cunova

WAVE® Mould Tube
INNOVATION & TECHNOLOGY

MELTING & CASTING
TECHNOLOGIES

CONTENT

cunova offers a unique combination of know-how and experience in all key technologies for the production of high-performance moulds for casting ferrous alloys.

The Company

cunova‘s corporate goal is to develop and manufacture products that meet customer demands, finding solutions for their specific applications, and providing services as a long-term partner. cunova’s strategy for accomplishing this goal is based on a highly skilled and experienced workforce. cunova has the ability to invent and develop new materials and innovative production processes via ongoing advancement and training of our employees and the continual improvement of its organisational structures.

cunova

AMT® ADVANCED MOULD TECHNOLOGY

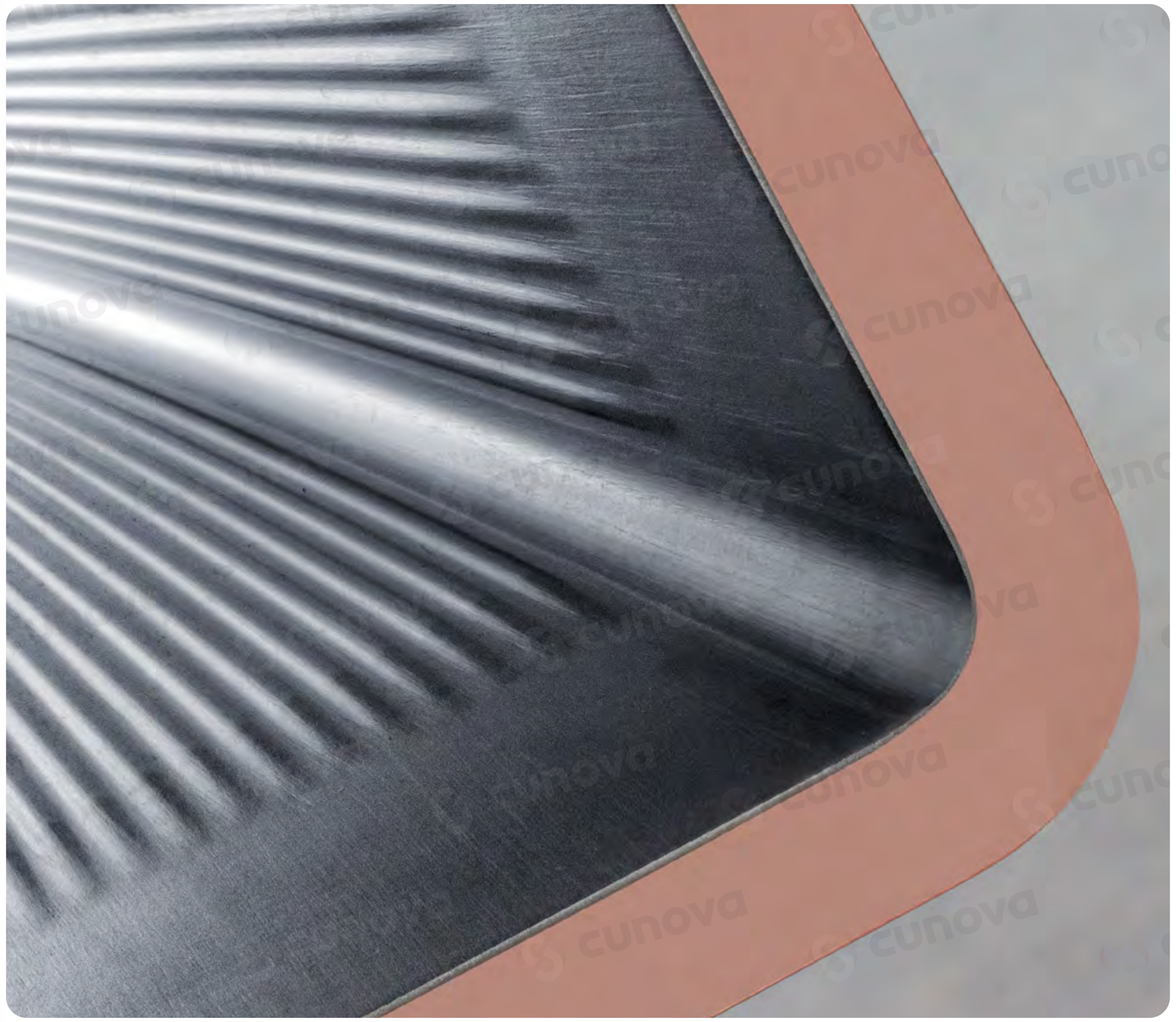
WAVE® Mould Tube

Challenge
- Reduce billet rhomboidity and improve billet shape

Solution
- WAVE Mould having special internal geometry (cunova patent) for a better guidance of the steel strand through the mould.

Application
- Billet and bloom moulds in all copper alloys
- Compatible with existing equipment

Advantages
- Reduced billet rhomboidity
- Improved billet shape
- Better internal billet quality
- More uniform shell growth
- Less „snaking“ of the billet
- Longer mould life



AMT® ADVANCED MOULD TECHNOLOGY

Function of the WAVE® Mould

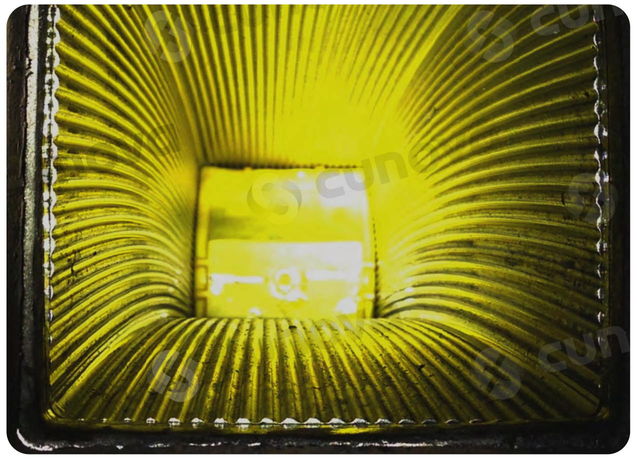
In the continuous casting of steel, the shape of the product is often a source of quality concerns. A common problem in billet casting is forming a non-square or rhomboid shape that can cause internal quality problems such as diagonal and off-cut corner hinge cracks.

Another common billet shape issue is bulging of the section, typically caused by insufficient mould taper and/or strand support for a given section size and casting speed.

The key feature of the WAVE Mould design is to super-impose a series of WAVE patterns onto the hot face side of the mould, causing a mirror image of this pattern to be formed on the billet surface as it begins to solidify.

These two surfaces will interlock and guide the shell through the length of the mould, while restraining any movement from side-to-side.

The mould and shell are thus “coupled” together to such a degree that a more equal heat extraction and hence uniform shell formation occurs during its critical time in the mould.



Advantages

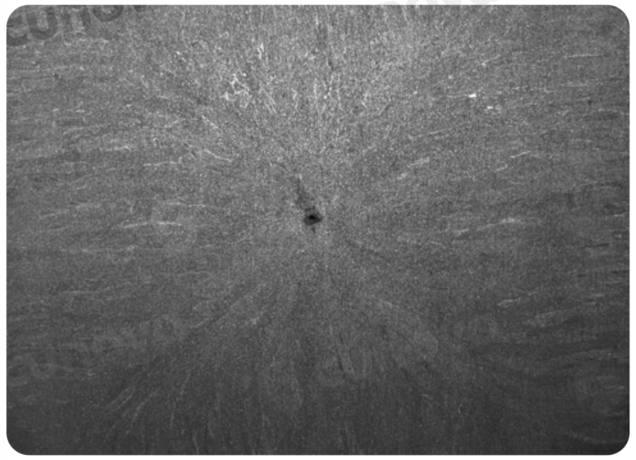
- Reduced billet rhomboidity
- Improved billet shape
- Better internal billet quality
- More uniform shell growth
- Less “snaking” of the billet
- Longer mould life

Results

Billets have less rhomboidity and fewer sub-surface cracks. A reduction in the Mn/S ratio (typically 30:1 for shape control) is possible while still maintaining good billed shape.
Reduction in the amount of scale formed during the casting operation as shown on the 2nd photo (2nd strand).
Currently, there are 80 steel plants using cunova WAVE Moulds with more than 115 section sizes around the world.

Extract of achieved casting results

USA:
160sq: Rhomboidity improved by 60 %
130sq: triple lifetime = 2,400 heats
South-Korea:
150sq: no more V-notches, double lifetime = 1,350 heats



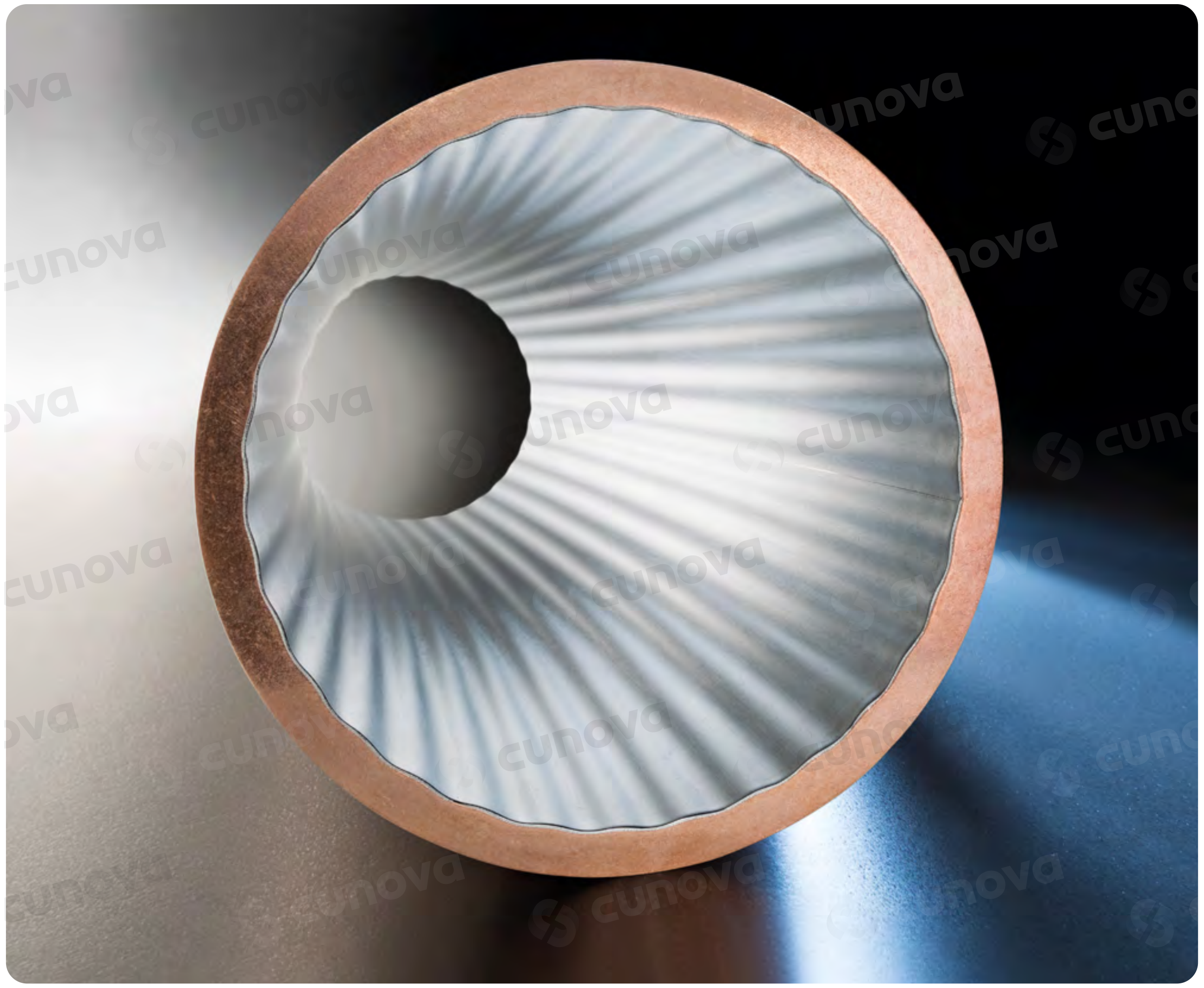
Round WAVE® Mould Tube

Challenge
- Improve billet shape and internal quality

Solution
- WAVE Mould having special internal geometry (cunova patent) for a better guidance of the steel strand through the mould.

Application
- Round moulds in all copper alloys
- All types of hot face coatings
- Compatible with existing equipment
- For oil and powder casting

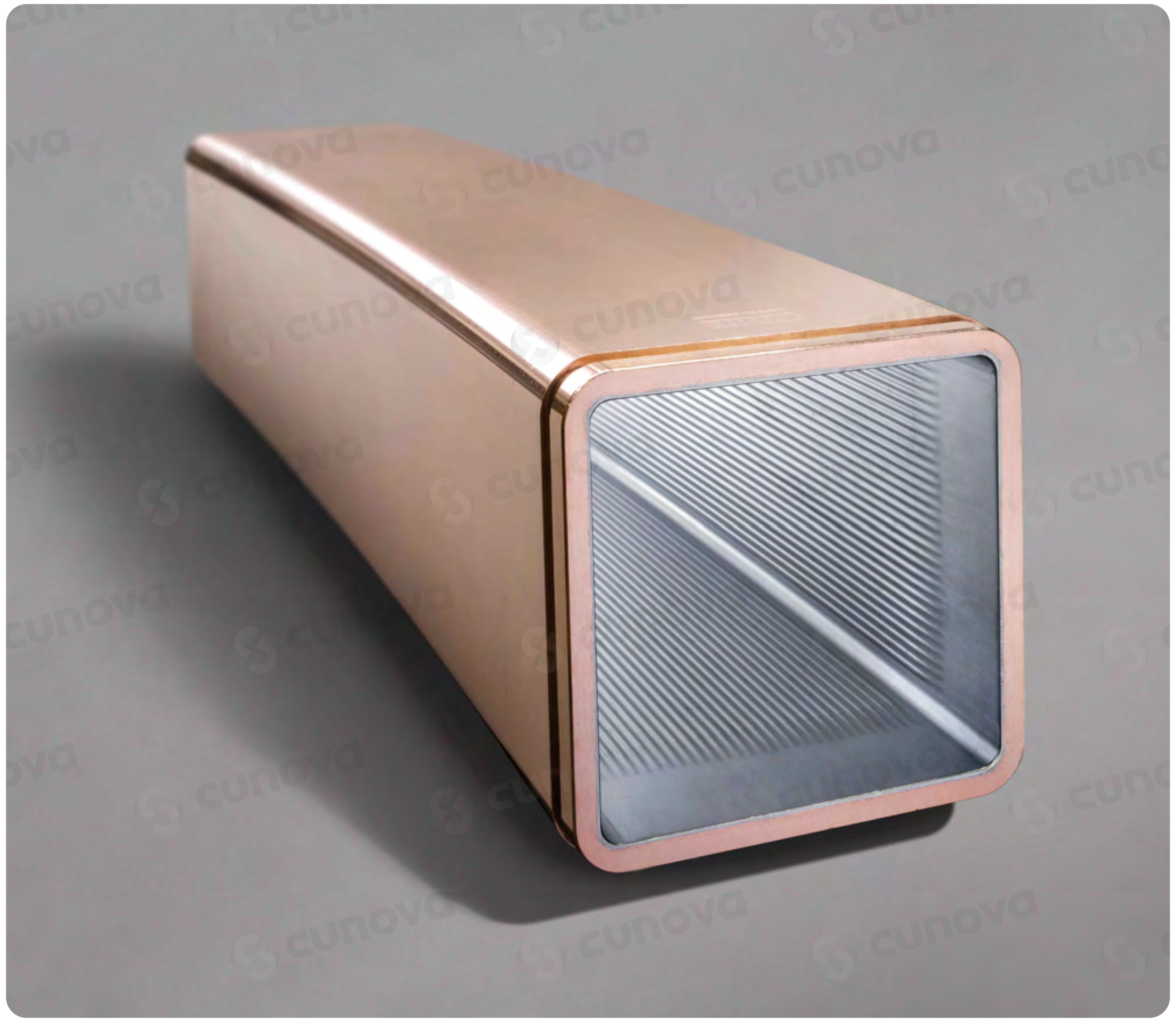
Advantages
- Improved product quality due to better strand guidance in the mould
- Decreased billet ovality
- Reduction in depression and longitudinally cracks
- Increased mould lifetime



WAVE® Mould Tube
Results at Nucor Jackson Inc., Mississippi

Tim Crothers[1], Ian Bakshi[2], [1]Nucor Steel Jackson Inc.3630 Fourth Street, Flowood, MS 39232 T: (601) 936-6221
tim.crothers@nucor.com [2]KME America Inc. 1000 Jorie Blvd., Ste. 111, Oak Brook, IL 60523 T: (630) 990-2025

Abstract
In 2011, Nucor Mississippi had severe problems with off-square billets that could not be controlled with the usual operating and maintenance adjustments.
A test with a new cunova mould design was made that had outstanding results in terms of both billet shape and mould life. In addition, there were significant cost savings achieved by reducing the amount of Manganese and Vanadium added to the steel in an effort to control the billet shape. This paper will present information on the operating, quality, and cost saving results when using the new WAVE Mould design.



Introduction

In 2011, Nucor Mississippi had severe problems with off-square billets that could not be controlled with the usual operating and maintenance adjustments. A test with a new cunova mould design was made that had outstanding results in terms of both billet shape and mould life. In addition, there were significant cost savings achieved by reducing the amount of Manganese and Vanadium added to the steel in an effort to control the billet shape. This paper will present information on the operating, quality, and cost saving results when using the new WAVE Mould design.

Source of Quality

In the continuous casting of steel, the shape of the product is often a source of quality concerns. A common problem in billet casting is forming a non-square or rhomboid shape that can cause internal quality problems such as diagonal and off-corner hinge cracks. Another common billet shape issue is bulging of the section, typically caused by insufficient mould taper and/or strand support for a given section size and casting speed.

Mould Condition

Clearly, the mould and its design have a role to play with regard to these shape issues. For example, it is well known that stronger tapers will reduce the degree of billet rhomboidity[1]. Correspondingly, as a mould tube wears the taper is reduced and this results in an increase in billet shape problems, as well as an increasing risk of a breakout[2].

A judgment as to the mould condition, either by measuring the inner profile or tracking the time (or tons) it has been used, is an important guide as to when it should be replaced to prevent such problems. The use of foot-rolls below the mould provides additional support for the relatively thin shell that will reduce bulging and improve billet shape. Their use has been found to lessen the degree of billet rhomboidity, even in cases where they are not strictly required for strand support[3]. Additionally, foot-rolls will compensate for machine alignment problems that are also known to cause billet shape issues.

Cause of misshapen Billets

Yet another cause of misshapen billets is inadequate mould water velocity and non-uniform flow[4]. This finding led to major improvements in mould cooling, such as the use of CNC-machined baffles and other types of tight-tolerance water jackets. The improved designs allowed for an increase in mould water velocity, through a reduction in the water gap dimension, that prevented boiling of the cooling water and greatly improved the uniformity of heat extraction from the copper mould.

Despite the many improvements to the mould system over the years, the problem of billet rhomboidity has not gone away, especially with regard to the mid carbon

---

[1] V. Krujelsis and J. Cook, "The Influence of mould tube Taper and Distortion of Cast Billet Quality", 1988, Steelmaking Conference Proceedings, pp. 349-352.
[2] I.V Samarasekera and J.K. Brimacombe, "The Continuous-Casting Mould", Continuous Casting Vol. Two: Heat Flow, Solidification, and Crack Formation, The Iron & Steel Society of AIME, 1984, pp.33-44
[3] I. Bakshi, "KME internal Report", 28th of Aug. 1997.
[4] R. Berryman, I.V. Samarasekera, & J.K. Brimacombe, "Cooling Water Flow in Continuous Casting Billet Moulds, Iron & Steelmaker", March 1988, pp. 69-77.

(0.2-0.4%) steels. In fact, rhomboidity can be considered the most vexing problem in billet casting and one that has regularly caused much consternation for machine operators. Past remedies have revolved around the belief that the source of the problem is related to cooling in the mould and thus could be rectified by improvements in taper, water velocity, oil lubrication and oscillator settings[5]. Other below-mould conditions such as spray water flow have not been thought to be a significant factor in this problem despite clear instances where events such as plugged spray nozzles or low temperature spray water have led to misshapen billets.

Severe and non-uniform mould wear associated with billet rhomboidity

Potential Solution for Billet Rhomboidity

With the preceding in mind, a comprehensive explanation as to the cause for billet rhomboidity is proposed as well as a potential solution. When liquid steel enters the mould tube the steel shell initially formed has no strength and acts like a waterfilled balloon, taking the shape of the mould containing it. Further down the mould, the shell starts to develop strength and can shift position relative to the copper mould walls as it contracts while solidifying.

As the vast majority of resistance to heat flow is governed by the air gap[6], it is this shifting of position relative to the cooling surfaces that results in non-uniform shell growth, differential stresses and resultant shape problems below the mould. External factors such as oscillator wobble and machine misalignment will act to move the shell position relative to the mould wall and create a non-uniform cooling condition. Similarly, plugged or poorly designed sprays below the mould will act on the shell in a manner so as to pull or twist the strand and transmit this action right up into the mould, also causing non-uniform cooling. This effect can be seen by looking at moulds at steel plants having rhomboid shape problems where a strong pattern of non-uniform wear, such as shown in the picture below, is seen.

It is the non-symmetrical heat extraction and resultant stresses in the forming steel shell that result in the strand distorting its shape upon exiting the bottom of the mould tube. In addition, the accompanying tensile strain as a result of this shape distortion will often result in cracks forming at the solidification front.

Mould Design ensure Uniform Cooling

With these arguments as to the cause of billet rhomboidity in mind, the challenge of developing a mould design that would better center the solidifying strand and ensure uniform cooling was undertaken.

WAVE® Mould Tube Design Concept

The solution proposed is called the WAVE Mould and its general design is shown in the figure 1. The key feature of this new design is to superimpose a series of wavy undulations onto the hot face side of the mould, causing a mirror image of the pattern to be formed on the billet surface as it begins to solidify. These two surfaces will then interlock and guide the shell through the length of the mould, while restraining any movement from side-to-side. The mould and shell are thus "coupled" together to such a degree that a more equal heat extraction and hence uniform shell formation occurs during its critical time in the mould.

Of course care must be taken in the design of the WAVE geometry so that the shell and mould are not held so rigidly together that it is not possible to cast successfully. To ensure that this is not the case, a special WAVE profile is used with its height and length designed so that the billet shell can shrink inwards without the WAVE peaks on either the copper mould or steel shell binding. The WAVE geometry will therefore vary depending on the section size being cast and linear position in the mould.

Typically, the WAVE amplitude is in the range of 0.5 – 5.0 mm and the WAVE lengths in the range of 1 – 30 mm; the exact values used are considered proprietary[7].

- Another benefit of the WAVE Mould geometry is a more **uniform distribution of mould oil** at the steel meniscus.
- Current mould oil distribution systems all work by introducing **lubricating oil through a plate** at the top of the mould housing and letting it weep down the mould wall to the steel meniscus.
- While a great deal of emphasis has been placed on ensuring that the distribution of oil to the top of the mould is uniform[8], the actual situation when it reaches the steel level is not certain. As the burning of the oil will affect heat transfer at the meniscus, it is clear that this **uniformity is important**.
- With the **WAVE Mould design** providing "channels" for the oil to flow along the length of the mould, it can be assured that the uniformity of the oil at the meniscus will be maintained from the oil plate right to the steel level.

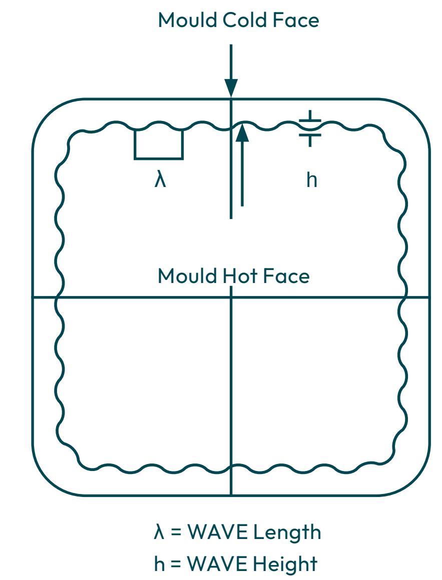


Fig. 1: Mould Design Parameters

[5] R. Bommaraju, I.V Samarasekera and J.K. Brimacombe, "Optimum Design and Operation of Moulds for the Continuous Casting of Steel Billets",

[6] AIST, "The Making, Shaping and Treating of Steel– Casting Volume, 11th Edition 2010, pp.94

[7] D.P. Lorento, US Patent 9,393,614B2, Jul 2016.

[8] I. Bakshi, A. Perri, J.K. Brimacombe, I.V. Samarasekera, and R.P Smith, US Patent 5027887, 1991.

WAVE® Mould Tube Design Concept

Plant Testing – Casting

In July 2013, a test of the WAVE Mould in the 140x140mm billet size was begun at the Jackson, Mississippi plant of Nucor Steel. Products produced here are rebar, merchant bar and forging quality steel grades using a 1993 billet continuous casting machine that was revamped in 2009, with the following characteristics:

Nucor Jackson Mississippi Casting Machine Details

Casting Machine	SMS Concast (2009)
Ladle Size	50t
Machine Radius	7.92m
No. strands	3 strands
Oscillator Type	Electro-Mechanical
Mould Lubrication	Oil Lubrication, 25ml/min
Section Size & Casting	100x100mm @ 4.5m/min
	115 x 115mm @ 3.8 m/min
	130 x 130mm @ 3.3m/min
	140x140mm @ 3.0m/min
	160 x 160mm @ 2.2m/min

Mould Type (standard)	cunova CuAg AMT
Mould Taper (standard)	Parabolic
Meniscus level	115mm
Mould length	812.8mm
EMS	No
Foot rolls	No
Sprays	Hydraulic, 2 zones (later 3 zones)
Withdrawal Unit	Two-Point Unbending
Billet Cut-Off	Oxygen Torches
In-Line Weighing System	Not at time of testing
Billet Discharge	Pusher

The impetus to try the WAVE Moulds was a "snaky" billet problem that started in April 2011. Even today, there is no explanation as to why steel grades that cast without difficulty prior to this suddenly could not be cast without shape issues afterwards. As detailed below, numerous steps were taken to identify and correct the problem, all without complete success.

"Snaky" billets are an indication of off-square shape (rhomboidity) in cross-section and are a problem commonly seen at this plant when casting steels in the ranges of 0.18–0.24% carbon. The distorted shape will almost always result in an off-corner hinge crack at the solidification front. If the shape problem is severe enough, the cracking will continue below the mould, often resulting in a breakout in this off-corner region[9].

The one factor that proved effective in controlling the billet shape problem was to adjust the steel chemistry so as to have minimum manganese to sulfur ratio of 30:1. This was achieved by lowering the carbon to allow for the increased manganese addition. For some grades, vanadium had to be added to meet the mechanical properties required of the steel. A considerable economic drawback to this solution is that the additional manganese and vanadium represents a substantial alloy cost increase of up to $6.00 USD per ton. Clearly, there was a need to find another solution.

"Snaky" billets cast with standard moulds seen on the cooling bed

Off-corner hinge cracks from rhomboid billet shape

[9] J.E. Lait, and J.K. Brimacombe, "Solidification During Continuous Casting of Steel", Continuous Casting Vol. Two: Heat Flow, Solidification, and Crack Formation, The Iron & Steel Society of AIME, 1984, pp.171-183.

AMT® ADVANCED MOULD TECHNOLOGY

WAVE® Mould Tube Design Concept

After the "snaky" billet problems began, various operating/maintenance parameters were checked and adjusted in an effort to control the shape problems. This included:

Casting Machine Parameters Checked/Adjusted

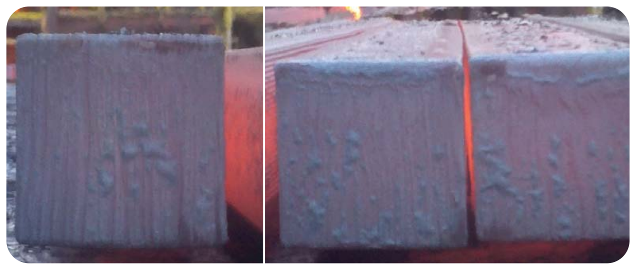
Verified tundish stream alignment	Measured water jacket distortion
Check mould lube flow	Replaced water jacket spacer pins
Tried different mould level settings with different speed combinations	Verified spray water alignment
Replaced mould tubes	Changed out spray water pumps (pulsing)

Check mould tapers	Redesigned zone I spray water pipes due to water pulsing
Trialed new mould taper	Checked spray water curves
Reviewed mould level control program	Replaced all spray nozzles with OEM
Reviewed thermocouple level control installation process	Adjusted scrap mix to increase Mn/S ratio Shop caster alignment
Verified stroke settings	Checked oscillation motion

Thus when there was an opportunity to try a new mould technology, designed with this problem in mind, a quick decision was made to move ahead with a test as soon as possible. After an agonizingly long wait for the first

WAVE Moulds to arrive, the first cast was made without any difficulties. While mould lube had been increased from 25 to 35 ml/min to compensate for the greater billet surface area, there was a slight amount of jerking initially. However, this was no worse than sometimes occurs when running a new mould and, in any case, went away after a short time. The chemistry cast was the problematic Grade 40 (0.25 C, Mn/S=20) steel. Right from the very first WAVE billet on the cooling bed, it was clear that the billet shape was greatly improved compared to the other two strands and rhomboidity was effectively gone!

A later measurement found that the diagonals were 194.8 mm, a variation of 1.3 % from the theoretical value of 197.4 mm. The measured billet dimensions wear 139.7–140.0 mm on the two sides, with the nominal value being 139.7 mm.



WAVE Mould billet (left) with excellent shape compared to standard mould billets (right)

Well-formed pattern on billet cast with WAVE Mould

The next step in the evaluation was to cast with the WAVE Moulds in all three strands. A wide variety of steel chemistries were cast without any operational difficulty. The rebar grades cast included:

Chemistry of Rebar Grades Cast with WAVE Mould

Chemistry	Grade 40	Grade 60
% Carbon	14–18, 20–24, 26–30	40–44
% Manganese	70, 80, 100	1.20

It was also seen that the WAVE pattern on the billet was well formed and a mirror image of the inside mould profile.

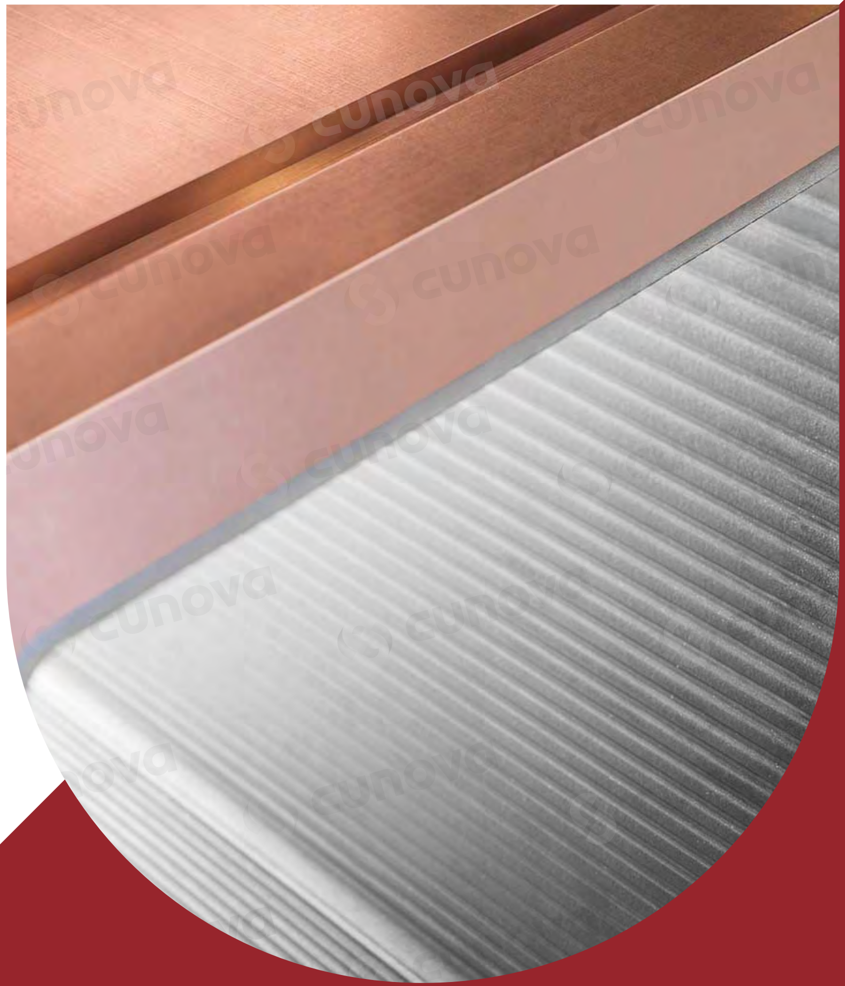
As has been the case with other users of WAVE Moulds, a substantial increase in mould life was obtained. While the life of the standard AMT moulds in the 140x140 mm billet size had been a very good 800 heats, it increased to an astounding 2400 heats after converting to the WAVE Mould. This tripling of mould life can be attributed to improved strand guidance in the mould that reduces movement of the shell and resultant abrasive wear. Of course, such high mould life cannot be obtained without having excellent overall caster maintenance and operating practices.

Plant Testing – Rolling

While the WAVE pattern on the billets is the key to the success of this novel mould design, there is naturally concern with regard to its influence on the surface quality of the finished rolled product. However, given the relatively shallow depth and special form of the WAVES, it was anticipated that this would not be a problem as was the case with earlier steel plants to use the WAVE Mould design. To check this, the WAVE billet rolled were tracked for each of the critical product shapes to verify there were indeed no quality issues. Specifically, the finished product categories analyzed and the results were as follows:

Rolling Trial Results

Section	Results
Rounds 0.906"	No upset failures or other visible defects, WAVES not visible after stand two
Angles	No defects reported
Strips	No defects reported
Rebar	No defects reported
Flats	No defects reported
Squares	No defects reported



Conclusion - WAVE® Mould Tube

Interestingly, a reduction in the amperage drawn by the roughing stands of between 50 – 100 A was measured. The drop in power input with the WAVE billets was attributed to their improved shape entering the mill. This in turn has allowed the reheat furnace temperature to be reduced by 30° C, with corresponding energy savings. Other benefits reported by the rolling mill with the WAVE billets are that split noses have “all but gone away” and there is better “spread” control between passes.

So, rather than being a reluctant customer of the differently shaped billets, today the rolling mill operators are enthusiastic supporters of the WAVE Mould.

Conclusion

A billet mould tube having special hot face geometry was tested at the Nucor Steel plant in Jackson, Mississippi. This new design, called the WAVE Mould, is achieving improvements in billet shape, internal quality, and alloy cost savings. The excellent results obtained, both in the melt shop and rolling mill, have led to the opinion that …

… the WAVE Mould is the best thing in casting since oscillation.

All three WAVE Mould strands in continuous operation

Further information on WAVE® Mould Tube:

T +49 541 321-3218
mouldtubes@cunova.com
www.cunova.com

cunova GmbH
Klosterstrasse 29
49074 Osnabrück
Germany

cunova Service Center:

cunova SERVICE GERMANY
cunova GmbH
Tel. +49 541 321 3218 | M: info@cunova.com

cunova SERVICE USA
cunova Service USA LLC
T: +1 814 827 7717 | M: sales@cunova.us

cunova SERVICE CHINA
M: service@cunova.com

cunova SERVICE UKRAINE
KME Magma Service
M: info@cunova.com

cunova SERVICE TURKEY
cunova Kalip Servis Sanayi ve Tic. A. Ş.
T: +90 212 244 7460 | M: cem.oz@cunova.com.tr

cunova SERVICE INDIA
cunova Service India Pvt. Ltd.
T: +91 966 331 4751 | M:prashant@cunova.in

cunova SERVICE MEXICO
cunova Mould Mexico S.A. de C.V.
T: +51 818 308 6810 | M: luis.iracheta@cunova.mx

cunova SERVICE SPAIN
cunova Service Spain S.A.
T: +34 946 360 128 | M: info@cunova.es