11-13 November / Kasım 2010, Tüyap, İstanbul
5th International Ankiros Foundry Congress
5. Uluslararası Ankiros Döküm Kongresi

DUCTILE IRON PIPE SURFACE CHARACTERIZATION AND PINHOLE FORMATION

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Content

1. INTRODUCTION

- It is well known fact that ductile iron pressure pipes are produced by centrifugal casting in industry(The De Lavaud Process).

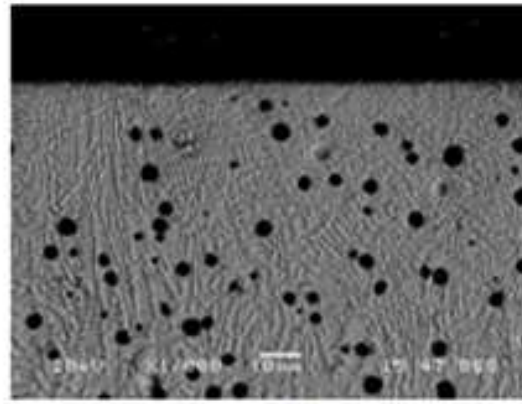
- The casting machine consists of a cylindrical steel mould surrounded by a water jacket and is mounted on rollers, so that it can be rotated.

- It facilitates to produce long (≈ 6 m) and big diameter (100 mm to 2000 mm) pipes.

- Centrifugal castings have many of the same defects as static castings.

- Cold shots due to unmelted globules, penetration (dips) due to mould coating, cold shuts (laps) due to misrun and pinholes (blowholes) due to moisture can be observed on pipe surface.

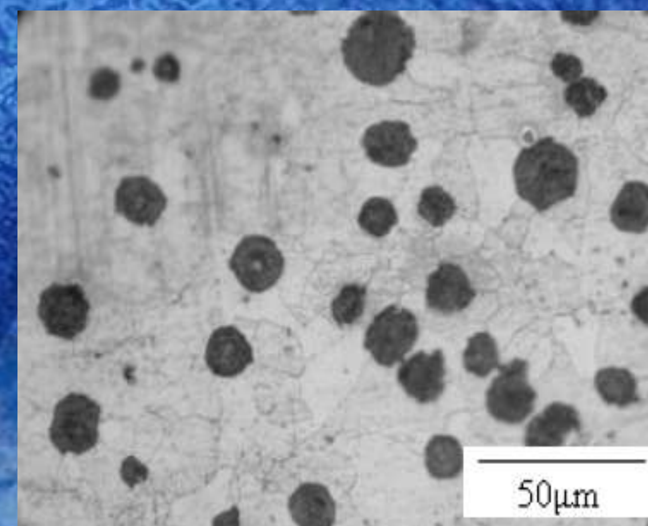
a)



b)

Ductile iron pipes: a) Hot surface of pipe during the removal from centrifugal casting machine. b) As-cast ductile iron pipe surface and structure (SEM)

c)



d)

Ductile iron pipes: c) DIPs at site d) Ductile iron pipe cross section micro structure after annealing treatment (Optical).

- Since ductile iron pipes are generally used as as-cast condition, unique surface structure becomes important.

- If, specifications indicate, surface coatings (Zn, Zn/Al, epoxy, bitumen, PE etc.) are applied on pipes for protection or seal.

- According to UK Water Industry Research (UKWIR) Report, pinholes in ductile iron pipes have an important role for defect formation and pipe failure.

- During the usage, if as cast pinhole defects are available, they deepen and penetrate all over the pipe width. Corrosion pinholes which formed later are out of scope of this article.

- The size and the number of pinholes significantly lower the fatigue strength as well as total performance of the casting. Obviously, this is important for pipes which are under cycling traffic load and water hammering.

- Cast iron mostly has a liquid film composed of a low melting point mix of oxides.

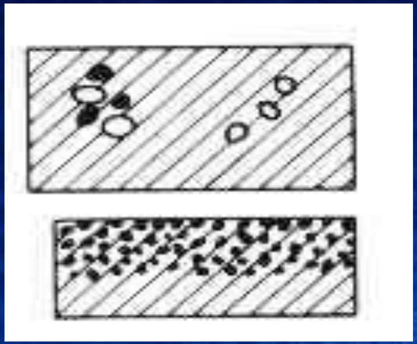
- On entrainment of the surface the liquid film joins to the other folded over liquid film and immediately coalesces, forms droplets and floats out.

- Small irregularly shaped graphite spheroids and possibly malformed spheroids form as a result of local loss of Mg.

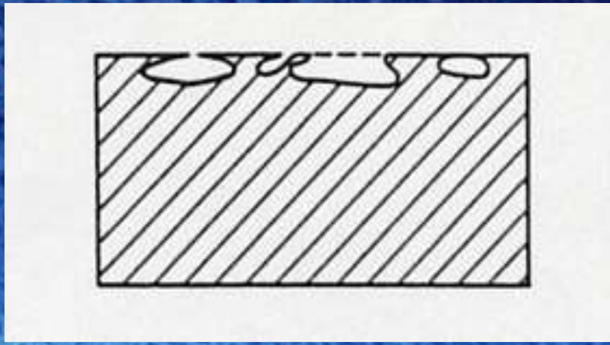
- Liquid films can easily move outs at centrifuging and there are no internal oxide problems in both of the irons as it is expected.

- Ductile iron pipe goes to annealing treatment after casting and thick layer of surface oxides form. Oxide layer on the surface protects the ductile iron from corrosion if it is continuous and smooth.

Defect B111. Blowholes and pinholes



Defect B121. Surface blowholes



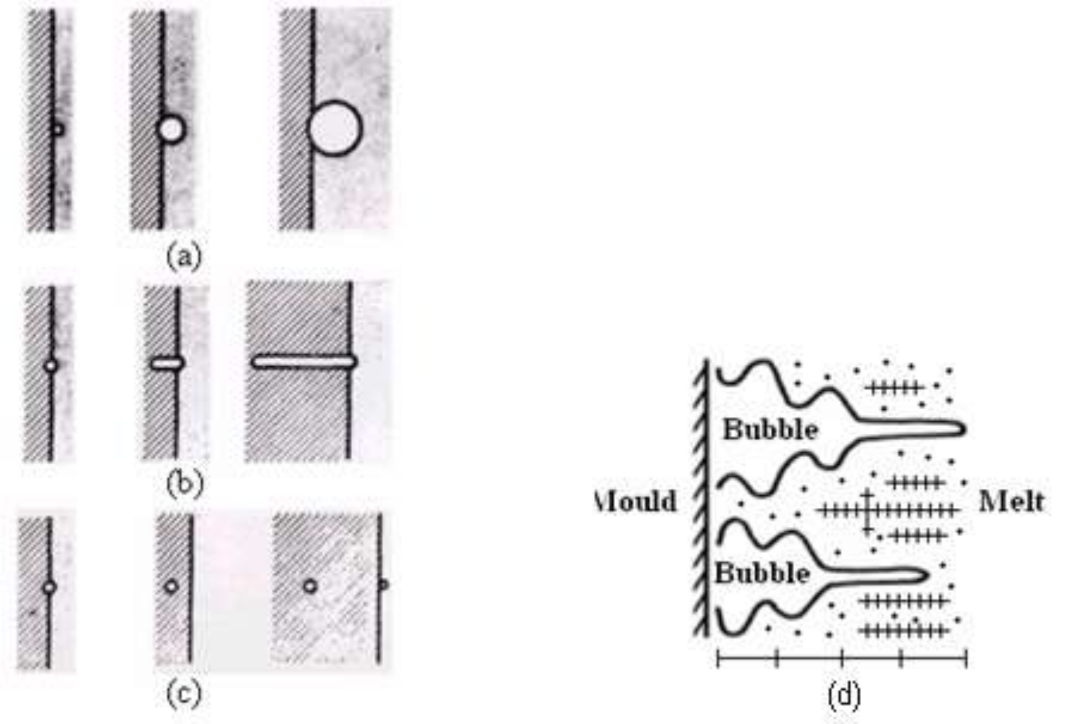
AFS International Atlas of Casting Defects

- **Pinholes are likely to occur on thinner pipe. One common cause of pinholes is moisture retained in the mould coating or some constituent of the coating that turns to a gas when the molten metal comes into contact with it.**

- **This gas, as well as gas generated from internal source of melt tends to migrate and the easiest path, in most cases, is through the molten metal.**

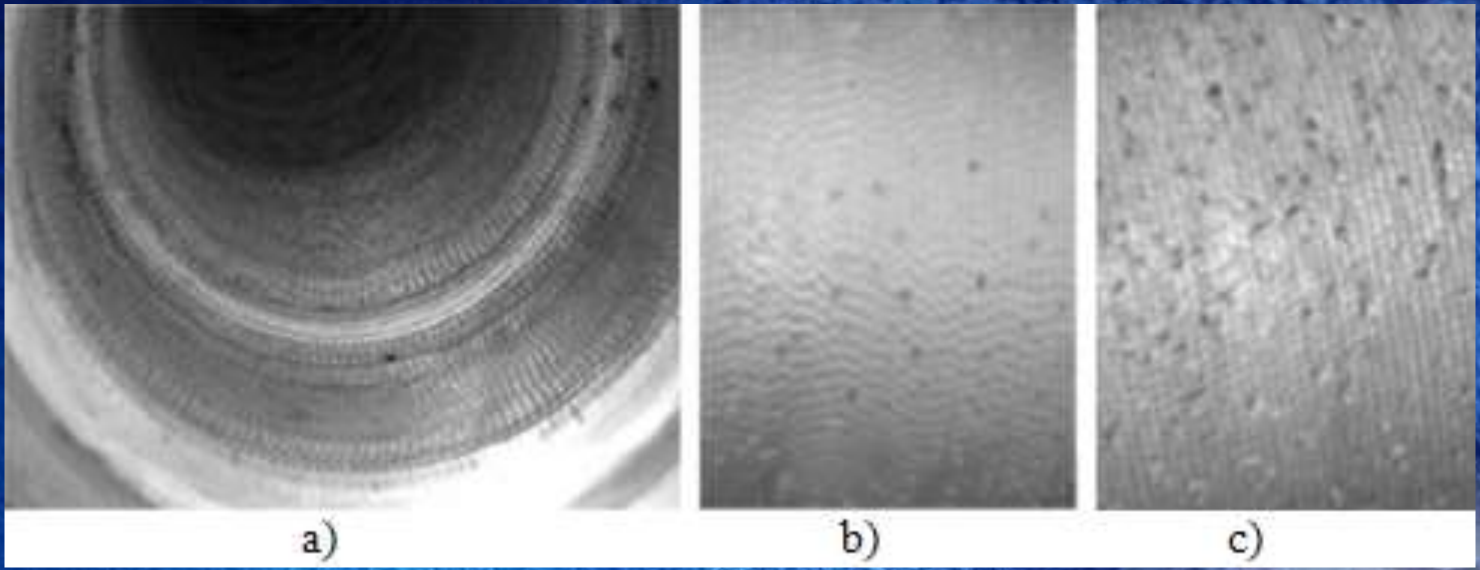
- **Surface and subsurface pinhole grows in competition with solid layer, into melt. The pore gains gas from the surface reaction, and loses it from its growing front. If growing front is entrapped by solid layer or if the surface of pinhole is covered by oxide, smooth pore shape becomes curved and twisted.**

- **However, when the molten metal is in the process of quick solidification and first solid layer forms immediately, the gas will become entrapped, curved as they emerge from the coating.**



Pinhole formation: a) Slow growth rate of solid layers. Bubble can move with the interface behavior of pushing (no pinhole left in the casting). b) Intermediate growth of solid layer. Bubble can become incorporated into the interface to grow as an elongated pinhole (surface pinholes on casting). c) Fast growth of solid layer. Surface entrapment of pinholes which can be rapidly overgrown by the interface (small holes separated in casting). d) Skech drawn at present work. Surface pores growing together from a mould surface of high gas content in centrifugal casting. Growing front elongates into a melt.

• Since layer formation rate or growth rate is very high in centrifugal casting (hundreds of μm/sec in centrifugal castings, tents of μm/sec in sand casting) cylindrical surface pinholes generally develop on pipes .



• Steel mould (a) and ductile iron pipes (b-c) produced centrifugally. a) Steel mould with internal wavy zone to hold solidifying pipe. b) Surface of pipe produced under very high molten metal temperature (Moulds internal wavy zone pass to pipe surface. Pin pointing pinholes are clear). c) Surface of pipe produced under very low molten metal temperature (Moulds internal wavy zone can hardly be seen on the pipe. Curved cylindrical pinholes are clear).

- **Corrective measures include elimination of gassing possibilities; use of an exothermic pipe eliminator to promote unidirectional solidification and the appropriate pouring temperature possible without causing cold shuts. Shortly, pinhole defects can be avoided by taking below given precautions:**

1. **Making the mould carefully and maintaining its temperature accurately,**
2. **Using coating materials that contain less volatile mixture, less moisture and no free water of crystallization,**
3. **Maintaining an accurate molten metal temperature,**
4. **Taking the relatively high mould rotation speed.**

- **Pinholes or pinhole defects may be categorized as entrapped, aspiration, evolution, reaction or other pinhole types. This article deals specifically with entrapped pinholes generally associated with mould coating volatiles and moistures.**

- **Surface oxide layers and protective values of them are also searched.**

2. EXPERIMENTAL PROCEDURES

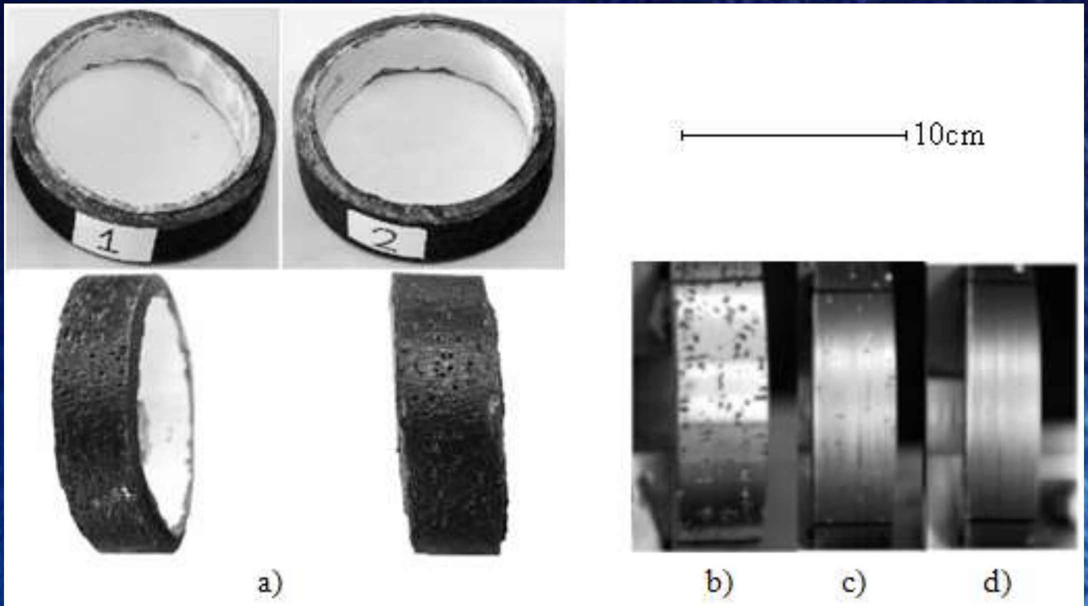
- The materials used for pinhole and surface oxidation study were GGG 40 grade ductile irons which were cast in steel mould water cooled De Lavoud type centrifugal casting machine.

- Normally, defect-free pipes are in production as long as process parameters such as melting condition, flowing rate, rotation speed and temperature, etc. are strictly followed.

- Surface topography, number, shape, volume fraction of pinholes in given area were examined.

- The specimens with machined layers up to 2mm of depth removed from surface gradually and at each stage pinholes were examined.

- One of the ductile iron pipe ring which has much pronounced pinholes are given in following figures which show changing of surface topography due to machining.



• Pinhole rich pipe rings , DN100 (118mm OD, 106mm ID) and surface machining. a) Four ductile iron pipe ring samples (6mm alloy wall thickness, 3mm internal cement lining and external bitumen paint are evident. Note that under the bitumen paint thin zinc coating and surface iron oxide are available. b) 0,5mm depth machining, c) 1mm depth machining, d) 1,5mm depth machining.

• Results were graphed and statistically analyzed using the proper procedure.

• Pinhole numbers by point counting and total surface area of pinholes by line intercept were measured on as-cast and machined surfaces.

• Changing the structure towards the surface, around the pinholes and chemical composition were searched by optical and SEM microscopy as well as EDS techniques.

•The hardness of matrix structure, oxide layers and the structure close to pinhole were measured by using a Vickers hardness tester. The hardness was measured at 10 points under a load of 100 gr.

3. RESULT AND DISCUSSION

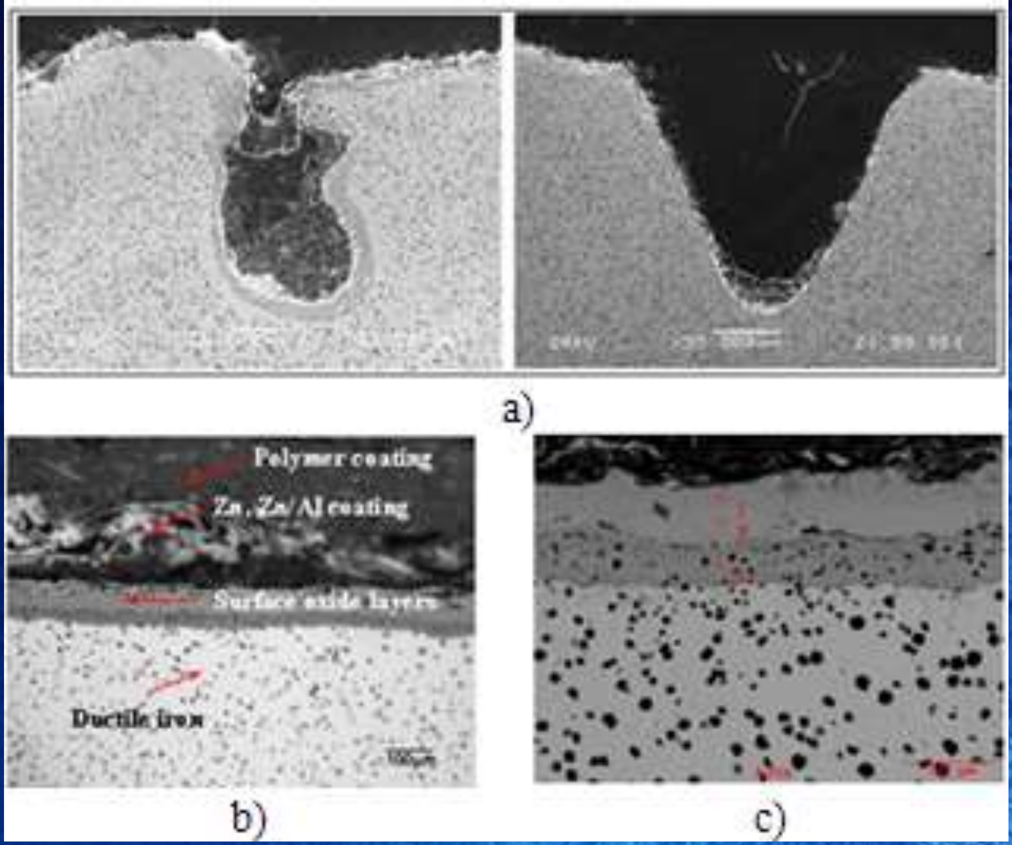
- It is believed that during centrifugal casting, when ductile iron liquid is hot enough or mould temperature is high, thin Fe layer develops at early stage.

- The wall of the pinhole canal can be covered by thin and fragmented oxide layer. SEM study showed thick iron oxide layer of the canal after annealing.

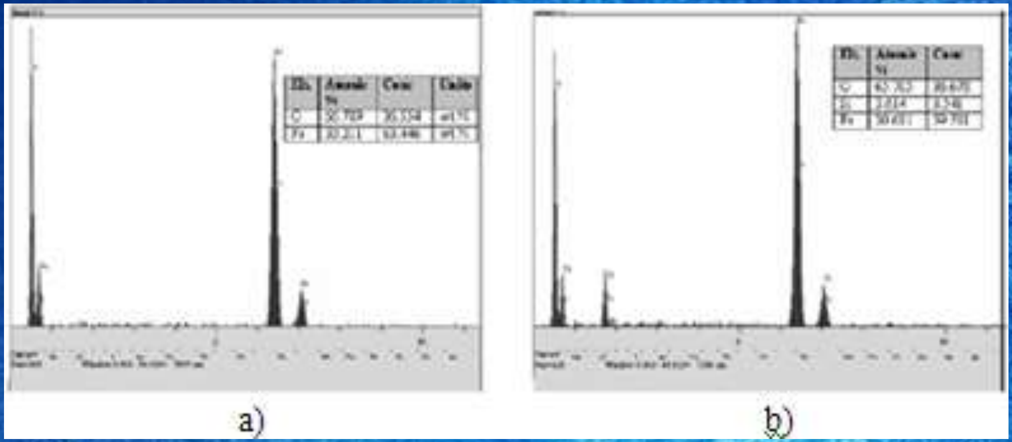
- If the first solid layer formed on the mould is thick enough under the condition of low liquid metal temperature (or cold mould), entrapped gas can't move inside towards the pipe wall. Entrapped gas amount and pressure increase by the time and lateral curved gas hole develops.

- Curved, dendrite or conical shape is evidenced during experimentation. As given in figure, pinhole lenght is as long as 1.7mm which is too much and unacceptible.

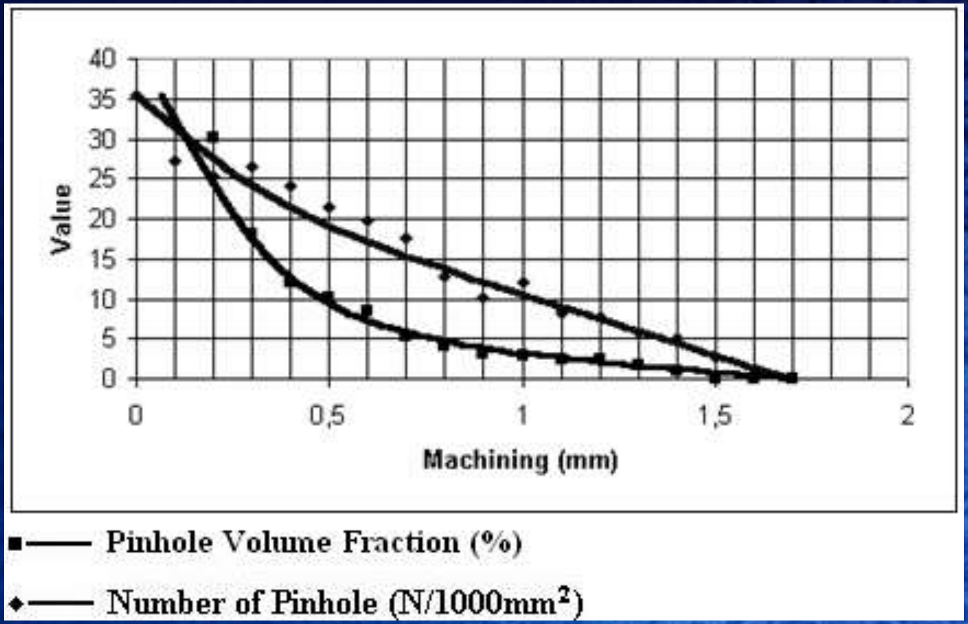
- Gradual decrease of number of pinholes with depth is understandable. Step reduction of volume ratio with depth implies conical shape of pinholes as sketched in figure.



Pinholes and oxide layers (SEM pictures) a) Shape and depth of pinholes in transverse section. b) Oxide layers on surface without pinhole. c) Oxide layers on pinhole edge. All pictures were taken after annealing treatment.



EDS pattern of sample given in figure . a) Point 2, b) Point 3



Changing the number and volume fraction of pinholes with machining depth from the surface.

- Optical and SEM microscopy study showed that ductile iron surface layer developed is nearly pure iron which is very ductile and easily deformed due to gas pressure. If conditions prevail gas penetrates inside from this hot iron layer.

- Iron film can be oxidized most probably at the lateral stages of solidification and during annealing.

- Rarely, fragmented oxide films observed on the surfaces of ductile iron pipes.

- It is clear from figure that oxide film is rather thick, if the heating temperature is high and period is long enough (~950°C,~ 1h).

- Around pinholes and on all the surfaces three oxide layers were recognized but there were no clear boundary between the layers. EDS tests supported these findings.

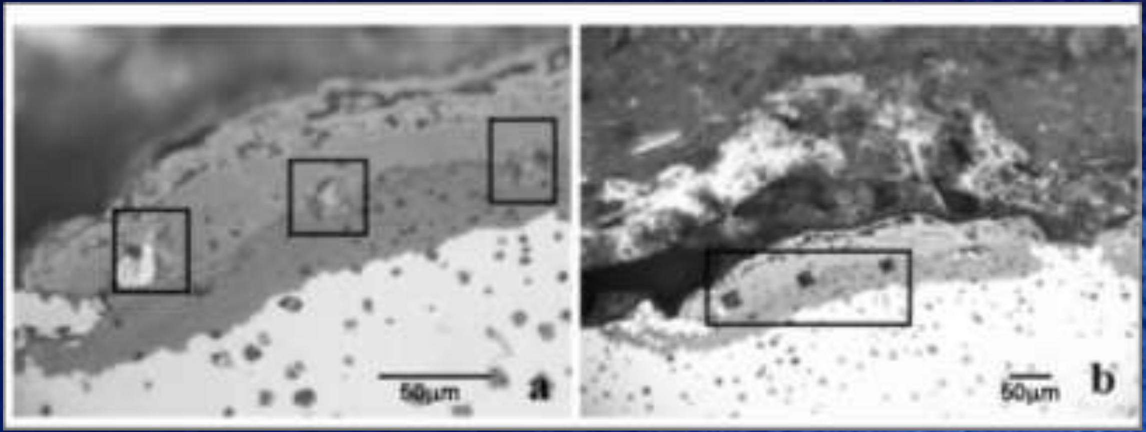
- While outer surface layer is oxygen rich, the layer nearby ductile matrix is oxygen poor.

- Total thickness of oxide layer was approximately 80 mm. The thicknesses of each layer were more or less equal.

- Fragmented surface oxides and other two layers with color differences can be seen in figures.

- Present result was compared with previous findings:

- The research study made by Horn measured total thickness of 143 mm with similar layers and structures observed at present research. Rather low thickness experienced in present work is due to different heat treatment and temperature.



Layers of annealing oxides and indenter traces. Mean values (HV): ductile iron substrate (belov matrix)=240±15, inner oxide layer(right trace)=480±25, middle oxide layer(middle trace)=380±27 and top oxide layer(left trace)=320±40.

- The hardness tests gave different values in different layers.
- Although, big hardness deviation was available in each layer, there are clear differences in morphology and hardness of layers as expected.
- Since oxide layer thickness was so small and upper layer was rather fragmented, taking the accurate measurement was difficult.
- Hardness of oxide in first layer was approximately 480HV which is 2 times higher than ductile iron matrix (240HV).

- Previous study on steel indicates that the first oxide layer adjacent to matrix is magnetite (Fe_3O_4).
- Annealed steel surface oxide bonding to matrix is relatively weak.
- Ductile iron annealing surface first oxide layer is Fe, Si, O rich and has good bonding.
- In steel because the different coefficient of expansion between the substrate (steel base) and the oxide cause the scale to become detached.
- However, in ductile iron, it is believed that availability of silicon in matrix is helped the formation of good bonding.

4. CONCLUSIONS

1. Using today’s state of the art ductile iron processing, foundries can produce castings with a very low incidence of pinhole defects.
2. The best results are obtained when melting and pouring is controlled carefully.
3. In addition to these, the centrifugal casting needs proper adjustment of mould temperature, mould coating and mould rotation.
4. When procedures aren’t followed with care, pinholes can be serious defect on ductile iron pipes produced by centrifugal casting.
5. Liquid metal composition (like Al, Mg levels) and availability of gas forming elements (H, N, O) in liquid affect pinhole formation.
6. Pinholes develop due to internal effects move inside the pipe and escape.
7. Solidification dynamics are involved in the centrifugal casting. Main cause of pinhole in this process is generally mould coating and parameters of centrifuging.

4. CONCLUSIONS

8. Surface pinholes with curved cylider and dendrite shape can penetrate to the pipe from surface to one fourth of the cross section.
9. Pinhole defects can be avoided by maintaining liquid-mould temperature accurately, using coating materials that contain less volatile mixture-less moisture and taking the relatively high mould rotation speed.
10. As-cast ductile iron pipe surface has both casting oxide and thick annealing oxide.
11. The abrasive blast surface preperation is not economical and negates the protective effects from resulting from annealing oxide.
12. It is observed that bonding between oxide layer and ductile iron matrix is relatively good and continuous. 3 easily detectable oxide layers cover all the surfaces of pipes as well as pinhole pools. It is believed that first layer above ductile iron matrix has remarkably good protective value against corrosion.

Acknowledgement

The work reported here is part of a research project on "105M061 High Performance Thermal Spray Coatings". The financial support by TUBITAK (The Scientific And Technological Research Council of Turkey)

TÜBİTAK

The Scientific and Technological Research Council of Turkey

Materials supply by ISKI (Istanbul Water And Sewerage Administration) are gratefully acknowledged.

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Thanks !

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