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Hook crack in electric resistance welding line pipe steel

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Abstract

One of the production methods for API line pipe steel is electric resistance welding (ERW). This kind of pipes is encountered with hook crack which is one of the defects that is observed in the upset zone of ERW pipes, detecting by ultrasonic inspection. Hook crack is a small crack following the weld flow lines and if severe enough, opened up at the pipe surface. These defects were commonly associated with sulphide stringers and non metallic oxide inclusions.

In this research, welds containing hook cracks were obtained from Ahvaz pipe making factory. Scanning electron microscope (SEM) examination showed that all hook cracks were associated with small non metallic inclusions and X-ray microprobe analysis (EDX) was performed to detect the main elements associated with the inclusion. Hook cracks were found to be associated with Al_2O_3, CaO, CaS and MgO.

This work revealed that these defects can be eliminated using; calcium treatment and Argon stirring improvement in ladle furnace, also using tundish refractory with higher quality and control of melt flow in ladle furnace and tundish.

Keywords

electric, crack, hook, steel, line, pipe, welding, resistance

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HOOK CRACK IN ELECTRIC RESISTANCE WELDED LINE PIPE STEEL

BY

SIMA AMINORROAYA*, HOSSEIN EDRIS**, MEHRDAD FATAHI***

SYNOPSIS:

One of the production methods for API line pipe steel is electric resistance welding (ERW). This kind of pipes is encountered with hook crack which is one of the defects that is observed in the upset zone of ERW pipes, detecting by ultrasonic inspection. Hook crack is a small crack following the weld flow lines and if severe enough, opened up at the pipe surface. These defects were commonly associated with sulphide stringers and non metallic oxide inclusions.

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Keywords: API steel, Hook crack, Inclusion, Electric Resistance Welding

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INTRODUCTION:

Electric resistance welding process, locally heats the edges of the plate to a suitable forging temperature then the edges are pushed together, upsetting the wall thickness and forming a bond. The sequence of operations required in the fabrication of electric resistance welded tubing are[1]:

I. *Slitting:* Many manufacturer of tubular goods purchase wide-width coils which can be slit into the desired widths. Plates are slit by tool steel discs then strips pass to the coiler. The banded coils are ready for the forming process.

II. *Forming:* ERW mills normally make use of three types of rolls to progressively form the flat steel station into the round form prior to welding. These three types of rolls are: 1) Breakdown of forming rolls which provide the initial shaping of the strip towards the round form, 2) Idler vertical closing rolls which further close and fluid the strip into the last section, 3) fin pass rolls which provide perfect guidance into the welding section. These rolls are shown schematically in Fig.1.

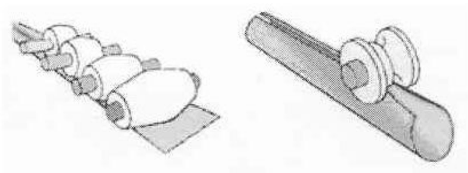

Fig.1: Schematic of forming rolls

III. *Welding:* After forming has occurred, the open tube passes directly into the welding section of the mill. The heat for welding is provided either by low-frequency power through electrodes wheels or radio-frequency power through sliding contacts or coil induction, typical radio-frequency power for welding is supplied at 450 KHZ higher or lower frequencies may be used.

IV. *Heat treatment:* After welding, the welded tube passes under a cutting tool which removes the flash resulting from the pressure during welding. After removing the flash, the tube is subjected to proper post-weld treatment as metallurgical required for instance such treatment may involve sub-Critical annealing or normalizing of the welded seam or normalizing of the full cross section of the tube.

V. *Sizing:* After Cooling, the tube is sized to obtain a round finished product of desired diameter. The sizing mill consists of several driven horizontal rolls and several idle vertical rolls. After the tube leaves the sizing mill, it is cut and is transferred to the finishing floor where they are straightened.

After finishing operation, tubes are inspected. Hook crack is one of the defects which is observed in the upset zone of the ERW pipe, after detection by ultrasonic inspection . they appear as small cracks following the weld flow lines and if severe enough, opened up at the pipe surface. If inclusions (usually manganese sulfide inclusions) exist in the wall thickness before the upsetting, they may crack during the upsetting process, creating the upturned fiber defect. In this weld, can also be observed that the upturned fiber on the inside of the weld. Hook crack are eliminated by using cleaner steel and reducing the heat input to the strip edges(a cold weld) [2]. Fig. 2 shows a scanning electron microscope micrograph of a typical hook crack, contain a flow line which has been deformed upward during weld upset.

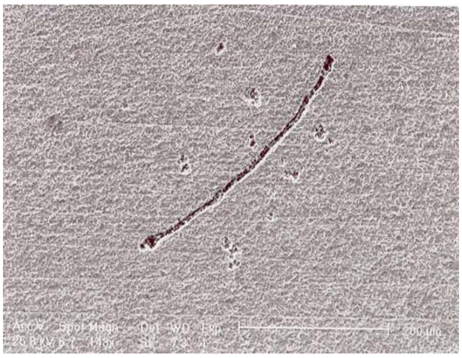

Fig.2: Typical hook crack

It should be mentioned that metallurgists regard nonmetallic inclusions as hook crack defect generator so steel manufacturer launched some researches on steel composition and also inclusion removal and their generation mechanisms on steelmaking and continuous casting processes [3,4].

Eaves et al. research [4] has shown that the inclusion composition which observed in the cracks were related to slab/coil edges or slab/coil center material . Edge related hook cracks were found to be associated with CaO, Al_2O_3 and CaS, whereas center ones were consistently linked to MnS and Al_2O_3 and also 76% of the problem was associated with slab/Coil centers.

The main reason of hook cracks formation in API steel pipes is non metallic inclusions. Generally, steelmaking in electric arc furnaces, secondary metallurgy in ladle furnaces, slab continuous casting and finally hot rolling are production processes for oil and gas transportation pipe line steel plates. Table 1 summarizes possible inclusion sources and their key elements [5].

Table1: Possible inclusion sources and key elements [5]

	Source	**Key elements**
Furnace	Furnace slag Furnace refractories Ferroalloys	Ca Ca Cr, Al, Si
Tapping	Launder refractories Oxidation	Mg, Ti, K FeO
Ladle	Deoxidation Ladle slag Ladle refractories	 Ca, Mg Mg, Ti, K
Teeming	Stopper and nozzle refractories Oxidation Deoxidation	Mg, Ti, K FeO
Ingot mold	Refractories Deoxidation	Mg, Ti, K
Heat treatment and rolling	Surface oxidation Surface sulfurization Inner oxidation Hot shortness	Feo FeS SiO_2 FeS
Welding	Welding slags Electrode coatings Steel inclusions Hot tearing	Ca, Ti Ti, V S

This table shows non-metallic inclusion generators exist at the beginning of EAF process and they are heading toward the end of welding process which production stages are finished. Electrodes coating usually will be an inclusion source entrance, when the weld process uses electrodes. However, in ERW method which does not use electrode, this possible inclusion source is omitted completely. On the other hand, hook cracks are observed in the plate thickness therefore surface oxidation through hot rolling and heat treatment can not be responsible for hook crack. It should be noted that there are strong stirring in electric arc furnaces in order to derive the intensive metallurgical reactions for this reason. As a matter of fact, inclusion removal is impossible in this stage of steelmaking process. Hence, Inclusion generation prohibition and its removal from the steel melt begin at the furnace tapping process and will be continued until solidification in the mold.

EXPERIMENTAL:

Mobarake Steel Company (MSC) is about 50 km far from Isfahan, a centrally located city in Iran. Steelmaking unit in this factory includes eight 200 metric tons electric arc furnaces which are equipped with eccentric bottom tapping (EBT) and also four ladle furnaces which stir with Argon blowing through porous plugs. Slabs cast with four vertical bending machines in this company. A part of MSC steel products is included steel for the manufacture of electric resistance welding line pipes to the API specifications. Ahvaz pipe making factory uses MSC steel plates to produce pipe for sweet and sour gas applications. Hook Cracks had been the most significant steel related defect reported by this factory. Welds containing hook cracks were obtained from Ahvaz pipe making factory. Table2 shows the sample numbers, sample codes in welding factory and also coil and melt numbers for each ultrasonic inspection and metallographic examinations confirmed defected samples. Scanning Electron Microscope (SEM) examination has shown that all hook cracks were associated with nonmetalic inclusions and X-ray microprobe (EDX) was performed to detect the main elements associated with the inclusions.

Table2: Sample numbers and their codes

Sample number	Ahvaz pipe making company code	Melt number	Coil number
1	130-6	070690	5526121
2	126-6	01056	5746021
3	101-16	030848	5626141
4	108-12	010857	5546271
5	138-4	010856	5626011
6	145-8	010856	5576111
7	9-13	911896	1646441
8	13-8	942047	1586501

DISSCUSTION:

It is clear that some of the coils are mentioned in table 2 came from the same melt. Because of that, the samples are rearranged in table 3 by the melt numbers. Energy dispersive spectroscopy analysis which was performed on inclusions, detected Ca, Al, Mg, S and O elements. In the last column of this table, the inclusions which might be associated with these elements are shown for each sample individually. Major compond of these elements are CaO. Al_2O_3, MgO and CaS.

Table3: elements and possible inclusions in cracks

Melt No.	Sample No.	Elements	Possible inclusions
030848	3	Ca, Al, S, O	CaS, Al_2O_3, CaO
		Ca, Al, O	CaO, Al_2O_3
010857	4	Mg, O	MgO
010856	2	Mg, Ca, Al, O	MgO, CaO, AL_2O_3
	5	Ca, Al, S, O	CaO, Al_2O_3, CaS
	6	Ca, Al, Mg, O	CaO, Al_2O_3, MgO
070690	1	Ca, Al, O	CaO, Al_2O_3,
911896	7	Al, O	Al_2O_3
942047	8	Al, Mg, O	Al_2O_3, MgO

Sims and Forgeng [5] classified the inclusion sources into two groups of endogenous and exogenous. The endogenous inclusions precipitate due to reaction from steel or during freezing. These kind of inclusions are small, numerous and rather uniformly distributed and also are typical of the steel in which they occur. The exogenous inclusions not only are produced from mechanical and chemical erosion of refractories and other materials that come in contact with molten steel, but also arise out of oxygen pick up by teeming stream and consequent oxide formation. This group of inclusions is large, scarce and haphazard in occurrence. Recent study on hook cracks has revealed that the inclusions are non-uniform in distribution and they were observed in some melts and also some coils of a melt. Therefore the inclusions which were detected in hook cracks are in the exogenous inclusion classification.

It is obvious that the first coil of the first melt of the continuous casting sequence has the most turbulence in tundish. It seems that mechanical erosion of refractories, slag-metal mixing and reoxidation of killed steels increase for this special coil. Hence the production history of the coils which were consisted hook cracks were investigated in order to find out that if they have been produced in mentioned above conditions. Table 4 summarizes the production history of supposed melts. It should be mentioned that non of the coils was the first slab of the first melt in continuous casting machine so it can be concluded that the slab position should be omitted as a source of observed inclusions.

Table4: production history of defective plates in continuous casting

Sample No.	Coil No.	Melt No.	Which melt of sequence	Which slab of mentioned melt
1	5526121	070690	First melt of third seq.	Fifth
2	5746021	010856	Second melt of third seq.	Sixth
3	5626141	030848	First melt of first seq.	Fifth
4	5546271	010857	Third melt of third seq.	Sixth
5	5626011	010856	Second melt of third seq.	Second
6	5576111	010856	Second melt of third seq.	Third
7	1646441	911896	First melt of second seq.	Fifth
8	1586501	942047	First melt of first seq.	Tenth

Steelmaking and continuous casting processes of API steel plate production in Mobarake Steel Company were investigated and possible inclusion sources at different stages of production and also their key elements summarized in table 5. The production histories of supposed melt showed that all melts had treated by calcium aluminate in ladle furnace but two last ones. As can be seen in table 4, the inclusions are included CaO- Al_2O_3, CaO-Al_2O_3-MgO. To study these combinations, Fig.3 shows a part of the CaO-MgO-Al_2O_3 phase diagram [6]. Composition of used calcium aluminate was 12CaO.7Al_2O_3. This flux is fluid in steelmaking temperature but it is able to create 3CaO.MgO.2Al_2O_3 particles, which is solid in the steelmaking temperature range, in compound with MgO. Of course, the solid inclusions have less opportunity to remove than liquid ones [7].

Table5: Possible inclusion sources in MSC

Production stage	Sources	Key elements
Electric arc furnace tapping	Furnace slag Oxidation	Ca, Si, Mg Al, Si, Mn
Ladle	Ladle slag Ladle refractories	Ca, Al, Mn Mg, Al, Ti
Ladle tapping	Oxidation Ladle slag Sand filler of nozzle	Al, Si, Mn Ca, Al, Mn Si, Cr, Mg, Al
Tundish	Tundish slag Tundish refractories Nozzle and stopper refractories	Si, Ca, Al Mg, Ti Mg, Al, Ti
Mold	Mold powder Oxidation	Si, Ca, Al, Mg Al, Mn, Si

Sims and Forgeng [5] discussed some of the common formation mechanisms of exogenous inclusions and concluded that mechanical erosion is not serious reason. The most serious damage to refractories and the most potent source of exogenous inclusions is a combination of chemical attack and mechanical erosion. Since the presence of CaO in inclusions is a common finding and exogenous slag particles are responsible for it [5], the Ca peak observation in EDX pattern of most existence inclusions in hook cracks of the present study have shown that slag particles were responsible for it. There are variety type of slag in different stages of steelmaking and continuous casting processes and these inclusions can be come from electric arc furnace, ladle furnace, tundish or mold slag. Since, Si has been observed in none of the inclusions and on the other hand, SiO_2 is the major component in mold powder, it is obvious that these non metallic inclusions can not be caused by mold powder entrapment.

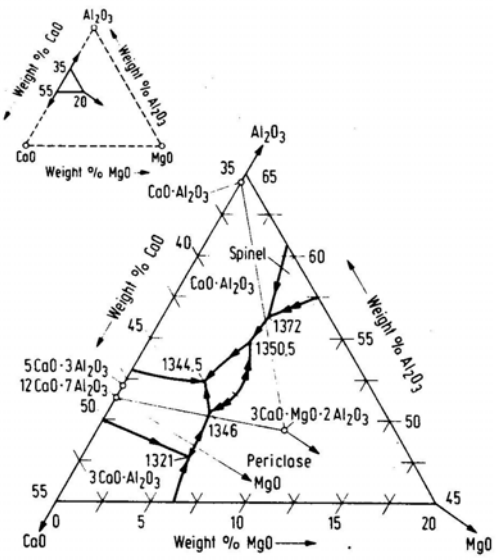

Fig.3: Ternary phase diagram of CaO-Al_2O_3-MgO[6]

As can be seen in table 3, there are inclusions contain S such as CaO-Al_2O_3-CaS. The presence of sulfur in samples 3 and 5 along with Al, Ca and O has shown that calcium Aluminate is entrapped in the melt after desulphurization. The summary of the samples with inclusions associated with them and their possible sources are shown in table 6. Table 7 summarizes the main sources beside the suggested elimination and reduction methods.

CONCLUSION:

Investigation on hook cracks in electric resistance welded line pipes which produced from Mobarake Steel Company coils has declared that this defect will be reduced by respect to below parameters in steelmaking and continuous casting processes of this company:

- control and reduction of EAF slag carry over to ladle and also ladle slag carry over to tundish
- Melt flow control in ladle furnace and tundish to promote flotation of inclusions
- Calcium treatment in ladle furnace for low sulfur content steel grades
- Using tundish refractory with higher quality
- Using suitable tundish powder instead rice ash

Table6: Possible non metallic inclusion sources which were observed in Hook crack samples

Sample No.	Observed inclusions	Possible inclusion sources
1	CaO, Al_2O_3	Entrapped calcium aluminate particles, Ladle and Tundish slag
2	CaO, Al_2O_3, MgO	Calcium aluminate in compond with MgO, Ladle and Tundish slag, Sand filler of nozzle
3	CaO, Al_2O_3 CaO, Al_2O_3, CaS	Entrapped calcium aluminate particles, Calcium aluminate after desulphurization, Ladle and Tundish slag
4	MgO	Tundish refractories
5	CaO, Al_2O_3, CaS	Calcium aluminate after desulphurization
6	CaO, Al_2O_3, MgO	Calcium aluminate in compond with MgO Ladle and Tundish slag, Sand filler of nozzle
7	Al_2O_3	Reoxidation of Aluminum
8	Al_2O_3, MgO	Ladle, nozzle and stopper refractories, Sand filler of nozzle

Table7: Inclusion sources and their suggested elimination methods

Inclusion sources	Inclusion reduction and elimination methods
Refractories	Selection of tundish refractory with higher quality Melt flow control in ladle Melt flow control in Tundish
Oxidation	Selection of tundish refractory with higher quality Melt flow control in ladle Melt flow control in Tundish
Slag	Reduction of slag carry over Melt flow control in Tundish Suitable Argon stirring in ladle Selection of suitable tundish powder
Nozzle sand	Melt flow control in Tundish Selection of suitable tundish powder
Inclusions which are caused by calcium aluminate	Melt flow control in ladle Suitable Argon stirring in ladle

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