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HIGH SPEED SBQ CASTING AT CHAPARRAL STEEL

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Abstract—Chaparral Steel is a 1.8 million ton per year "market mill" located just South of Dallas, Texas. Our current product mix consists of 75% structural, 20% special bar quality (SBQ) and 5% rebar. This production is achieved with two ultra high powered EAFs, three casters, two structural mills and one bar mill.

In the summer of 1995, Chaparral Steel converted the SBQ, four strand 5 × 634″ caster to high speed casting. Prior to that conversion "A" caster would run at approximately 85 tons per hour, which caused a bottleneck in the shop because the furnace could out-pace the casting machine. Consequently furnace delays were very frequent.

With the advent of high speed casting, the casting speed increased from 80 to 120″ per minute. "A" caster can now run at more than 140 tons per hour, easily outpacing "A" furnace. This allows us to run most of the time with three strands operating, essentially leaving one strand as an in-line spare. This in-line spare gives us the flexibility to either terminate cast on a strand with quality problems, or run on four strands when extra short term casting capacity is required.

Résumé—Acier Chaparral est un "moulin de marché" de 1.8 million de tonnes par année, situé juste au sud de Dallas, au Texas. Présentement, nos produits consistent en 75% de produits de structure, 20% de "Barres de Qualité Spéciale" (SBQ) et 5% de barres nervurées. On obtient cette production grâce à deux EAFs à pouvoir ultra élevé, trois appareils à couler, deux moulins structuraux et un moulin pour barres.

Au cours de l'été 1995, Acier Chaparral a converti l'appareil à couler SBQ, à quatre lignes de 5 × 634″, en appareil à couler à haute vitesse. Avant cette conversion, l'appareil "A" fonctionnait approximativement à 85 tonnes à l'heure, ce qui causait un étranglement dans l'atelier parce que le four pouvait fonctionner plus rapidement que l'appareil de coulage. Conséquemment, les délais du four étaient très fréquents.

Avec l'arrivée du coulage à haute vitesse, la vitesse de coulage a augmenté de 80 à 120 pouces par minutes. L'appareil "A" peut maintenant fonctionnere à plus de 140 tonnes à l'heure, dépassant facilement le four "A". Ceci nous permet de fonctionner la plupart du temps avec trois lignes en opération, laissant essentiellement une ligne de réserve disponible. Cette ligne de réserve nous donne la flexibilité soit de terminer la coulée sur une ligne ayant des problèmes de qualité, soit de fonctionner avec les quatre lignes quand une capacité de coulage à très court terme est requise.

THE EQUIPMENT

Ten new, stainless steel mold housings and foot roll assemblies, as well as numerous 40″ long chrome plated Cu–Cr–Zr molds form the heart of the new caster. Eight inches longer than the molds they replaced, the new longer molds are critical for support of the solidifying shell at the new higher casting speeds.

The addition of foot rolls provides additional support for the shell after the strand exits the mold.

While not critical to the implementation of high speed casting, the addition of dual coil EMS units provides us with greater stirring flexibility. The upper coil operates at up to 200 A and can be stirred in either direction, acting as a break or an assist to the lower and larger coil which stirs the liquid steel in only one direction and can operate at up to 400 A (Fig. 1).

Four new oscillators plus one spare were also purchased. These are heavy-duty short lever arm designs with variable speed and frequency capabilities. Our new oscillators are currently set at 175 cycles per minute and stroke of 0.4″.

The spray water cooling system has also changed substantially. Prior to high speed casting, the spray water cooling system on "A" caster consisted of a four nozzle spray ring and a single 6′ set of spray risers (Fig. 2).

The new system consists of a modified spray ring and spray risers that provides three zones of "soft" cooling extending 26′ from below the molds to the straighteners. Zone 1 consists of the spray ring located immediately below the mold; Zone 2, the first two sets of risers; and, Zone 3 the final two sets of risers (Fig. 3).

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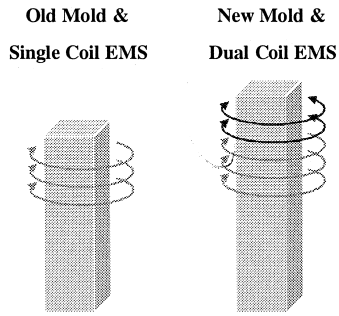

Fig. 1. Old 32″ mold and single coil EMS vs new 40″ mold and dual coil EMS.

The new system is designed to eliminate reheat cracking while providing the necessary cooling profiles at the higher casting speeds. The system is automated and varies linearly with casting speed, and is a substantial improvement over the one it replaced.

Figure 4 shows a predicted cooling profile using the University of British Columbia's CRAC-X program [1] for a 1045 grade cast on our current $5 \times 6\frac{3}{4}''$ mold. The program shows surface temperature and shell thickness as a function of distance below the meniscus. One of the most important parameters is the point of final solidification, which in this case is 16 m below the meniscus or 1 m before the torches.

One can also see the surface temperature of the billet as it moves through the mold and each of the three cooling zones, which is indicated by the discontinuities on the black curve.

All tundishes used on our oil cast product were modified to increase their capacity from 12 tons up to 18 tons. We did this by raising the overall height 10″, thereby achieving better inclusion floatation, better head pressure at the nozzles and a sufficient residence time to allow sequence casting at the higher casting speeds.

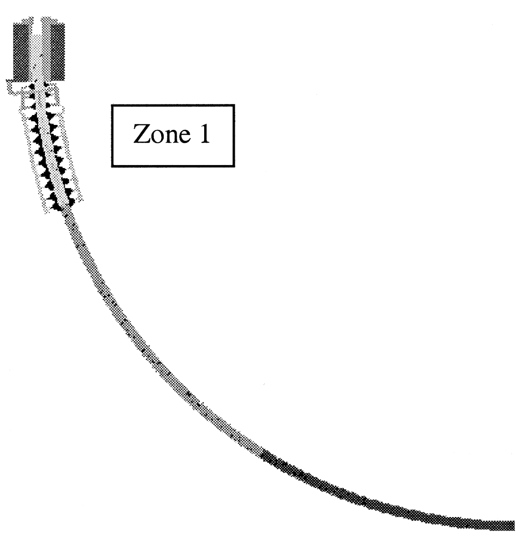

Fig. 2. Original cooling system consisiting of spray ring and single 6′ set of spray risers.

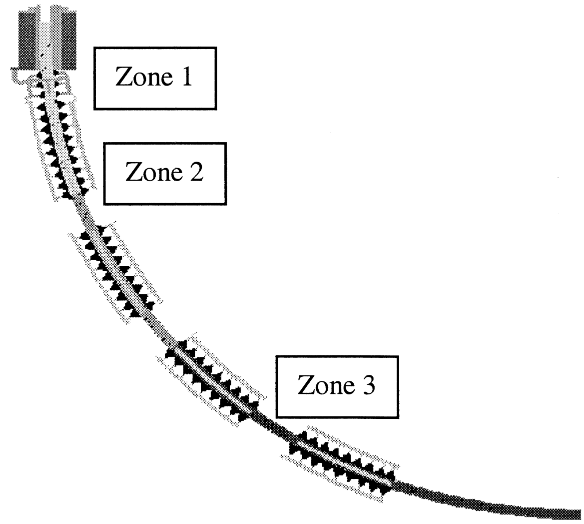

Fig. 3. New cooling system consisting of spray ring and four sets of risers.

Finally the cutting distances on the cut off torches were lengthened to enable billets to be cut at the higher casting speeds.

THE CHALLENGES

High speed casting has presented many challenges to us over the last 3 years. This paper will try to cover a few of the highlights.

Mold life

Mold life has proven to be one of our greatest challenges, and earlier this year we began to experience a high frequency of chrome chipping and copper cracking at the meniscus level. Figure 5 is a photograph of one of our molds showing

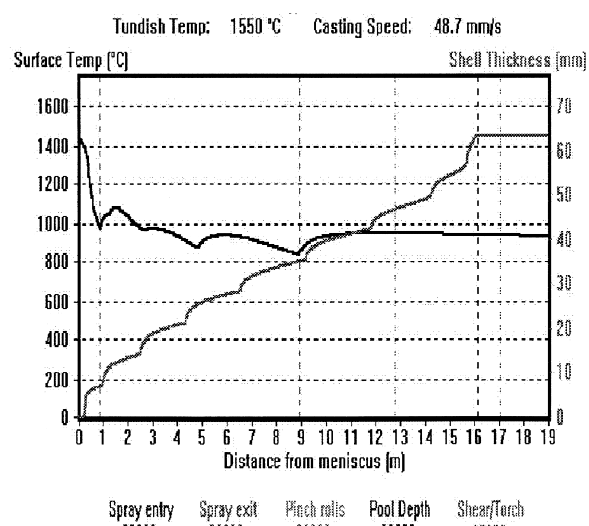

Fig. 4. Predicted surface temperature and shell thickness profiles for 1045 on current $5 \times 6\frac{3}{4}''$ mold.

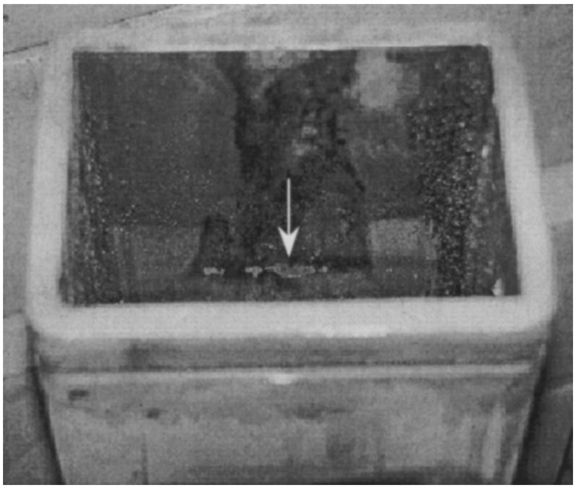

Fig. 5. $5 \times 6\frac{3}{4}''$ mold tube exhibiting chrome chipping at the meniscus location (arrow).

some typical chrome chipping. During this period, this type of chipping was often associated with heavy longitudinal cracks in the Cu–Cr–Zr substrate of the mold.

On one of the molds that we were able to destructively test, metallography revealed that the cracks under the chipped chrome had metallic deposits consisting mainly of zinc and lead (Fig. 6).

In addition, hardness measurements taken transversely on the surface of the cracked face showed significant softening compared to the adjacent non-cracked face (Table 1).

Further study of the literature [2] suggested that the mechanism for the chrome chipping was zinc penetration through microcracks in the chrome (Fig. 7). The zinc then reacts with the copper substrate to form intermetallic brass resulting in a volume increase which causes the plated chrome to "lift off".

Once the chrome chips, the Cu–Cr–Zr substrate is directly exposed to the solidifying steel shell and eventually cracks due to thermal cycling and high temperature fatigue. At Chaparral, this mechanism was being aggravated by our practice of recycling zinc rich EAF dust in the furnace.

The immediate problem was alleviated somewhat by removing the recycled EAF dust, relocating the meniscus to a lower level, and boosting the mold cooling water flow rate by 12 GPM, the maximum flow rate available to us in the short term. We have also recently installed booster pumps to our existing mold water cooling system during our summer shutdown, which should help to further reduce the mold hot face temperatures and these types of failures.

Table 1. Comparison of mold tube hardnesses

Sample ID	Hardness readings (HRB)	Average HRB
Cracked face	58.3 59.6 57.4 60.8 61.1 62.1	60
Adjacent non-cracked face	75.7 75.8 75.9 75.6 75.9 75.5	76

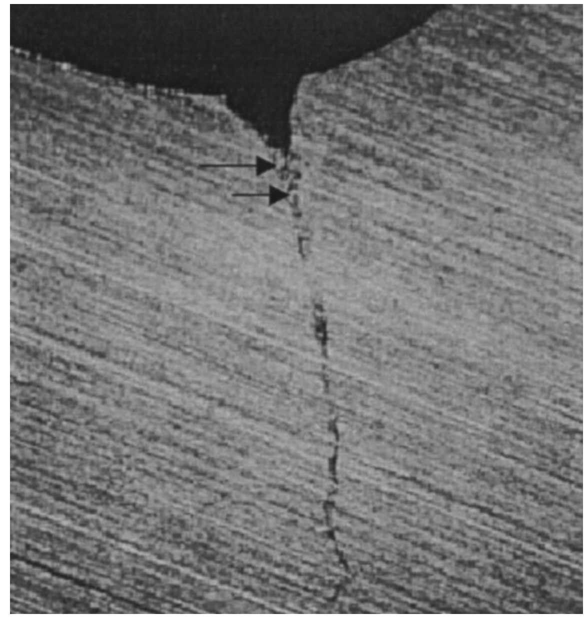

Fig. 6. Longitudinal cracks under chrome chipping with zinc and lead deposits.

Billet quality

I want to talk about the two largest billet quality issues we have faced and are currently facing at Chaparral. These issues, while not severe, represent a continuous improvement effort on our part.

The first issue is transverse corner cracks or TCCs. Figure 8 represents the history of TCCs at Chaparral since the implementation of high speed casting. As you can see we have had 2 successive months without TCCs. The question is how did we get rid of them?

Although TCCs have been a significant problem for us on our Mn–Si killed oil cast products, they appear only rarely on our powder cast Si–Al killed products. At Chaparral, we have historically run the meniscus of our oil cast material at

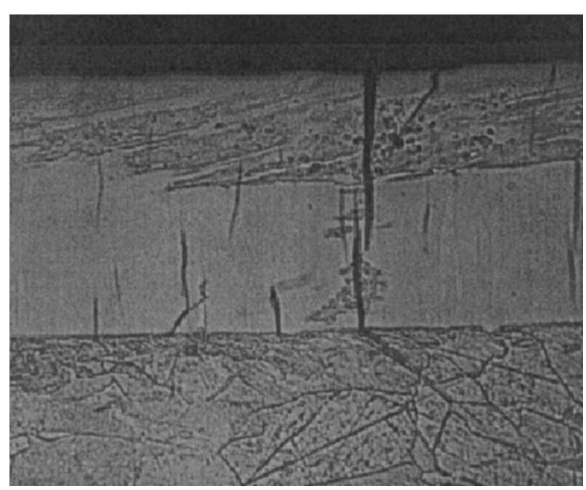

Fig. 7. Microcracks in mold chrome plating.

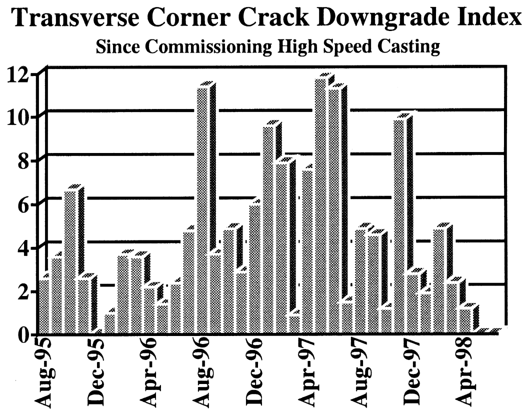

Fig. 8. Transverse corner crack downgrade index.

131 mm from the top of the mold. On our current $5 \times 6\frac{3}{4}''$ parabolic molds, the mold taper at this level is 2.42% per meter.

If you recall, I mentioned the chipping and cracking problems we were having in the molds in the meniscus area earlier this year. In early February, we decided to move the steel meniscus lower and away from the damaged areas in the mold. This change not only alleviated our mold wear problem, it also resulted in an immediate and drastic reduction in TCCs.

With our new and current lower operating level, we have dropped the meniscus 30 mm to 161 mm from the top of the mold, giving us a taper of just above 2% per meter at the new meniscus level.

We believe the reason that TCCs have disappeared is that the lower initial taper at the lower meniscus level reduces the binding between the solidifying shell and the mold, and ultimately reduces the generation of longitudinal stresses on the solidifying shell that can cause transverse corner cracks to form.

The second largest quality issue we face is Hinge Cracks, also known as off corner internal cracks. In Fig. 9 we have the historical performance of hinge cracks since the implementation of high speed casting. As with TCCs these defects occur primarily on our oil cast products. Hinge cracks still present a significant challenge for us.

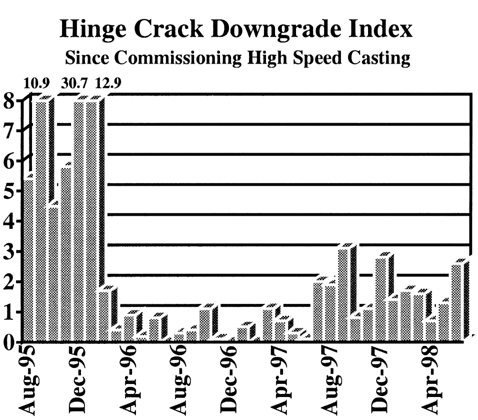

Fig. 9. Hinge crack downgrade index.

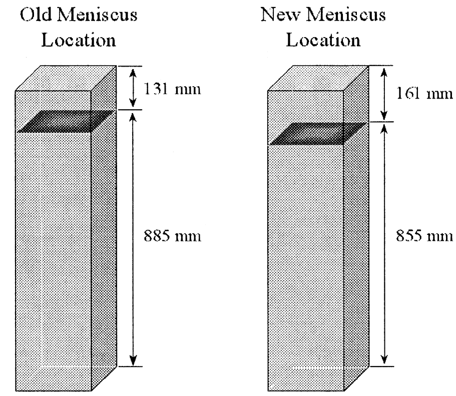

Fig. 10. Previous and current meniscus location.

We believe that hinge cracks have been difficult for us to solve because there are several mechanisms acting against us in eliminating this problem. The first and most obvious mechanism is the loss of effective mold length by running the meniscus at 161 mm. The 30 mm loss of effective mold length means we have a thinner shell at the mold exit, which can be more prone to hinging (Fig. 10).

The second mechanism has to do with our stirring patterns on oil cast. We currently stir our dual coil EMS unit in two basically different ways. For our powder cast ceramic shroud silicon aluminum killed practice, we stir clockwise with the bottom or primary coil at 250 A and we stir the top or secondary coil counter clockwise at 60 A (Fig. 11). This stirring pattern was determined by water modeling to offer the most stable meniscus, which we implemented to solve another problem we were having with mold powder entrapment on our powder cast product.

The combination of this stirring practice and the mold powder lubrication result in a typical oscillation pattern shown in Fig. 12. Note the nice repeatable and uniform pattern.

In Fig. 13, we have the sulphur print from the billet shown in Fig. 12. It should be pointed out that we rarely have any substantial hinge cracks on our powder cast product, but it is also important to point out that in addition to the stable stirring practice, we also are casting

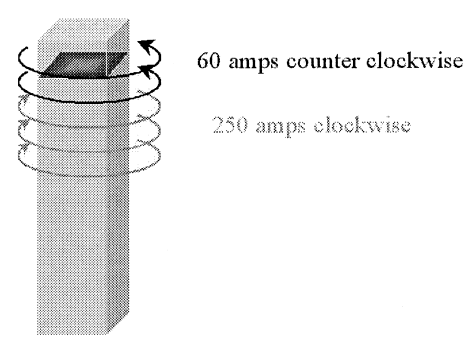

Fig. 11. Dual coil EMS settings on SEN, powder cast, Si–Al killed grades.

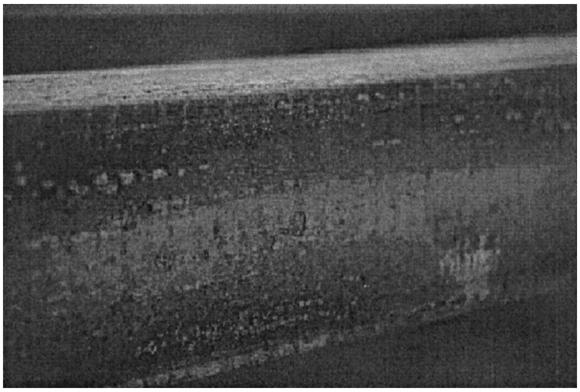

Fig. 12. Oscillation marks on powder cast Si-Al killed grades.

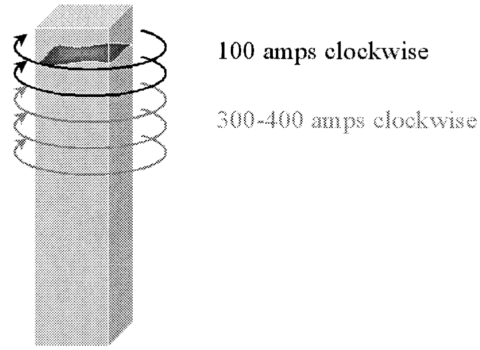

Fig. 14. Dual coil EMS settings on oil cast Si killed grades.

with mold powder as well as a higher meniscus level, and slower cast speeds than we do with oil cast.

On the other hand, the EMS stirring practice on our oil cast products is a substantial departure from our powder cast practice. We stir both coils in the same direction, with the top coil at 100 A, and the bottom coil at 300–400 A depending on the steel grade being cast (Fig. 14).

There is strong evidence that the stirring practice on our oil cast silicon killed practice sets up a standing wave in the meniscus area similar to the one shown in Fig. 15.

Examination of an oil cast billet (Fig. 16) lends support for this mechanism, although this oscillation mark pattern is more severe than on our typical oil cast, it is not uncommon, and the characteristic sine wave pattern is usually present to some degree. This unevenness at the meniscus, among other things, promotes uneven shell growth, which can lead to hinge crack formation.

And in fact, a transverse sulfur print of the billet in Fig. 16 does indeed reveal the presence of hinge cracks in the upper left and right as well as the lower left corners (Fig. 17).

Although there appears to be a strong case for stirring induced problems, and a fairly obvious course of action, another problem we have identified has made us hesitant about immediate implementation of any changes in the oil cast stirring practices, and that is the problem of oil distribution and consumption.

Since the advent of high speed casting, and for various quality reasons, Chaparral has increased its mold lubrication consumption from 60 to 90 to 120 ml/min, where we are today.

Using in-house designed segmented oil collector pans (Fig. 18), we have started to characterize the oil delivery on our strands as a function of position around the mold hot face perimeter, following the work done by Bakshi *et al.* [3] at the University of British Columbia.

The oil flow has been measured in-situ on several occasions, with the mold divided up into 14 discrete segments. The graph in Fig. 19 shows a typical distribution pattern for a mold and jacket assembly after several heats. There is very little difference in this pattern when we do the same test on a new mold and oil distribution plate, or on a mold and plate with many heats on it.

Consequently, with this type of oil distribution, we are concerned that a quiet meniscus stirring practice, while likely beneficial from a hinge crack reduction standpoint, may magnify the discrepancy in oil delivery already present and result in an increased frequency of stickers and bleeds.

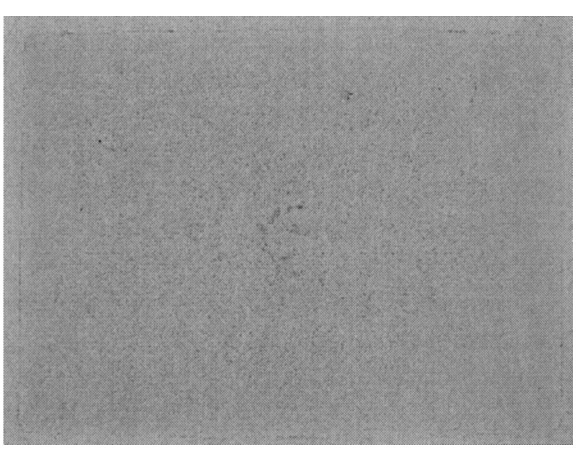

Fig. 13. Sulfur print from Si–Al killed billet in Fig. 12.

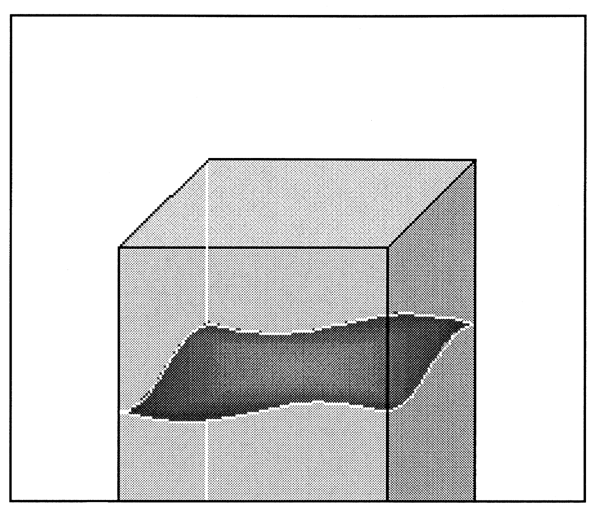

Fig. 15. Uneven meniscus created on oil cast product.

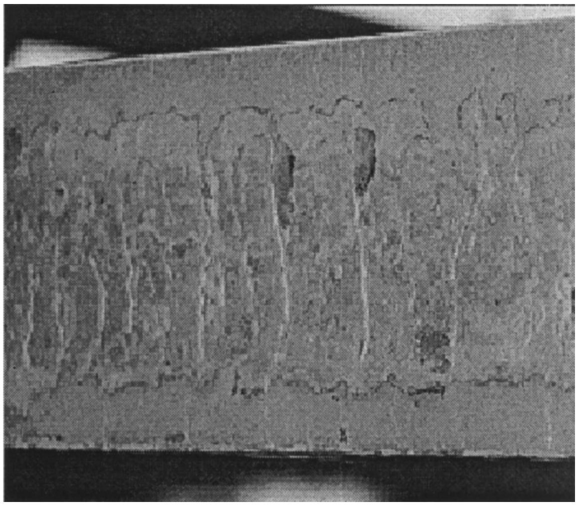

Fig. 16. Oscillation marks on oil cast billet.

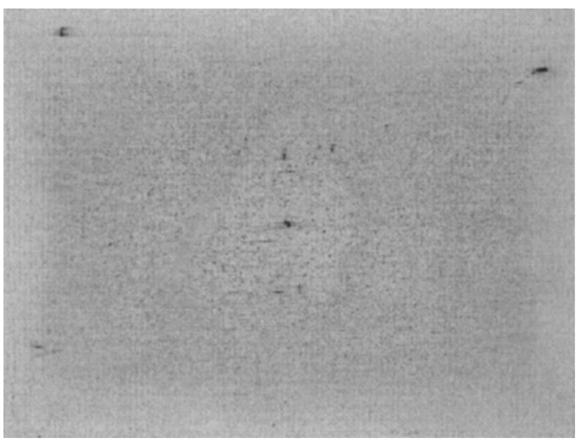

Fig. 17. Transverse sulfur print of billet shown in Fig. 16.

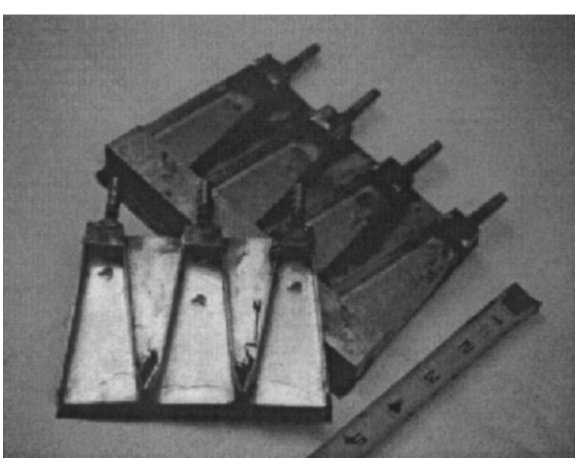

Fig. 18. Mold lubrication oil collector pans.

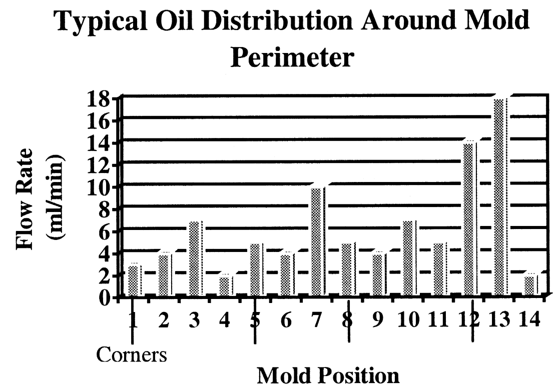

Fig. 19. Typical oil distribution around mold perimeter.

So far, in our efforts to improve our oil delivery distribution, we have modified the shims on the oil distribution plate so they stop $\frac{1}{4}''$ short of the hot face. Distribution measurements taken with this modification in place showed little improvement to the above profile; however we discovered that we were operating under extremely low flow conditions during these trials.

Further work has been proposed and is under way to increase the oil reservoir volume and reduce the horizontal distance the oil has to travel from the reservoir to the hot face.

Once we improve our oil distribution and then our stirring practice, we should be able to substantially reduce or even eliminate the hinge crack problem.

THE FUTURE

What does the future hold for Chaparral? Well, we don't have to peer too deep into the crystal ball to know that almost everything we know about casting a $5 \times 6\frac{3}{4}''$ SBQ section will have to be modified when we start casting a $6\frac{1}{2}''$ square in the autumn of 1998.

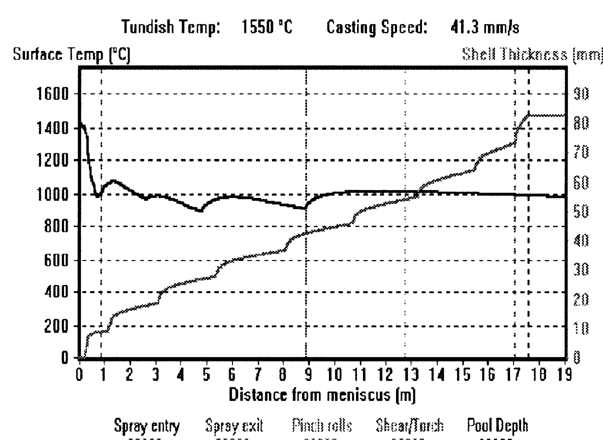

Fig. 20. Predicted surface temperature and shell thickness profiles on grade 1045 for new $6\frac{1}{2}''$ square SBQ billet using our current spray plan.

One envelope we know we will be pushing is the metallurgical length of the new billet, which, at $17\frac{1}{2}$ m is past the torches with our current spray profile (Fig. 20). This means we will require a more aggressive cooling profile, which will present its own set of challenges.

We will also be working with a new section, new casting speeds, new mold tapers and mold wall thicknesses, new spray risers, new mold water flow rates, and a new oil delivery system. All of which will present their own unique set of challenges.

Also, looking forward, we have just completed our revamp of "B" caster to high speed casting in very much the same way as we did on "A" caster (40″ molds, new oscillators, new spray risers new EMS units, and so on), the only real exceptions are the omission of footrolls, and the oscillators on this machine will be retractable.

In conclusion, high speed casting has been a success at Chaparral Steel. Not only has it increased our production capacity and flexibility, but it has also led us to a greater understanding of the process and how it impacts on the quality of our finished product.

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