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SURFACE CRACK CHARACTERIZATION OF TWIN ROLL CASTER SHELLS AND ITS INFLUENCE ON AS-CAST STRIP SURFACE QUALITY

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Abstract

Caster shells are the most critical components of the twin roll casting process that has significant contribution to the surface quality of the as-cast sheet. Due to their high cost, they also have an impact on the cost structure of as-cast sheet. Twin-roll strip casting is a complex process, which involves high solidification rate and subsequent deformation at the roll bite. Solidified metal exerts enormous mechanical loads on the caster rolls and this results in bending of the caster roll along with the shell. Liquid metal also raises the temperature of the shell considerably at a limited depth and upon leaving the roll bite cooling cycle starts. Heating-cooling cycles at the outer skin of the shell lead to thermal fatigue. Coupled effect of thermal and mechanical fatigue causes surface cracks to appear. These are the features impair the surface properties, even performance of products.

Present study aims to elucidate surface crack formation mechanism of caster shells. Metallographic investigations and SEM studies were conducted on the caster shells. The results are correlated with physical and mechanical properties of the shell materials. Studies were extended to aluminum foil and sheet products in which caster shell related defects were observed.

Keywords: Twin roll casting, thermal crack, caster shell.

1. Introduction

Twin roll casting is a production method that combines both solidification and rolling in the same process [1]. The liquid metal is fed through a ceramic nozzle into the roll bite [2]. The caster rolls are composed of two structural parts: core and shell shrink-fitted around the core. Cooling water is circulated between the core and the shell through the grooves machined on the core. Contact time along the contact arc between the liquid, and further solidified metal, is so short that highest temperature at the outer skin of the shell cannot diffuse through all the way down to the interface between core and shell. Hence, limited depth of shell is exposed to thermal cycle between the liquid metal temperature and shell surface temperature at every revolution of the caster roll. Having considerable massive geometry and the material of which produced, caster roll is exposed to cyclic mechanical loading generated by the bending of the whole structure due to distributed load exerted by the solidified metal. At every revolution of the roll, load at certain point of the outer skin of the shell oscillates between compression and tension. These two loads, namely mechanical and thermal, are the major driving forces for crack propagation mechanism [3].

During casting, surface properties of the shell must be altered with appropriate agent to prevent sticking of liquid aluminium to bare shell surface. Graphite, that is suspension in water, is the commonly used releasing agent in twin roll casting. Required amount of graphite is determined by the alloy composition and casting parameters (casting speed, casting temperature). Obvious consequence of excessive graphite on the shell surface is lack of heat extraction from the liquid metal and results in micro and macroscopic defects [4,5]. Presence of excessively sprayed graphite on the shell surface, particularly associated with the surface cracks leads to premature degradation of as-cast sheet surface quality. It is quite understandable to observe propagation of crack on the shell surface due to thermal and mechanical loads with increasing casting tonnages. As the loading mode turns in tensile when a particular crack is at the top position of the upper roll (or lowest position of the bottom roll), the crack tip will continue to propagate. A crack reached to critical size will leave an imprint on the sheet surface. As the size and width of the crack increase, its imprint becomes more visible. Visual deterioration of the sheet surface dramatically increases with the casting tonnage. The surface quality of the sheet cannot be refurbished with rolling operations if final thickness of the product requires only one or two moderate cold rolling reductions.

Present study aims to characterize cracks generated on the surface of caster shell and their detrimental influences on as-cast sheet quality. Coupled effect of mechanical and thermal properties of caster shells are believed to be predominant factors for generation of crack, its propagation and intensity on the surface.

2. Experimental

Characterizations studies were conducted on the caster shells that reached to their end of life and cut-off from the core. Surface of the shells were investigated by employing SEM (JEOL 5600). Samples were metallographically prepared to investigate crack paths and depths through the thickness. Since crack propagation is closely related to the casting tonnage, changes in the visual appearance of the as-cast sheet due to size and intensity of the cracks were investigated on the samples gathered from different casting tonnages of the same caster shell between two reconditioning (turning and grinding) operation.

3. Results and discussion

Figure 1 shows the surface appearance of the caster shell. Immediately after starting to casting operation, the shell surface turns into gray in color. Although releasing agent properly performs its function, steel surface is covered with thin layer of aluminum and/or aluminum oxide layer.

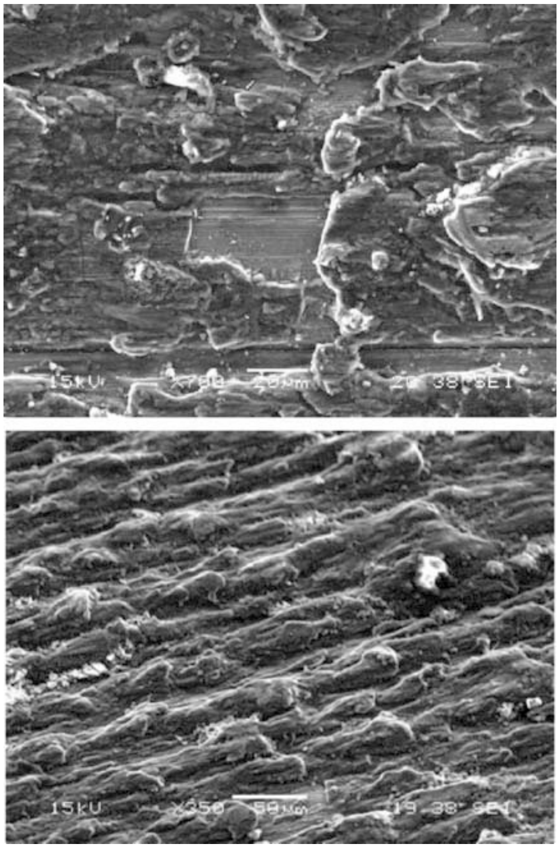


Figure 1. Surface of the caster shell.

Two types of cracks were observed on the shell surface depending on the direction they developed; longitudinal and transverse (Figure 2). The formation and propagation mechanism of longitudinal ones are associated with the mechanical stresses generated due to bending of caster roll by the exerted forces of solidified aluminum in between the roll gap.

Longitudinal cracks are not always bridged with the transverse ones. Thermal properties of the shell material, position of the crack from the edge of roll casting tonnage and the diameter of the roll seem to be important factors for bridging to occur. Figure 3 shows series of cracks which were not bridged.

Figure 2. Longitudinal and transverse cracks on the shell surface.

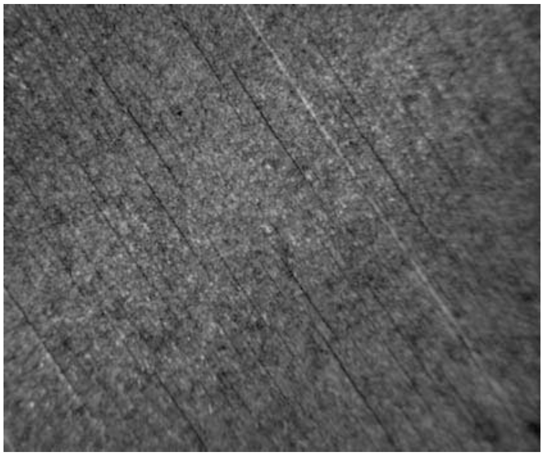


Figure 3. Longitudinal cracks on the shell surface.

Depth of longitudinal cracks varies from the edge to center of shell. Since their propagation is mainly driven by mechanical loads due to bending of the roll, they are deep at the center and becomes shallower towards the edge. Their depth can reach up to 0,850 mm at the center of the shell width (Figure 4).

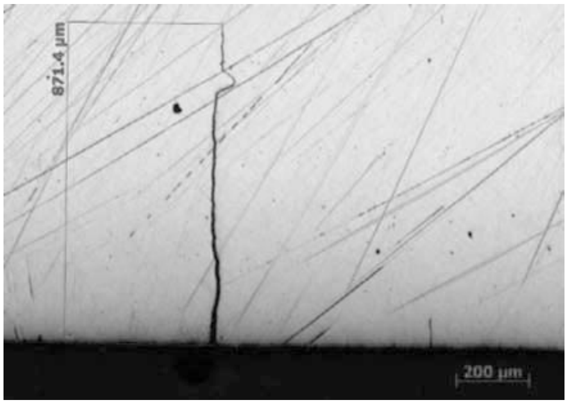
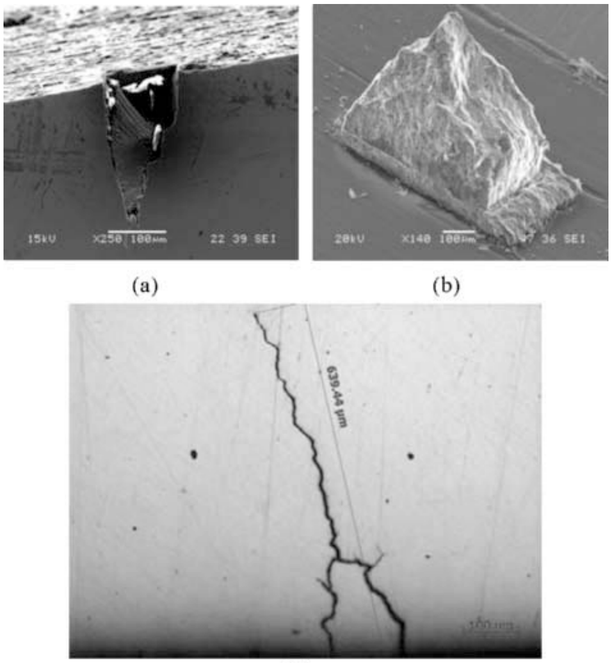


Figure 4. Crack profile through the thickness

Propagating cracks in transverse and/or longitudinal directions can coalescence at critical depth and lead to formation of loosely attached volume at the shell surface. Figure 5 (a) shows one of these volumes at the cross section and partly removed. The particle on Figure 5 (b) was easily dislodged and transferred to adhesive carbon tape from arbitrarily chosen area. Figure 5 (c) shows two cracks merged into one and propagated along the depth.



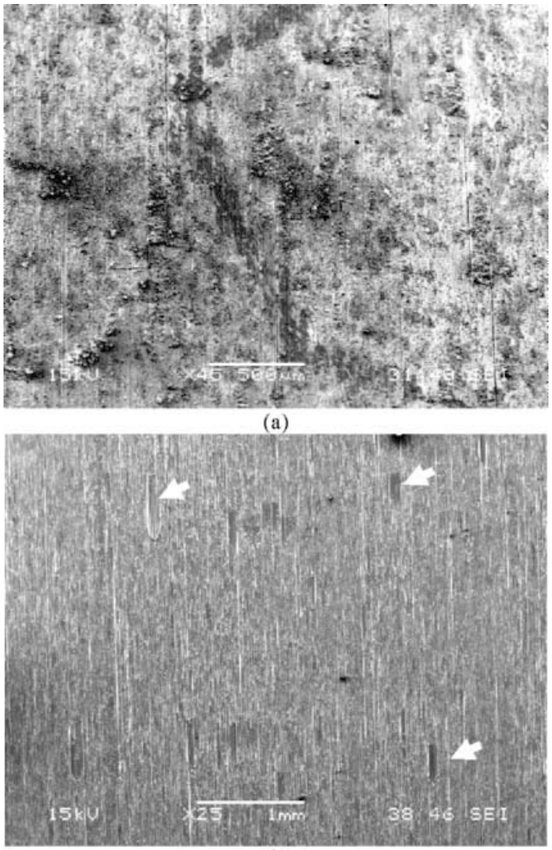
(a) (b)

(c)

Figure 5. (a)Dislodged volume and (b) particle. (c) Merging two cracks.

It is quite evident that if such a void is created at the surface during casting operation, liquid metal can readily fill this volume and micro-sticking or in worst scenario tearing of the strip, if casting gauge is low, can result in.

The area surrounded by bridging transverse and two longitudinal cracks is prone to build up aluminum/aluminum oxide layer compared to surrounding areas. This area is also slightly protruded from the overall surface topography. Coupling effect of these two, namely building of aluminum/aluminum oxide and protrusion deteriorate the as-cast surface quality. Figure 6 shows these formation on the shell surface and their imprints on the as-cast sheet surface.



(a)

(b)

Figure 5. (a) Shell surface and (b) as-cast sheet surface

One of the important advantage of TRC is casting at optimum thickness allowing minimum number of rolling passes to achieve the final product gauge. On the other hand, coupling this advantage with a lean down streaming operation (without intermediate or homogenization anneal) contributes significantly to the cost structure of a material produced out of TRC. As-cast surface quality determines final product quality in different aspects. A material cast at its optimized thickness must have proper surface features allowing to be produced with minimum number of rolling passes to final gauge and have acceptable surface features. But an as-cast sheet having defects introduced by the shell surface due to abovementioned structural features might still bear the traces of them even it is exposed to two rolling passes.

Intensity and characteristics of surface cracks (with or without transverse ones) are closely related to the mechanical and thermal properties of the shell material, amount of tonnage cast. The most straight forward correlation can be established between the alloy combination cast and their tonnage between two reconditioning (turning and grinding) of the caster roll Figure 6. Increasing casting tonnage leads to increase in number and severity of the cracks and associated material accumulation behind the transverse cracks. Therefore, surface defects generated on the sheet surface at higher casting tonnages cannot be readily eliminated for those finals gauges requiring only one or two rolling passes.

Since thick gauge material production can be in the product portfolio of a company of which production technique is TRC, and cannot be avoided, surface quality of the initial material must comply certain characteristics. Hence, imprints of the shell cracks on as-cast sheet surface must be minimized for quality concerns by taking necessary measures on the shell performance. These topographic features can also be the origin of another problem typically encountered in thin gauge materials. This is called smut. There are well established rolling practices to remove it from the sheet surface but the key point is to minimize it at its source, that is those topographical features, on the as-cast sheet surface.

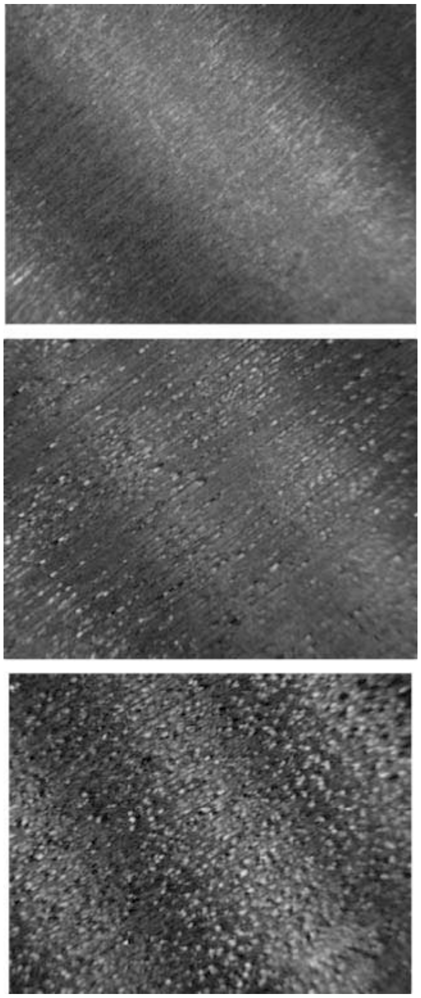


Figure 6. Increasing intensity of surface cracks on the as-cast sheet surface with increasing casting tonnage (a) 100 tons, (b) 400 tons, (c) 800 tons.

Caster shell is a costly consumable in TRC operation. Depending on the depth of crack formed during the course of casting batch (total tonnage between two reconditioning) critical depth of materials need to be removed from the surface by turning first and then by grinding, without leaving any crack on the shell. But this operation should be carefully handled. Unnecessarily removed depth stands for cost and reduce the total life of caster shell. Best method is to measure the depth of cracks along the width and determine the removal rate prior to turning operation. However there is no available non-destructive technique, neither ultrasonic nor Eddy current, providing reliable results compared to the precision of metallographic techniques to measure critical dimensions of a crack; depth, width and length [6]. Cracks still left over after reconditioning are the first crack initiation points of next casting batch.

Considering two types of loading (mechanical and thermal) a caster shell is exposed to and geometry of the roll, caster shell must comply some critical mechanical properties. But they are not limited with the macroscopic properties such as tensile and yield strength. Fracture toughness of the material has also pronounced contribution to crack formation and propagation. Shell producers have their own chemical compositional ranges and final annealing operations to tailor mechanical properties. But recent studies and on-site observations showed that along with the properly tailored mechanical properties, thermal properties of the shell enhance shell performance. However, this requires an optimized solution for determining the chemical composition of the steel used. While some elements are the primary requirements for achieving strength, same elements might deteriorate thermal properties [7, 8].

Retarding crack initiation and further propagation should be the ultimate goal for designing shell properties. This will provide extended casting batches that will provide ideal surface topography for those final products necessitating only one or two rolling passes. Then, aesthetical properties of TRC can compete with its DC cast-hot rolled counterparts.

4. Conclusions

1. Mechanical properties of the caster shell material is not the sole property determining shell performance for long casting tonnages. Instantly raising temperature within very limited depth upon contact of liquid metal results in thermal stress to be generated within a certain volume. If thermal expansion cannot be accommodated by the mechanical properties and penetration of heat cannot be managed properly, transverse cracks are created.

2. Transverse cracks are mainly responsible from the features imprinted on the as-cast sheet and impairment of the topography and aesthetical appearance of the material at final gauges.

3. Excessive spraying of releasing agent leads to build up of aluminum/aluminum oxide preferentially at the area surrounded by two longitudinal cracks and a bridging transverse crack.

4. If bridging of cracks extends deep into the shell and merge by releasing a volume of material, this volume can be dislodged from the surface by its interaction with solidifying and simultaneously deformed aluminum.

5. Topographical features of the as-cast sheet that are mainly introduced by the caster shell determine some critical quality

issues of TRC materials. As long as their formation mechanisms are well understood, some critical shortcomings of TRC that are attributed to casters shell, will be overcome.

REFERENCES

[1] H. Zhao, D. Y. Ju, L. Hu, "Evaluation on Microstructure of Thin Strip Produced by Twin-Roll Continious Casting, J. Material Science Tech., Vol.20, 2004.

[2] O. Keleş, M. Dündar, "Aluminum foil: Its typical quality problems and their causes", Journal of Materials Processing Technology, 186, pp. 125–137, 2007.

[3] R.D. Mercado-Solis, J. Talamantes-Silva, J.H. Beynon, M.A.L. Hernandez-Rodriguez, "Modelling Surface Thermal Damage to Hot Mill Rolls", Wear, 263, 207.

[4] P. Y. Menet, F. Basson, K. Maiwald, R. Cayol and M. Bosh, "Strip Casting Technology.. A Key to Product Quality", Proceeding of the International Melt Quality Workshop, Madrid, 2001.

[5] E. K. Vukelja, I. Duplancic, B. Lela, "Continuous Roll casting of Aluminum Alloys-Casting Parameters Analysis", Metabk, 49(2), pp.115-118, 2010.

[6] P.K. Chen, K.Y. Tsai, "Using NDT Methods for Inspection Work Rolls", 18th World Conference on Non-destructive Testing, 2012.

[7] "Alloy Steel Roll Caster Shell", US Patent 5599497.

[8] Breyer J. P., Walmag G., "Metallurgy of High Chromium-Molybdenum White Iron and Steel Rolls", Rolls for the Metalworking Industries, pp. 29-40, 2002.