STUDYING THE REASONS OF SURFACE DEFECTS IN THE CONTINUOUS CASTING BILLETS +

Saheb M. Mahdi *

Abstract:

Understanding the defects reasons in the continuous casting products is one of the main targets of manufacturing engineers, for those modern engineering techniques are desires, such as automation production process, control the product with X- ray, and infrared controlling. Iron and steel plants began to update production processes to satisfy the quality standard requirement. In this study defects that have appeared in the billets was recognized. Most of these defects can be confining in the surface and internal defects. Controlling on the molten steel will prevent the billets from most of these defects. This study was conduct in the iron and steel complex / Misrata-Libya. Defected of DIN St37-3 steel billets for the period of six months were document and sorted according to four types of the surface defects. These defects are longitudinal surface cracks, slag spots, arrest teeming defects and corner cracks. To precept the reasons of these defects, the controlling factors of the molten steel was studied, such as oxygen blowing, aluminum percentage added according to the required chemical composition, casting speed , tapping temperature and the treatment time. The conclusion was that most types of the generated defects were due to the presence of non-metallic inclusions in the molten steel, as well as it was due to the working circumstances.

KEYWORDS: continuous casting, steel billet, surface defects

دراسة أسباب العيوب السطحية في بلاطات المنتجة بسباكة بالصب المستمر

صاحب محمد مهدي

المستخلص :

أن معرفة أسباب العيوب في منتجات الصب المستمر هي واحدة مـن الأهـداف الأساسـية لمهندسـي التصنيع، والذي يستدعي استخدام تقنيات هندسية حديثة ، مثل اتمتة عملية الانتـاج ، اسـتخدام الاشـعة السـينية للمراقبة ، استخدام الموجات التحت حمراء للمراقبة . لذلك بدأت مصانع الحديد والصلب بتحديث عملياتها الإنتاجية، لغرض الحصول على الجودة المطلوبة في منتجاتها . تتضمن هذه الدراسة تحديد العيوب التي تظهر في البلاطـات. يمكن حصر اغلب تلك العيوب إما بالعيوب السطحية أو العيوب الداخلية. إن السيطرة على مصهور الـصلب سـوف يمنع تكون اغلب تلك العيوب في البلاطات. تمت هذه الدراسة في مصنع الحديد والصلب بمصراته – ليبيا.إذ تم عزل بلاطات الصلب St37-3 المعابة في فترة الدراسة والتي امتدت لمدة ستة أشهر، لاسيما تلك البلاطات التي تـضمنت

+Received on 7/2/2012 , Accepted on 22/10/2012 .

*Ass. Lecturer / College of Engineering/ Mustansiriya University

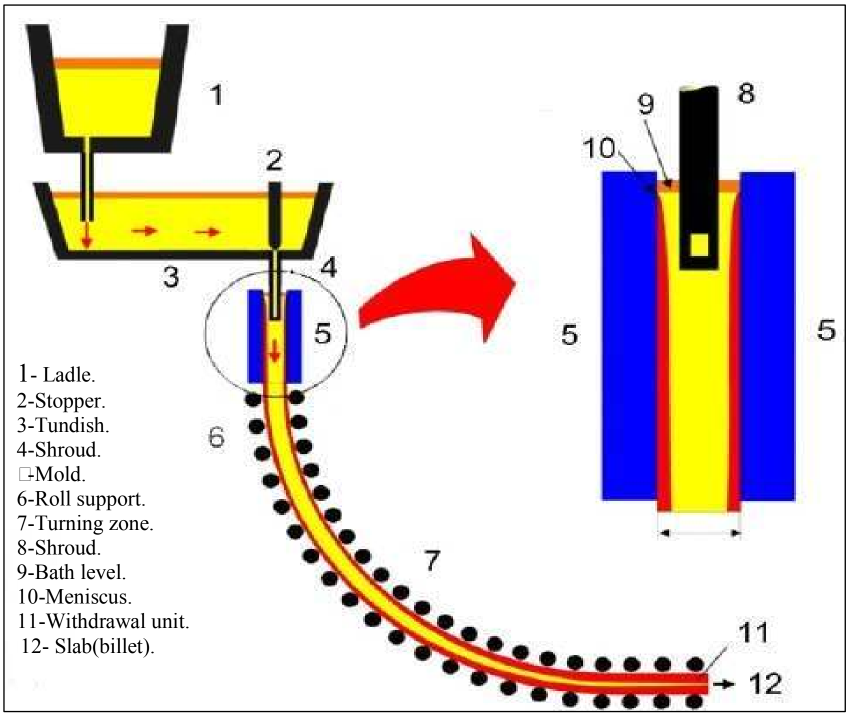
أربعة أنواع من العيوب هي ، شقوق السطح الطولية، بقع الخبث، عيوب توقف الصب والشقوق الزاوية. ولمعرفة أسباب تلك العيوب فقد تم دراسة عوامل السيطرة على مصهور الصلب ومن تلك العوامل، ضخ الأوكسجين, نسبة الألمنيوم المضاف اعتمادا على التركيب الكيماوي، سرعة الصب، درجة حرارة الصب وزمن المعالجة. إن الاستنتاجات التي تم الوصول إليها هو إن اغلب أنواع العيوب المتكونة يمكن أن تكون بسبب وجود المتضمنات اللامعدنية في مصهور الصلب، بالإضافة إلى عدم السيطرة على ظروف العمل.

Introduction:

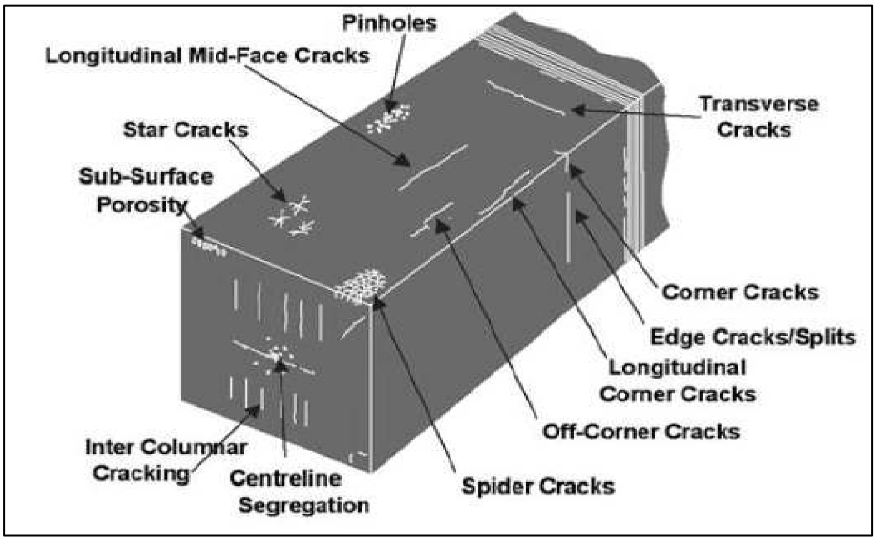
The annual production of Iron and steel making represents about 9□% of all metals in the world. They are still cheaper compare with other materials of the same uses. Where are in some cases no material can replace their uses and features[1]. In other cases, they are in competition by further metallic and non-metallic materials. Pure iron is useless because of its poor mechanical properties. Carbon is the main element added to iron to be useful in engineering practices. Carbon percent added to the base iron divided it to two main categories. One is term steel with carbon up to 2%, and the other called cast iron with carbon up to 6.67%. There is no limit for iron and steel alloys, by adding other elements such as Manganese, Chrome, Tungsten …atc, as well non-metallic materials like Silicon, Phosphor, and sulfur[2]. Any of these elements are added or removed to get the desire alloy of iron or steel with the required properties like malleability, ductility, strength[3,4]. Controlling of steel or cast iron can obtained through molten metal purification. Gases and non desirable materials must be removed, while another materials are added at the same time[□]. Existence of non-metallic inclusions in the ingots or billets had harmful effects on the steel products[6]. Also high gases concentration in the steel products will cause internal defects (micro cracks, porosities, vacancies)[7] which harm the mechanical properties of products, as well as it will affect other properties like magnetic permeability, electrical conductivity….etc. The demands of steels with insignificant quantity of gases, non-metallic inclusions, micro-porosity and homogeneous in its properties are increased to produce different kinds of industrial materials[8,9]. These requirements for steel products cannot be carry out without using advance technique, like using vacuum furnaces or inert gas blowing. The continuous casting process, both in the technological aspect as well as on the plant parameters, was and remained a basic concern of all the specialists in the major steel-making companies. The world energy crises, the consumers' quality demands, the need to adjust prices to the market demand, were the main factors that stimulated the technological development and generalization of the continuous casting process in the last 60-70 years[10]. Continuous casting process can illustrate as shown in figure (1)[11]. Continuous casting products can be exposing to defects; all defects can be separate into three main groups[12]:-

- Melting and casting defects,
- Charge heating up defects,
- Deformation working defects.

The billets occasionally suffered a range of surface defects, needing expensive, time-consuming surface grinding, and in severe cases, even downgrading or rejection. The reconditioning yard was often a bottleneck in the process, and the cost associated with removing these defects was about $3 □00 000 per year[13]. Understanding and controlling the casting process is important because it may introduce defects that persist into the final product, even after many later processing steps. These defects include oxide inclusions, porosity, segregation, and cracks[14].These defects can enumerate as shown the figure(2)[1].



Figure(1) illustrate continuous casting process.[11]



Figure(2) Schematic show the surface defects in the continuous casting

<u>Experimental work:</u>

In order to obtain the desired data, it should be analyzing by following up the below steps:

1- Knowing the charge, operation sequences and melting processes of electric arc furnace. As well as it should be known the following processes, how can the additives alloy added into the furnace and ladle, observing ladle treatment process, and how the workers are pouring the molten steel in the continuous casting mold.

2- Watch the daily and monthly reports of the heats production for six months (The period of the study). Then from the above reports, the defected heats that are chemically defected were isolated in order to study.

3- The operating values are well arranging in suitable tables.

4- The tabulated data is schematically drawing as shown in figures (6, 7, 8, 9, 10 &11).

□- Study those figures to attain the reasons for defects causes.

Results and Discussion:

Table (1) shows the chemical composition for steel grade DIN St37-3 . This grade of steel was study during the six months period.

Table (1) The chemical composition desired for the steel grade DIN St 37-3.

C	Mn	Si	P	S	Al	Fe
0.1	0.4 - 0.7	0.1	0.04	0.04	> 0.02	Rem.

From the daily and monthly operating reports, four kinds of defects has been detect. From fig.(3) the following defects were observed:

1- Longitudinal Surface Cracks.
2- Slag Spots defects.
3- Arrest Teeming.
4- Corner Cracks.

Fig.(3): Types and Number of defects in each month of study period.

Numbers of defects that were collect are ninety- three (93) defects. Sixty(60) of them are longitudinal surface cracks, nineteen (19) of them are slag spot defects, ten (10) are arrest teeming defects and four (4) are corner cracks.

To analyze the reasons of these defects, the graphs of working circumstance were draw in order to indicate the out of limits heats. The analysis is:

1- Longitudinal Surface Cracks: The causes for longitudinal surface Cracks are:

1.1 - Al% in the mold is higher than 0.04%, as shown in fig.(4) Where:
Total aluminum % = Al% dissolved in the molten steel + Al% in the alumina (Al_2O_3)
1.2 - Tapping speed is within allowable limits [as shown in fig.(□)], except few heats, tapping speeds are slightly lower than the average speed. The speed must be lower than 1.6 m/min; the pouring temperature is within the allowable limits. When the temperature is raised, the tapping speed must be reduced, and vice versa.
1.3 - Actually, there are another reasons like:
a) The direct cooling water splash is proportional to tapping speed which governed by a self-controlling system.
b) The interior taper mold shape is slightly small.
c) The immersion depth of snorkel is not enough; it must be between (80 to 160 mm).
d) Block of direct cooling spray nozzles around the hot billet, especially in the upper region.
e) Present of scratches in the mold's copper plates.
f) The viscosity of the mold powder is increased.
The reasons for longitudinal surface crack which shown its image in fig.(6) are:
i) From fig.(4), as mention above Al% rise may hardened mold powder layer (as lubricant), which yield to initiation of longitudinal crack.
ii) The speed of the withdrawn billet from the mold is inversely proportional to tapping temperature and directly proportional to the tapping speed, which must not exceed (1.6 m/min.), as shown in (fig.□).
iii) The blocking of some spray nozzles yield to inefficient cooling, which will increase the length and depth of initiated cracks.
iv) Lose of the mold side’s inclination will cause deep cracks to appear.
v) Inexact depth of snorkel will increase the probability of longitudinal surface cracks to appear.
vi) The increasing of the mold powder viscosity will cause to dissimilar cooling of the billet inside the mold, which will create the cracks.

Fig.(4): Quantity of Total Aluminum percent in the mold, It must be less than 0.04% Al.

Fig.(5) Casting speed of the Heats in M/min. It must be less than 1.6

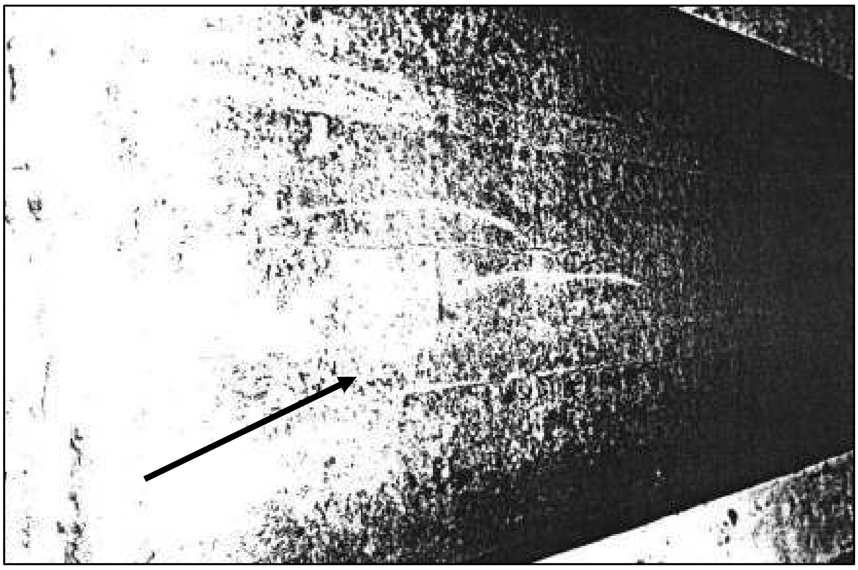


Fig.(6) show straight Longitudinal Surface

2- Slag Spots defects:
Type of steel, tapping speed, tundish temperature, total aluminum percent in the mold, the percent of active oxygen content in the molten steel of the ladle, total stirring time with argon

gas, and heats sequence in the tapping cycle are compared with the required working instructions, it's found that the percent of active oxygen was higher than (10 part per million) (10 p.p.m.) for some heats, as shown in fig.(7).
The reasons for slag spots defect which shown its image in fig.(8) are:
i) The existence of great layer of slag in the tundish may occasionally allow slag to penetrate into the billet.
ii) From fig.(7), the rise of the active oxygen percent in the steel (grade St 37-3), which is forming Alumina.
iii) From fig.(4), it found other reason for slag spots appearance such as plenty of hardened deposit alumina slag, thickness of mold powder, the remained of Alumina accumulation from the snorkel during cleaning process, lowering the head level of molten steel in the tapping side of the tundish will cause the slag to enter into the mold.

Fig.(7) Quantity of Active Oxygen, it must be less than (10 part per million.

Fig.(8) show slag spot defect.

3- Arrest Teeming:-

From the operating values for the billets that contain a defect it is notified that:

3.1 High argon blowing on the stopping bar will cause added aluminum to float.

3.2 From the actual working conditions, another reasons are found :

a) Large fluctuate of molten level in the mold.

b) The billet pauses in the continuous casting machine.

The reasons for arrest teeming defects are:

i) Also from fig.(4), Al% rise more than 0.04%, means rise of alumina. This rise will work to clog the snorkel.

ii) The rise of Argon quantity on stopping bar causes the floating Aluminum to oxidize.

iii) Worker's faults, like (large fluctuation of molten level in the mold and billet stopping in the machine).

4- Corner Cracks:

To understand the reasons of corner cracks defects, remark notes are list below:

4.1 For steel grade (St 37-3) the main tundish temperature must be (1□48 ± □°C).It is clear from fig.(9) that there is a variation in temperature up to 1□°C. This will lower billet temperature below the desired range.

4.2 Increasing total Al% have a bad effect on molten steel purity.

4.3 Figure (10) represent, the treatment time, the values are above the limits, which must be close to (30) minutes as maximum.

4.4 Actually, there are other reasons such as:

a) Increase S% in the steel for some heats than allowable limit.

b) The super cooling takes place in the edges.

c) Excess friction takes place in the edges.

d) Incorrect rollers exactness in the straightening zone, or the in the bending zone.

The reasons for corner cracks which shown its image in fig.(11) are:

i) Figure(9), shows the variation in temperature up to(1□°C) which leads to thermal stresses in the billet when it passes through the rolling machine.

ii) Total Al% rising will increase powder viscosity and then leads to increase the friction between mold and billet.

iii) Figure(10), shows that the rising treatment time will decrease tundish temperature from the minimum limits required for grade steel (St 37-3).

iv) The increase in S% acts with iron to form Iron sulfide, which is easy to fuse causing cracks in grain boundary's structure.

v) Non-uniform powder distribution and impurities existence help the occurrence of corner cracks.

vi) Non-uniform edges temperature of the billet will help the occurrence of corner cracks.

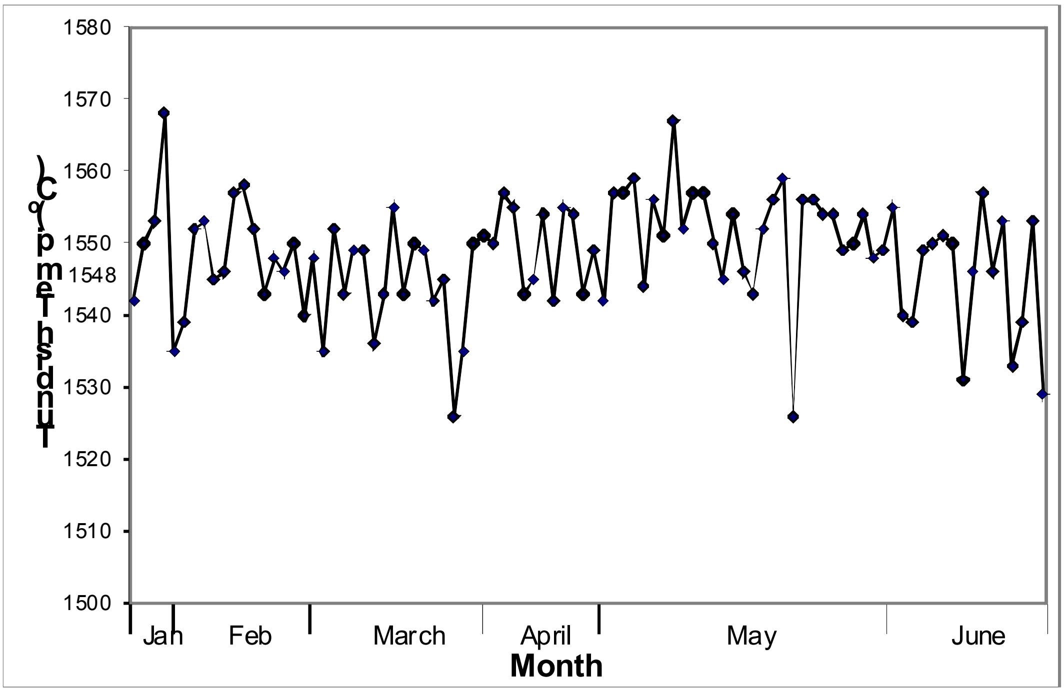


Fig.(9) Tundish Temperature, which must be in the limit of 1548°C higher or below with ± 5°C .

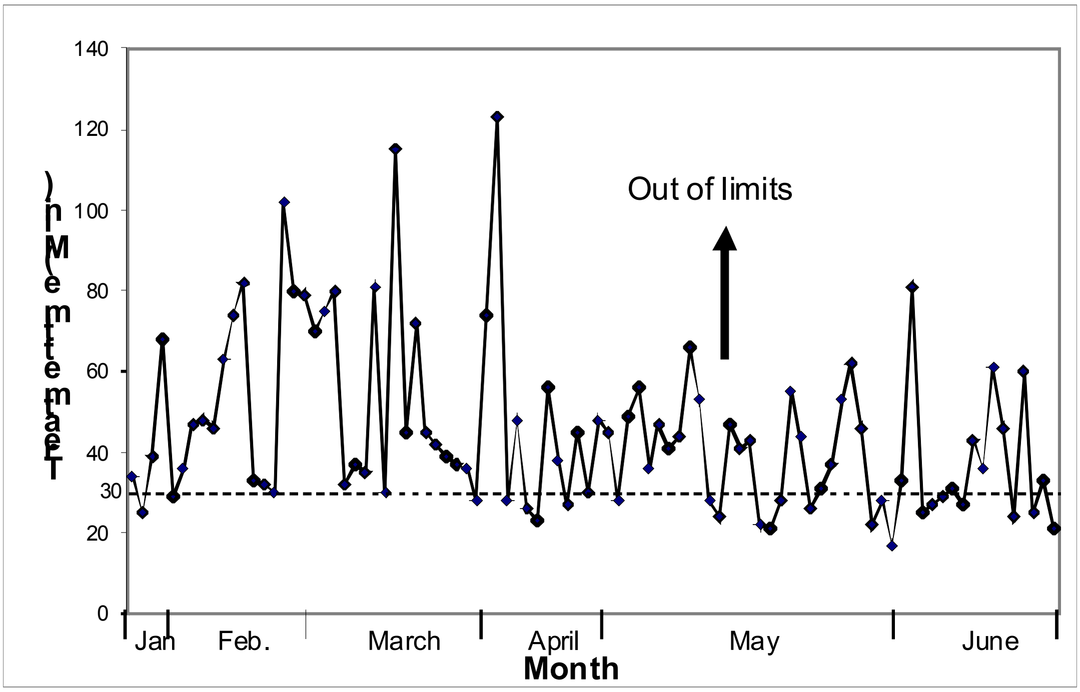


Fig.(10): Treatment time in minutes , it must be in the limit of 30 min.

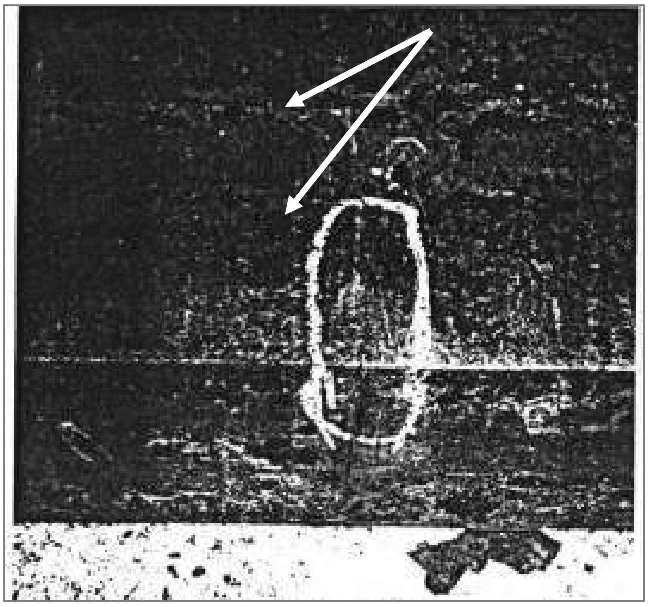


Fig.(11) show Corner Crack defect.

Conclusions:

The conclusions are as follow:-

1- Whenever the active oxygen percent becomes over than (10 part per million (p.p.m.)), the added Aluminum to the ladle during the treatment stage will oxidize and Alumina percent will increase in the molten steel, which is causing the impurities to be increased in the steel, leading to initiate longitudinal cracks and forming spot slag defects.

2- Whenever total Al% becomes higher than (0.04%), alumina percent increases in the molten steel, leads to increase inclusions in the steel. These inclusions will increase the probability of longitudinal cracks and spot slag defects.

3- Occasionally, during tapping (between the ladle and tundish), Aluminum will re-oxidize in case of partial shielding of low or bad blowing with Argon, which leads to increase the probability of longitudinal cracks and spot slag defects.

4- The stoppage of hardened mold powder during tapping will cause the longitudinal cracks and spot slag defects.

5- Lower or fluctuation of molten steel level is largely affect on arrest teeming defect. As well, it may cause longitudinal cracks and spot slag defects, especially at the beginning of tapping.

6- If the immersion depth of snorkel is not between (80 to 160 mm) from the mold tip, this will increase the probability of longitudinal cracks.

7- Increasing the impurities percent specially the alumina in the molten steel, makes the mold powder to be more viscous and harder, it will increase friction between copper mold sides and the billet, which initiates longitudinal cracks.

References:

1- Congress of The U.S.A., A technical Memorandum, "Benefits of Increased use of Continuous Casting *By the U.S. Steel Industry*", October 1979.

2- Haruyoshi Tannabe and Masayuki Nakada, "Steel Technologies Contributing to Steel Industries*", Nkk Technical review* No. 88 (2003). pp.18-27.

3-Australian Steel Institute," The Evolution of Australian Material Standards for Structural Steel " *, Journal of Australian steel institute* , Steel construction , volume 33 , Number 2 , June 1999.

4- Mayumi Okimori , Yoshimori Fukuda , Shigenori Tanaka , Masatake Hojo and Takeshi Nakano , "Improvement of Surface Quality of Austenitic Stainless Steel ", *Nippon Steel Technical Report* No. 87 January 2003.

□- Shufeng Yang, Jingshe Li, Lifeng Zhang, Kent Peaslee, Zaifei Wang," Evolution of Mgo·Al2O3 Based Inclusions in Alloy Steel During the Refining Process ", *Metallurgical and Mining Industry*,Vol. 2, No. 2,2010, pp87-92

6-Saheb M. Mahdi, Meftah A. Shetwan, "Quality Oscillation of Hot Rolled Coils Steel ", *Inzynieria I Aparatura Chemiczna* , 44 – September 200□, pp□1-□2.

7-B.G.Thomas and S.P.Vanka, "Flow Dynamics and Inclusion Transport in Continuous Casting of Steel", Manufacturing *and Industrial Innovation Research Conf.*, San Juan, Puerto Rico, January 7-10, 2002.

8- S. Mazumdar and S. K. Ray , " Solidification Control in Continuous Casting of Steel " *, sadhana* , Vol. 26 , part 1 & 2 , February – April 2001 , PP. 179-198.

9 - N. Pradhan, N. Banerjee, B. B. Reddy, S. K. Sahay, D. S. Basu, P. K. Bhor, S. Das and S. Bhattyacharya , "Control of defects during continuous casting of line pipe (API) quality steels " *, Scandanavian Journal of Metallurgy* Volume 34 Issue 4 August 200□, pp. 232 .

10- Erika Monica POPA, Imre KISS," Assessment of surface defects in the continuous cast steel",*Acta Technica Corviniensis-Bulletin of Engineering,Tome* IV(2011). ISSN 2067-3809.

11- Mirko Javurek “continuous casting”,*http://en.wikipedia.org/wiki/Continuous_casting* , 26 January 2008.

12- I. Mamuzic et al, " The analysis of defects on continuous cast billets", *METALURGIJA* 44 (200□) 3,pp 201-207.

13- B. G. Thomas, M. S. Jenkins, and R. B. Mahapatra," Investigation of strand surface defects using mould instrumentation and modeling", *Iron making and Steelmaking* VOL 31 NO 6, 2004, pp48□-494.

14- B.G. Thomas," Continuous Casting (metallurgy)", "Continuous Casting", *Yearbook of Science and Technology*, McGraw-Hill, 2004. pp1-6

1□- Lukas Pindor, Stepan Hefner, Jiri Cibulka, Rostislav Turon,” Non-Destructive Testing of Continuously Cast Billets by Means of the Laser Triangulation Method”, *18th World Conference on Nondestructive Testing*, 16-20 April 2012, Durban, South Africa.