

RAPID THICK STRIP CASTING - CONTINUOUS CASTING WITH MOVING MOULDS

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Moving mould for the future... Due to mechanical reasons, conventional lubricated oscillating moulds limit the casting velocity. If the friction in the mould grows too strongly, the thin strand shell can tear, in a worst case followed by a breakout. However these constraints are not applicable to moving moulds.

RTSC (Rapid Thick Strip Casting) is an innovative concept for the production of hot strip. The particular innovation of the mechanism consists in replacing the stationary oscillating mould with a mould performing a caterpillar motion. A new mould design is able to eliminate former failures and problems. The key factor in the new design consists of a parallelogram-shaped strand cross section. Straight below the caterpillar-mould, a shaping machine is placed with a secondary cooling zone. This is where the conventional rectangular shape is formed by inline-shaping with liquid core.

RTSC is a new technology offering the option of high productivity. Studies indicate that a casting speed in a range of 20 to 30 m/min at a final as-cast cross section of e.g. 20 mm x 1600 mm is possible. The strand width is easily adjustable and the final product only requires low metal forming degrees in comparison to conventional slabs.

KEYWORDS: RTSC technology, moving mould, oscillating mould, caterpillar motion, parallelogram-shaped cross section, temperature field, continuous casting, near-net-shape casting

INTRODUCTION

The productivity of a CC is limited by cross section and casting speed. Since the thickness is chosen in terms of rolling degree in near-net-shape casting (NNSC), the casting speed is the parameter that allows higher output. Nevertheless, at continuous casting due to mechanical reasons, the conventional oscillating moulds limit the casting velocity and consequently the productivity by use of lubricating fluxes. If the casting velocity increases, the thermal and mechanical loads of the mould rise as well. This results in wear on the mould surface and the shell thickness of the strand decreases as well. If the mechanical loads grow too strongly and on the other side the shell thickness is reduced, the strand shell will tear, in worst case followed by a breakout [1].

Therefore, engineering companies and developers of the latest caster generations have searched for a new way to avoid lubrication problems in order to reach a higher productivity. It was publicly accepted, that in future a new technical solution perhaps without stationary moulds is needed. If the stationary mould is replaced by a moving mould, there is only marginal friction between mould and cast material. The mechanical loads on the strand shell decreases and the casting velocity can be risen. Thus, new casting systems were created as twin roll [2] with up to 90 m/min speed or belt casting processes [3]. The RTSC (Rapid Thin Strip Casting) technology represents such a development as well. Hot strip thickness after direct inline-rolling will be between 1 mm and 15 mm at forming degrees of more than 3.

RTSC (RAPID THIN STRIP CASTING) TECHNOLOGY

RTSC is a new concept of casting technology for flat products. The system was invented before 2000 and it was internationally introduced on the Korean-German New Steel Technology Symposium in 2005 [4]. Since then, the concept has been improved and several detail developments have been performed. In 2007, the RWTH Aachen did a theoretical study [5] on this system. The conclusions of this study were implemented to improve the concept.

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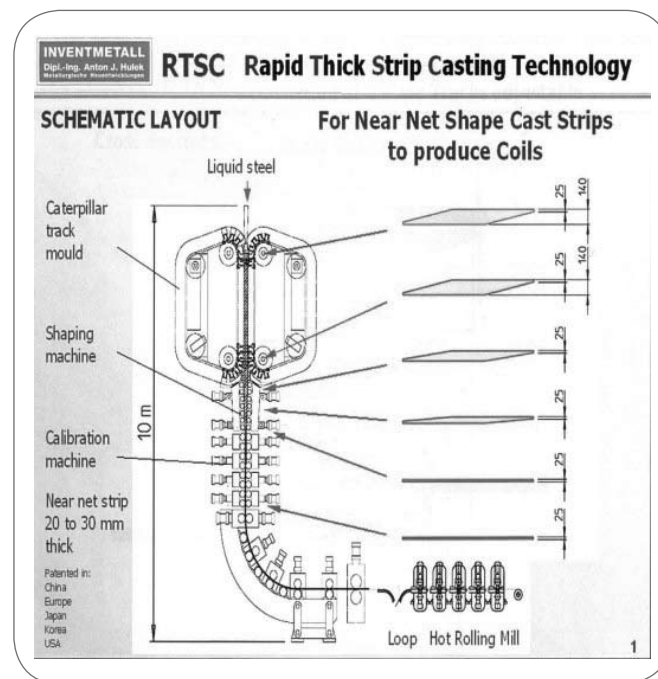


Fig. 1

Schematic layout of the RTSC technology and development of cross section of the as-cast strand [4].
Layout schematico della tecnologia RTSC e sviluppo della sezione trasversale della linea di colata as-cast.

The RTSC represents an innovation for continuous casting with the key factor in the mould design. The new mould consists of two moving caterpillar modules with a parallelogram-shaped cross section. Thus, the strand in the mould has an unconventional cross section instead of the conventional rectangular shape. The single modules of the caterpillar move on rails. They close with each other at the beginning of the casting tube and then move downstream with the strand. They are subsequently opened, retracted from the casting material and led back to the starting point. The single mould modules are cooled with sprayed water. Straight below the caterpillar-mould, a shaping machine is placed with the secondary cooling zone. Here, the conventional rectangular shape is formed by inline-shaping with a liquid core. Subsequently, the solidification ends in a so-called calibrating machine. The primary task of the calibrating machine is to guide and support the as-cast strip. Finally, the strand is guided to a bending machine and to the hot rolling stands. The rectangular strip has directly approximately 20 mm thickness. The schematic layout of the RTSC plant with the development of the cross section of the strand can be seen in Fig. 1.

This new cast technology promises several advantages in the range of strip casting compared to conventional technology. Studies show that RTSC enables a very high output with a casting speed up to 30 m/min as illustrated in Fig. 2, where the output is plotted over casting speed with different cross section's thickness as parameter. Furthermore, the lubrication problem is solved and there only low metal forming degrees are needed in comparison to conventional slabs. The final strip thickness is easily adjustable in a range of 20 to 30 mm; also the width is variable. The production range of the process can fill the gap, which arises in the use

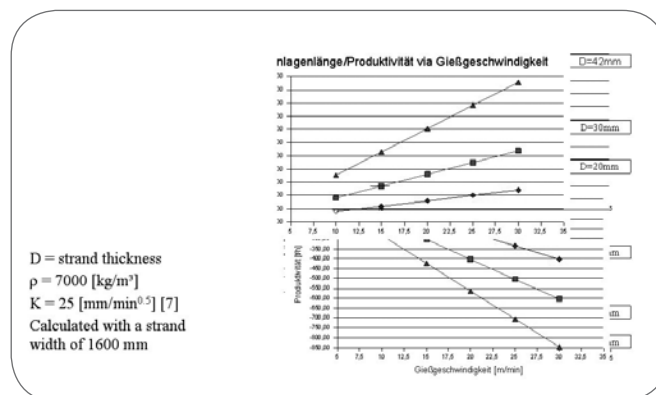


Fig. 2

Productivity and machine length is plotted vs. casting speed with different cross section's thickness as parameter (theoretical).

Produttività e lunghezza della macchina in relazione alla velocità di colata con diversi spessori della sezione trasversale come parametro (teorico).

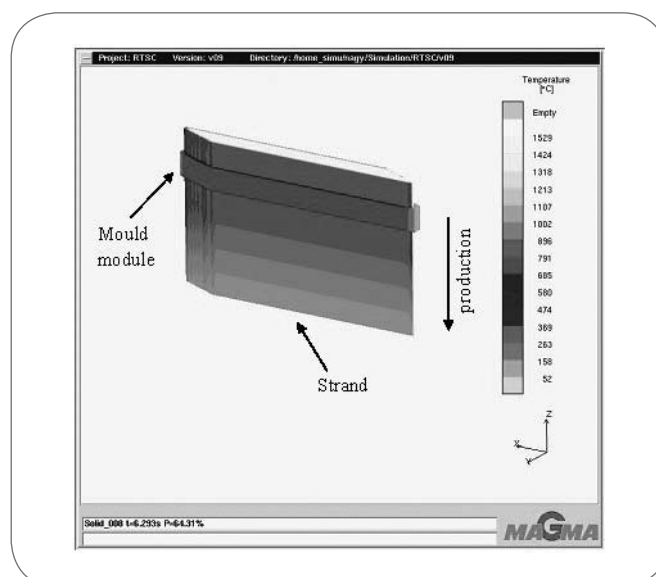


Fig. 3

The casting material with a single mould module, calculated with a Magma® Software [7].

Il materiale di colata con un singolo modulo di lingottiera, calcolato con Software Magma®.

of twin roll or belt casting processes and e.g. CSP technology [6].

THE CATERPILLAR-MOULD

The new caterpillar-mould is the core of the construction. The thermomechanical behaviour of the mould (deformation and stresses) and its durability are the essential factors for the economic efficiency and the serviceability. The mould consists of two moving caterpillar tracks with a parallelogram-shaped cross section. Each half of the mould is covering a narrow and wide side of the strand. Thus, both plate tracks fully enclose the whole strand (see Fig. 3). It is

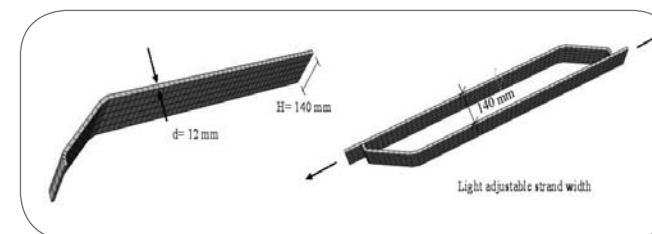


Fig. 4

A part of a parallelogram-shaped mould module (left) and the light adjustable strand width (right).

Parte di un modulo di lingottiera a forma di parallelogramma (sinistra) e la leggera adattabile larghezza della linea di colata (destra).

a special feature of the new design that the narrow side has exactly the thickness of the finished cast product, for example 25 mm. The height of the parallelogram, which represents the inner clearance of the mould, is approximately 140 mm to allow the use of a SEN. The free surface of liquid is covered by a lid and argon protection gas. The two halves of the mould's modules can be slid on each other and so the strip width can easily be adjusted (see Fig. 4).

The inside of the mould consists of a 30 mm thick copper alloyed plate in which channels are milled to a depth of 18 mm for cooling. Through this treatment the panels are sufficiently firm and have a large thermal gradient. These copper plates are fixed to a supporting structure. It ensures that the required pressure between the two halves of the mould can be applied and the mould stays tight all along. The back of the track is provided with spray water cooling, which is crucial for the whole mechanism. For prevention of leakages a special profile was developed for the edges of the modules. It assures the perfect intersection of copper plates to each other and versus the structure material. The mould length depends on the casting velocity and it is evaluated according to:

$$L_{\text{mould}} = s^2 \cdot v_G / K^2 \quad (\text{eq. 1.})$$

with,

s – shell thickness at the end of the mould

v_G – casting velocity

K – solidification coefficient (calculated with 25 mm/min^{0.5} [8])

The casting speed is variable between 10 and 30 m/min and the length of the mould results correspondingly between 1.1 and 3.5 m. The outputs are accordingly different.

The speed of the mould is exactly the same as the casting speed. Thus, there is no relative movement between strip and mould and therefore no friction. This results in reduced mechanical demands for the strand shell. The analysis of the mould is separated in a thermal and a geometrical verification.

THERMOTECNICAL ANALYSIS OF THE MOVING MOULD

The RTSC moving mould allows a very fast casting process. For the efficiency, the thermal demands are more authori-

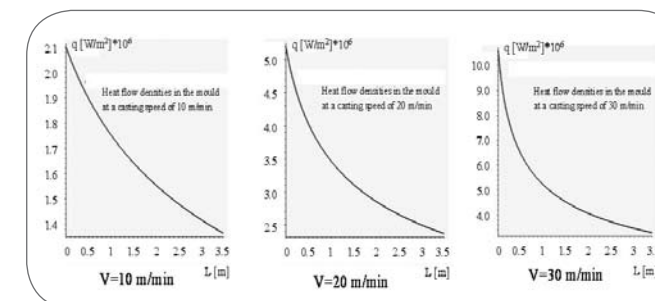


Fig. 5

Local heat fluxes vs. mould length for 10 m/min, 20 m/min and 30 m/min casting speed, with a mould length of 3.5 m.

Flussi locali di calore in relazione a lunghezza della lingottiera per velocità di colata di 10 m/min, 20 m/min e 30 m/min, con una lunghezza di lingottiera di 3,5 m.

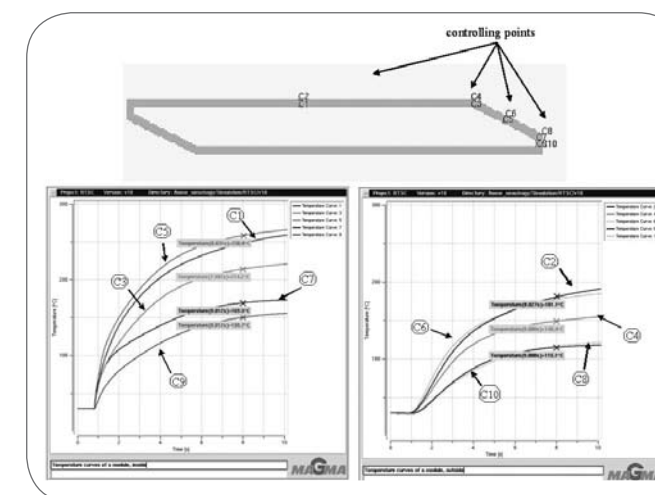


Fig. 6

Temperature distribution in the controlling points, inside (left) and outside (right) of the copper plates. (calculated with a Magma® Software).

Distribuzione della temperatura nei punti di controllo, all'interno (sinistra) e all'esterno (destra) della piastre di rame. (calcolate con un Software Magma®).

tative than the mechanical demands. There is a similar situation as with other NNSC processes. Because of the design, the thermal calculation was done on the basis of one dimensional heat transport. Here, a large thermal gradient is reached. The heat transports in the vertical and in the latitudinal direction can be neglected. The time dependent heat fluxes were calculated according to Wosch [9]. As verification the integral average value of the heat fluxes was compared with the average heat flux from the overall heat balance calculation. Subsequently, the thermal process was patterned with numerical methods for more detailed information in the mould. The authoritative heat flux results from the maximum speed by 30 m/min and from the corresponding mould length of 3.5 m. At this velocity, the average heat flux is $q_{\text{aver}} = 4.8 \text{ MW/m}^2$. The appropriate local values amount to $q_{\text{max}} = 10.8 \text{ MW/m}^2$ at the meniscus and $q_{\text{min}} = 3.3 \text{ MW/m}^2$ at the mould's end (distribution see Fig. 5).

A single module at a velocity of 30 m/min is just 7 s in con-

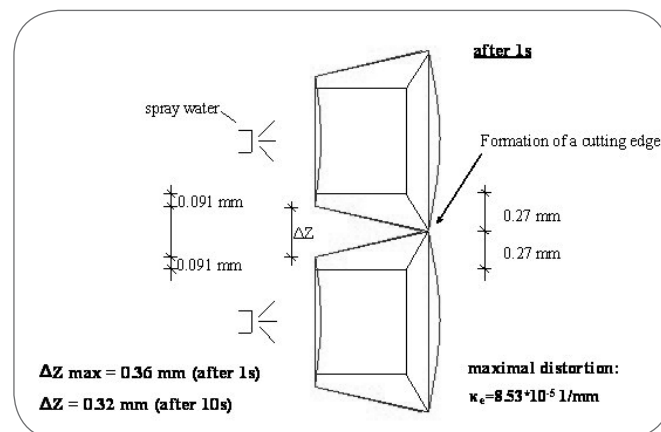


Fig. 7

Original shape (black) and the deformation (red) of the mould modules as well as formation of a cutting edge.

Forma originale (nero) e deformazione (rosso) dei moduli della lingottiera e formazione di una linea di taglio.

tact with the hot steel. Sub-sequently, the module reaches the maximal temperature of 260°C according to calculations. The computation of the temperature distribution for the copper plate can be seen in Fig. 6. These temperatures are no problem for copper materials as Elbrodur® [10] used regularly in CC technology.

After the warm-up phase there is a 15 s cool down phase. During this time, the cooling can be set so that the plates have a temperature at the starting point according to the metallurgical requirements.

This cyclic temperature change and stress conditions cause fatigue on the Cu material. In this respect the temperature amplitude as well as the temperature level have to be taken into account. A coating e.g. with nickel or special surface roughness will extend lifetime and periods of maintenance.

GEOMETRICAL ANALYSIS OF THE MOVING MOULD

Since the mould consists of lots of moving parts, the geometry of the single elements is a special aspect. Several loads are applied on the modules, thermal and mechanical. Stresses and strains, caused by thermal gradients in the plates by heating and cooling phases, can cause deflections. Those deflections have to be limited in order to maintain the required dimensional accuracy. The several elements in the downward movement automatically close the gap between the modules through their dead weight. Through the dimensional accuracy of the modules as well as the special labyrinth seal assures that no water vapour gets to the strand shell.

Taking the worst case into consideration, the maximal thermal gradient in the module was calculated and the appropriate deformation was checked. In Fig. 7 the corresponding deformation figure is illustrated. Due to deformation, a cutting edge emerges between the mould elements with a maximal clearance on the water side of $\Delta z = 0.36$ mm.

Besides temperature and dead weight, ferrostatic pressure imposes on the plate materials. The buoyancy force of the

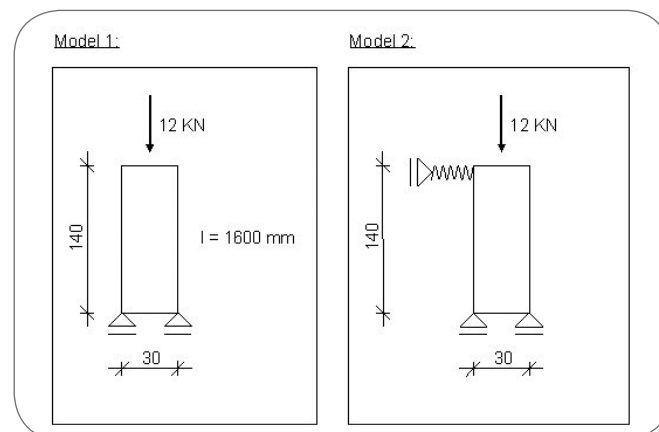


Fig. 8

The mechanical model of the lowest mould module.

Modello meccanico del modulo di lingottiera inferiore.

melt in the upper mould area is negligible.

A single mould module has a dimension of 30x140x1600 mm and weighs 50 kg. With a height of 140 mm and a mould length of 3.5 m, a total of 25 modules are necessary in the casting tube. The maximal vertical load at the last element is 0.25 MPa. In order to support the modules and as a drop control a chain wheel is implemented. This chain wheel for the control can be situated in a higher level.

The connection between copper plate and structure material plays an extraordinary role. It ensures that the plates have no rigid constraints. For this reason the fixing is carried out by a form-fit connection and not by a frictional connection. The plates are able to push each other in vertical direction due to their thermal expansion. There is equilibrium of forces from dead weight and residual stress in every module.

The strains in the horizontal lateral direction and in the vertical direction are not constrained. There, the modules are able to slide on each other and respectively to expand against the thin shell without any constrain. The mechanical model with the constraints can be seen in Fig. 8.

THE STRAND CROSS SECTION

The strand in the new mould has an unconventional parallelogram cross section instead of the conventional rectangular shape. This special shape with liquid core is formed in the shaping machine. Because of the special strand profile the solidification process is not complete homogeneous throughout the cross section. Due to the higher cooling effectivity at the corners, the heat withdrawal at the corner is higher, leading to a lower final temperature. In order to avoid supercooling, the heat withdrawal must be reduced with rounded corners, nickel plating, surface wrinkling or regulating of local spray water's intensity. The cooling must be regulable, so that, independently of the casting velocity the strand centre remains liquid in the shaping machine. Final solidification takes place in the calibrating machine. The length of this component defines the limit of the casting velocity, see temperature distribution in Fig. 9. The secondary role of the calibration machine is the support of the strand against the internal ferrostatic pressure.

The two most important parameters are the thickness of the strand shell and the length of the calibration machine. The limits of a RTSC plant are defined with these two parameters.

The regulation of the narrow face taper is realised through mechanically pivoting the two mould halves. The mechanics is continuously variable and it is convenient to adjust the shell thickness by more or less contact. The shrinkings of the strand according to

$$\Delta l = l_{\text{shell}} \cdot \alpha_0 \cdot \Delta T \quad (\text{eq.2})$$

with,

l_{shell} – strand shell length/thickness

α_0 – $1.6 \cdot 10^{-5}$ 1/K

ΔT – temperature difference

amount in the direction of thickness of $\Delta l \approx 60$ μm and in the width direction of $\Delta l \approx 4$ mm/side. In the direction of thickness the high ferrostatic pressure forces out the thin strand shell. In the width direction the mould is movable by request.

SUMMARY

RTSC (Rapid Thick Strip Casting) is a new concept of casting technology for flat products. It represents an innovation for continuous casting with the key factor in the mould design. By vertical arrangement and sophisticated chain module designs problems of tightness [11], like observed in e.g. Hazelett casters for steel, are overcome. The particular innovation of the mechanism consists in a mould performing a caterpillar motion with a special parallelogram-shaped cross section.

The casting speed of this technology is variable between 10

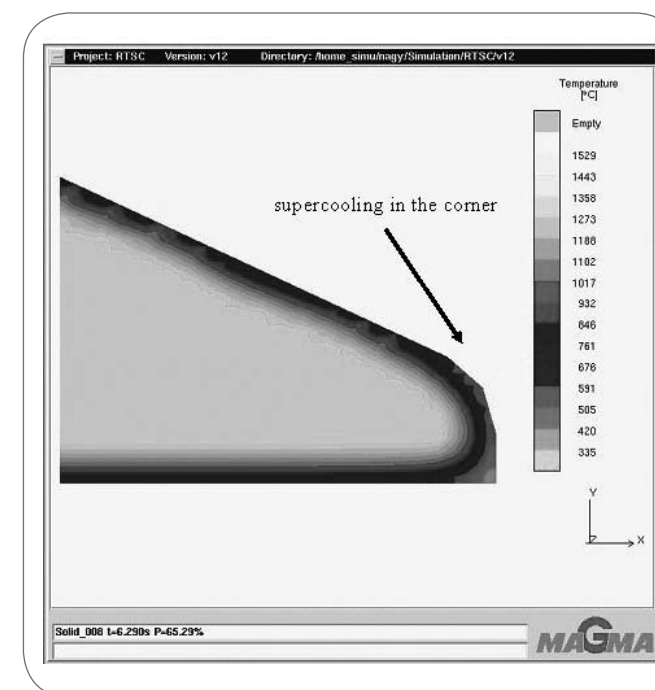


Fig. 9

Supercooling in the corner.
Sottoraffreddamento nell'angolo.

and 30 m/min and as a consequence the mould's length is between 1.1 and 3.5 m. The regulation of the narrow face taper is realised through mechanically pivoting of the two mould halves and the mould modules are cooled by sprayed water.

A single module at a velocity of 30 m/min is just 7 s in contact with the cast material. Subsequently, the module reaches the maximal temperatures, which are tolerable for conventional copper alloy plates.

Thermal gradient in the plates causes small deflections by elastic expansion; a special edge profile of the modules was designed.

It is well known that at extreme high production rates the melt delivery must be controlled carefully.

After the theoretical analysis of the RTSC technology, it can be said that this system seems to afford important advantages and some restrictions. On the one hand it offers a high productivity without lubrication problems, low effort in thickness reduction and a flexible cross section. On the other hand, it is necessary to get more reliable results and practical experiments must be carried out in the future.

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ABSTRACT

RAPID THICK STRIP CASTING - COLATA CONTINUA CON LINGOTTIERA IN MOVIMENTO

Parole chiave: acciaio, colata continua, tecnologie, processi

Lingottiere in movimento per il futuro ... Per cause meccaniche, gli stampi convenzionali oscillanti lubrificati limitano la velocità di colata. Se l'attrito nello stampo aumenta troppo, il sottile spessore del guscio si può deteriorare e, nel peggiore dei casi, portare alla completa rottura. Questi inconvenienti non sono invece riscontrabili nel caso di lingottiere in movimento. Il RTSC (Rapid Thick Strip Casting) è un concetto innovativo nella produzione di nastri a caldo. La particolare innovazione del meccanismo consiste nel sostituire la lingottiera oscillante con una lingottiera in mo-

vimento secondo uno schema tipico che si potrebbe definire a caterpillar (millepiedi). La nuova concezione di lingottiera è in grado di eliminare i problemi esistenti. Il punto di forza della nuova soluzione è costituito dalla sezione a forma di parallelogramma dello strand. Al di sotto della lingottiera-caterpillar, è posta una macchina di formatura dotata di una zona di raffreddamento secondario. Questo è il punto in cui la geometria rettangolare convenzionale viene realizzata mediante formatura in linea con nucleo liquido.

La nuova tecnologia RTSC offre la possibilità di avere una elevata produttività. Gli studi indicano che è possibile ottenere una velocità di colata fra i 20 e i 30 m / min con una sezione finale di prodotto as-cast, ad esempio, di 20 mm x 1600 mm. La larghezza della sezione è facilmente regolabile e il prodotto finale richiede solo modesti interventi di formatura del metallo rispetto alle bramme convenzionali.