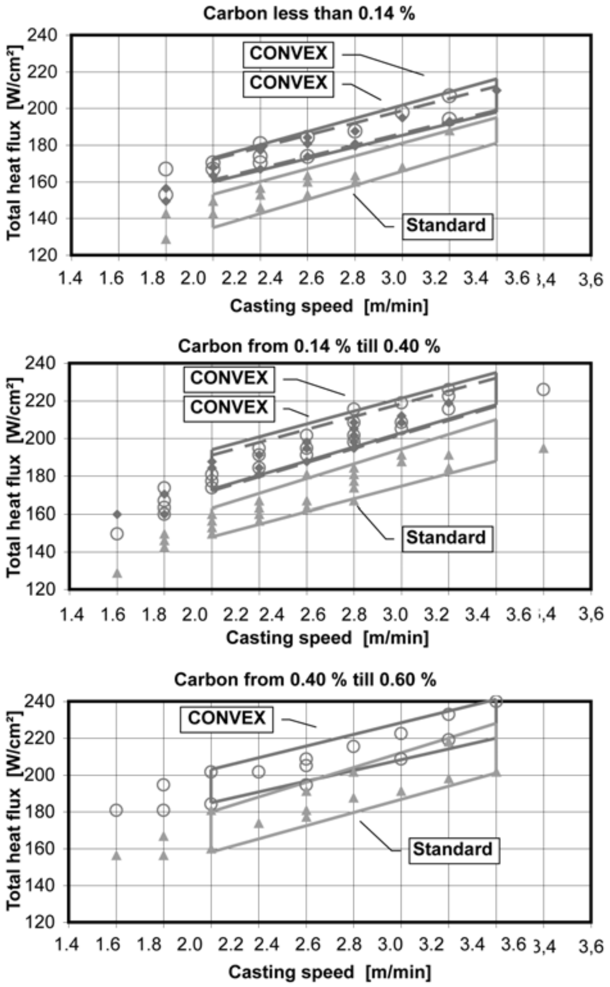


Fig. 11 – Heat flux vs. casting speed for different Carbon content and different mould type[1]

In fact round sections have a big advantage over square ones, since they have no corners. Therefore there are also no corner-related defects. With the CONVEX round mould we have not only 15% more heat flux than normal moulds (Fig.11), but also:

- Rounds have a higher heat transfer than rectangular sections, which means there is still an unused potential in terms of casting speed.
- The heat transfer is uniform over the length of the mould.
- This heat flow uniformity along the perimeter is achieved due to an improved mould-to-billet contact and due to a guidance of the strand inside the mould which prevents any “rotation” or “twist” of the strand as experienced on conventional moulds for round sections.

References for casting of rounds with CONVEX moulds:
Dia 150 mm up to dia. 525 mm !
.

3.2 CONVEX for Beam Blank sections (BBL)

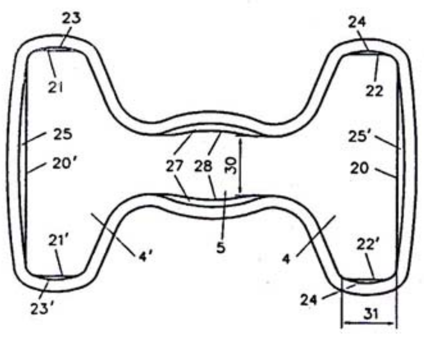


Fig. 12 – Beam Blank shape with CONVEX[2]

The already described deficiency of the “fillet” part may be eliminated by the introduction of a Convex shape. (Fig. 12) The intention is to “push” from the centre by the balloon shaped faces and thereby taking the force which acts at these parts. Also the web structure can profit from an accelerated solidification due to better contact of strand to mould.

4 INTEGRATED MOULD

CONCAST has applied intensive research and development concerning primary solidification and has come up with a sort of a solidification “reactor” all in one.
This composite and integrated mould body contains an “endless” mould lining since the copper liner for rapid heat dissipation is very thin and directly connected to the structural body with the necessary mechanical strength. (Fig.13)
The result is a patented mould with a compact design and full of all desired features.

Fig. 13 – The CONCAST Integrated Mould

Highlights of the Concast Integrated Mould

- Uniform temperature-field along the perimeter of a mould-section including the corner area
- Higher heat transfer with thin copper layer
- Precision machined mould faces to achieve close to perfect mould geometry
- Greater mechanical stability against thermal deformation
- Improved penetration of electro-magnetic field generated by stirrers (MEMS)
- Renewable copper part
- Integrated mould instrumentation
- Simplified maintenance
- Higher productivity
- Lower running cost

The classical construction of a copper tube with a concentric cooling gap does not permit to adopt different cooling intensity to different areas of the billet (corners, faces, top or bottom). With the new system cooling channels are integrated in the mould construction. This design counteracts the normally inherent two-dimensional heat-flux in the corner areas (see Fig 4). The copper part is thinner thanks to the design, which allows direct contact with the supporting steel body. Therefore the copper wall temperature is lower, which results in significantly reduced heat load and longer service life.
The mould can be fitted with temperature, friction, mould powder thickness, and other sensors to constitute and “instrumented mould” for detailed real-time process control (prediction of quality, solidification modeling, diagnostic purposes, break-out prevention etc).
The copper part of the mould is no longer conceived as a wear part but is instead in permanent use. The refurbishing service includes copper deposition followed by precision machining and chromium-, Nickel- or composite plating to recover the inner geometry. Owing to this concept, changes of inner geometry (i.e. for plant trials) are possible in shortest time.
The inner part of the mould (copper) is machined by a 4 axis CNC machine tool. With this digital machining process one is not anymore dependent on a costly section and taper related tooling for both: first geometry and any desired taper adjustments.

5 ALL-CONVEX MOULD SHAPE

The evolution of the CONVEX concept proceeds in the direction to ensure production of SBQ steel-grades with best quality, at the highest productivity, at industrial scale and repeatability. The emphasis here is first of all on quality.
The computer designed “ALL-CONVEX” mould produces a much more uniform temperature distribution in the billet shell compared to the present mould designs.
This is achieved by a new geometry of the corner areas, which is achieved by a so-called super-circle profile instead of the standard corner radius. (Fig.14)

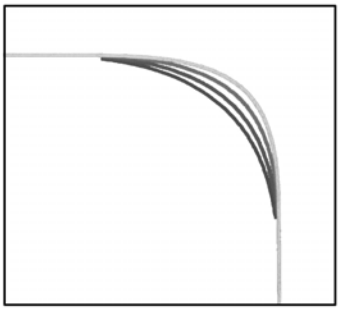


Fig. 14 – Super-Circle shape

Fig. 15 – “Four round Mould tube”

This completely new geometry for a mould-cavity was developed for the purpose of producing high quality steels (SBQ steel-grades) in square, rectangular section respectively at the highest possible productivity rate (high casting speed).
An eye-catcher is definitely the generous and specially dimensioned corner rounding. (Fig.15) Contrary to any other previously applied corner rounding this one has neither a circular shape nor is it constant along the whole mould length; it is of a so-called super-elliptic geometry, which varies over the mould length and appears as a rather large “radius”.
This perfect strand-mould contact provides uniform shell-growth especially in the corners and the areas near them. Weak spots are eliminated temperature distribution and homogeneity of the macro-structure is promoted.
Larger super-elliptic corner radii of the ALL-CONVEX mould permit a more uniform solidification of the strand shell, overcoming the problems related to the solidification of square billets. The new technology for mould cavity machining available at CONCAST allows free-form possibilities.
We have been complimented by the rolling mill department for these large rounded corners for the simple fact that the rolls last much longer compared to rolling of semis with small radius corners.
The FEM analysis of solidification demonstrates that with a traditional mould shape the area of an initially cast rounded corner shrinks and forms a smaller radius, which consequently leads to the formation of the air gap. The change of shape, (Fig 14) along the CONVEX funnel to the exit of the mould reduces the amount of the air gap and provides a “near to perfect” mould- strand contact.
Specific characteristics:

- CONVEX geometry as known.
- Super-elliptic shape of the corner with large radius. (typically > 10 % of the billet nominal side length).
- A certain determined relation between the taper measured between face centres and between corners.

6 MOULD POWDER THICKNESS CONTROL

A new sensor combination was developed to determine slag thickness. One of the sensors must be of radioactive type (like Berthold) which is sensitive to powder thickness and density. The other one can be of inductive type which is not sensitive to the powder thickness and supplies a signal strictly related to the meniscus level.
The control concept (Fig.16) consists of the comparison of the signals related to the steel level given by the radioactive and the new system. To be comparable both signal are conditioned and transformed in mm. The difference between the two values is a function of the powder thickness and powder density. A preset powder thickness is used to actuate the powder supply and refills the mould cavity to the setpoint.
A suitable algorithm correlates all data for the PLC in order to control the powder feeder.

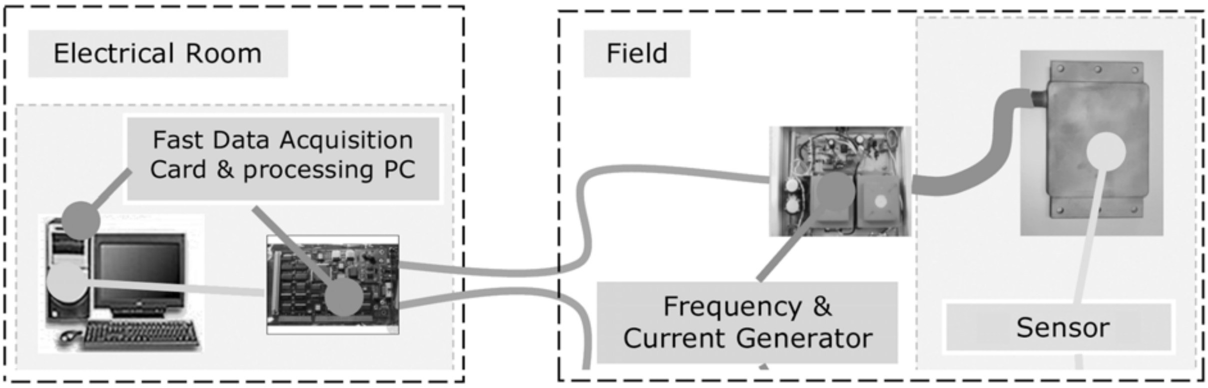


Fig. 16 –Schematic of Mould powder control system

7 MOULD THERMAL CONDITION MAPPING

The 20 thermocouples (Fig.17) strategically placed in a pattern across the mould are used to show the operator the thermal condition of the mould copper. Thermocouples can determine B/O danger and provide the possibility to slow down casting speed and save the strand.

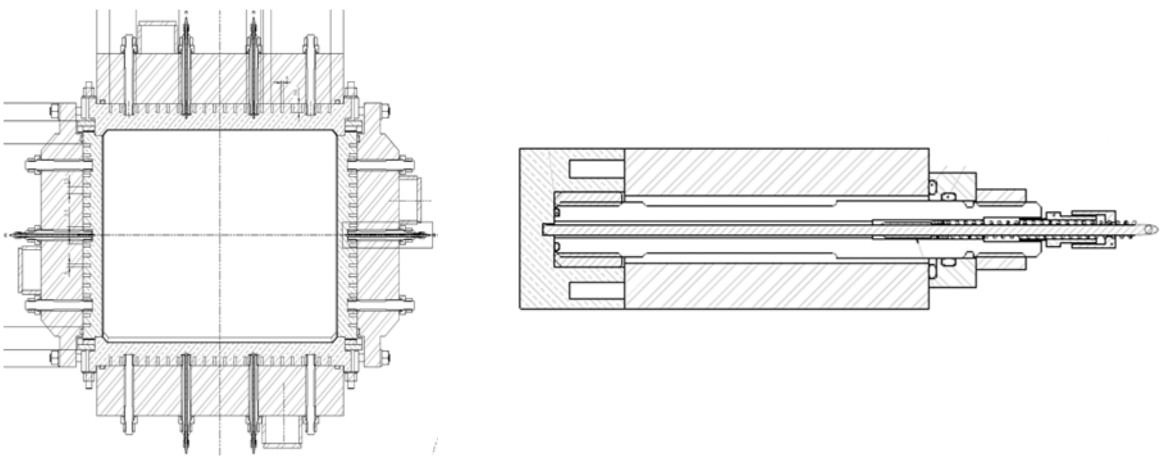


Fig. 17 – Thermocouple installation[3]

8 OPTIMIZATION, REFURBISHING

8.1 Optimization

Usually the first step to optimize existing mould systems is by analyzing the casting operation problems and hence to assess improvement possibilities. When performance problems (B/O, defects in product, certain improper behavior for particular steel grades) are clearly defined an action schedule can be established. In many instants a change of taper/ shape will be suggested and should soonest possible be introduced.

8.2 Refurbishing

We have developed, patented and introduced this technology in our CONMOULD[4] facility. It reshapes moulds with a machine tool, CNC, 4 axis control, to any desired taper, geometry and shape. This manufacturing procedure (Fig.18) does not require costly tooling as needed for the traditional making of a different geometry. The new method is mostly applied at for a small number of tubes to first make trial casts and if necessary modify again until the best shape is found. Thereafter new and used moulds can be manufactured with the best performing shape for this particular steel plant.
A similar or complementary method for mould refurbishing is available at the ACCUMOLD[5] works in Huron Park, ON, Canada where all mould copper types (tubes and plates) and in particular moulds for beam blanks are already refurbished since 30 years with the well proven explosion forming method.

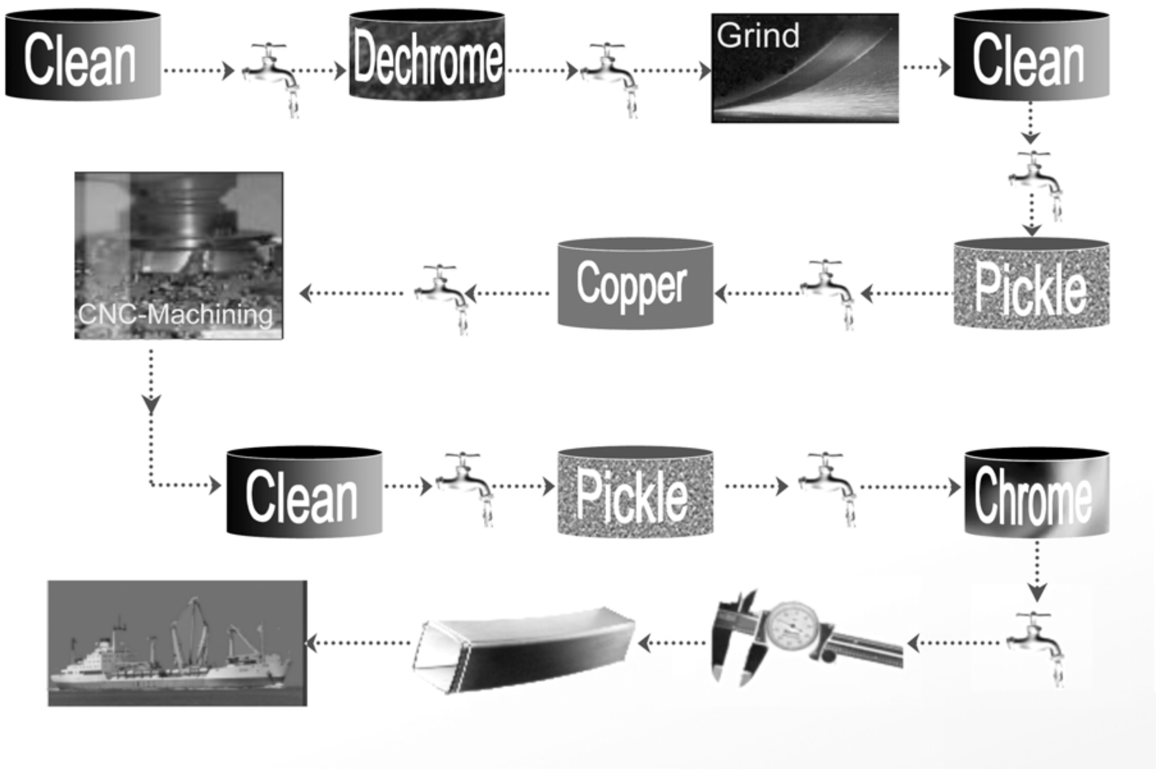


Fig. 18 – Mould refurbishing process at Conmould workshop[4]

9 CONCLUSION

Mould systems for the continuous casting of long products (billets, blooms and beam blanks) have been described and pros and contras were discussed.
The particular mould design characteristics and its influence on the product quality (surface and internal quality) have been mentioned. Furthermore, newly developed mould shapes, mould systems and auxiliary items such as sensors for mould conditions are introduced. Recent development of alternative refurbishing (recycling) processes for mould copper allow for multiple reuse of mould tubes i.e. economical use of energy and improvement of environmental condition.

BIBLIOGRAPHY

1 Kluge J., Krull J., Kawa F., Stilli A., ICS 2001, International Conference Science and Technology, Swansea, UK, Convex for Rounds at HKM, Duisburg, Germany
2 Patent application Convex for Round casting by Concast AG, 2001
3 Concast plate mould for Jianjng Xing Cheng, Bloom section: 490x370mm
4 Conmould Switzerland is a Division of Concast AG, Zurich, Switzerland
5 Accumold is a Division of Concast AG, Zurich, Switzerland