Zorica Kovačević[1)]
Zoran Karastojković[2)]
Vujadin Aleksić[3)]

1) Institute for Testing of Materials, Belgrade, Blvd. vojvode Mišića 43, mail: zorica.kovacevic@ institutims.rs

2) Technical College, Novi Beograd, Blvd. Dr Zorana Djindjića 152a, mail: zoran.karastojkovic@ gmail.com

3) Institute for Testing of Materials, Belgrade, Blvd. vojvode Mišića 43, mail: vujadin.aleksic@ institutims.rs

MICROSTRUCTURE AND CHARACTERISATION OF QUALITY WATER PIPES AFTER 50 YEARS IN SERVICE

Abstract: *Grey cast iron is the most common material used in-service water pipes and water distribution in Serbia. It is also a material which has the largest number of damages and failures per kilometer of pipeline per year. However, during a long service period, because of the surrounding environment (soil), decreases the quality and reliability of this material, so that after fifty years of work, the pipe is damaged, and the usefulness of reduced or completely eliminated. It was found that the graphitization, ie. graphitic corrosion in those pipes, is the most responsible for their degradation, with the entire water system in the city is becoming unreliable.*

In this paper is presented metallographic view of graphitization, ie. graphite corrosion of water pipes after 50 years in-service. The form of graphitization can be identified as the structural changes and the reduction of mechanical properties. In real terms the changes were observed in the hardness of the initial value of about 220-390 HV to 40 HV. Macro- and micro structural analysis were performed to identify the cause of failure tubes.

Keywords: *graphitization & failure, water pipes, gray cast iron, characterization of quality*

1. INTRODUCTION

Cast Iron has, for hundreds of years, been the preferred piping material throughout the world for drain, waste, and vent plumbing applications and water distribution. Gray iron can be cast in the form of pipe at low cost and has excellent strength properties. Unique corrosion resistance characteristics make cast iron soil pipe ideally suited for plumbing applications.

Cast iron and steel corrode; however, because of the free graphite content of cast iron (3% - 4% by weight or about 10% by volume), an insoluble graphitic layer of corrosion products is left behind in the process of corrosion. These corrosion products are very dense, adherent, have considerable strength, and form a barrier against further corrosion. Because of the absence of free graphite in steel, the corrosion products have little or no strength or adherence and flake off as they are formed, thus presenting fresh surfaces for further corrosion.

However, the sensitivity of the tube material to corrosion and brittleness of cast iron, is largely responsible for their failure during service. Cast Iron is a material which has the largest number of damages and failures per kilometer of pipeline per year. Unusually large number of accidents hapened at the water supply network during the period from 31 December to 4 January 2009. About 80 water pipes were broken in Belgrade, which is above average large number of failures (by 21 water pipe is just a shot in one day. The main reason for the frequent failure of water pipes is because many years prior to 2000. they were not renewed and changed, so in some parts of the water supply network are old more than half a century.

2. CAUSES OF FAILURE

2.1. Corrosion

Corrosion induced failures are common to all pipe diameters. Although many of the failure modes described, corrosion pitting is frequently associated with these failures, having produced the weakening in the fabric of the pipe that allowed the failure to occur. As an example, all circumferential failures investigated in "IMS" have been associated with corrosion pitting. Simple corrosion pitting is a minor failure mode in small diameter pipes, but more important in diameters above about 300 mm [1].

Figure 1 – Heavily corroded gray cast iron pipe

Investigation of the effects of corrosion on gray cast iron failures in particular is complicated by the presence of two separate but closely related corrosion processes that may affect the pipes. Simple corrosion pitting can occur in much the same way as steel pipes. However, graphitisation can also take place [2]. This process removes some of the iron in the pipe, but leaves behind a matrix of graphite flakes that is held together in part by iron oxide, see Figure 1.

Graphitisation can form a solid substance on the pipe, producing the appearance of an undamaged material. In many cases this corrosion product may also be strong enough to temporarily resist the pipe’s internal water pressure [3].

Areas of graphitisation are often thought to be composed solely of the graphite flakes. In reality, chemical analysis shows the presence of iron oxide, which appears to be essential for the process [4].

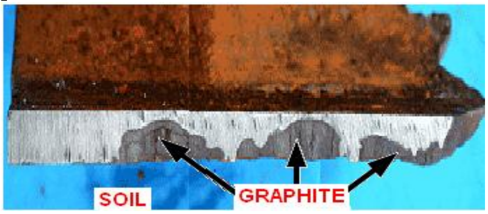


Figure 2 – Cross-section of cast iron pipe showing graphitisation.

Iron oxide therefore appears to be necessary to form the corrosion product known as graphitization, see Figure 2. In addition, it also suggests that a slow corrosion process is required for the graphite to bond with the iron oxide.

2.2. Porosity

Gray cast iron pipe was manufactured using a number of different methods, with the two most common being pit casting and spin or centrifugal casting [5]. Porosity, Figure 3, is the most common manufacturing defect in pit cast pipe.

Figure 3 – Pit cast pipe showing porosity (black dots on cut metal surface) [5].

It is produced by air being trapped in the metal as it solidifies. Air in pit cast pipe may have had to travel from the bottom of the pipe to the top to escape, providing much greater opportunities for entrapment than in spun cast gray iron pipe, where the air only needed to reach the inner wall of the pipe surface to escape.

2.3. Inclusions

Inclusions are unintentional objects created in metals during manufacturing that are not part of the he continuous fabric of the material, Figure 3. T

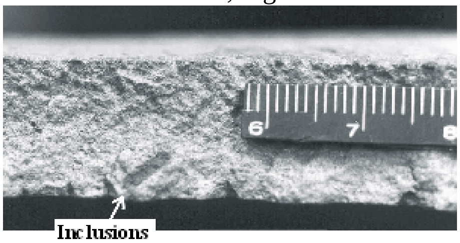


Figure 3 – Inclusion along a fracture surface

hey weaken the pipe metal by acting as crack formers, reducing the total cross-section of metal in the pipe and producing stress concentrations.

3. EXPERIMENTAL RESULTS

3.1. Chemical composition

The water pipe is made from SL 250, with outer diameter of 150mm, wall thickness was 6mm.

The chemical composition of this kind of gray iron, on principal elements, are shown in Table 1.

Element	Chemical content, wt. %
C	2,95
Si	0,67
Mn	0,42
P	0,14
S	-
Cr	-
Mo	0,13

Tabla 1- Chemical composition of gray iron SL 250

In routine analyses, even in some laboratories or institutes, the detailed determination of chemical composition of cast iron often is neglected, and this is an explanation for lack the data of sulfur on chromium content.

3.2. Tensile strength

Tensile characteristics are determined according to standard no SRPS EN 10002-1/1996, from the specimens taken in the longitudinal direction of pipe. Such obtained values are given in Table 2.

characteristics	N^0 specimen 1/2/3
Specimen diameter, mm	5,9 / 6 / 6,2
Area of specimen, mm2	27,34 / 28,26 / 30,17
Max. force, kN	3,62 / 3,96 / 4,96
Tensile strentgth, MPa	132 / 140 / 164

Tabla 1- Mechanical characteristic of cast iron pipe

3.3. Micro -hardness measurements

3.3.1. Specimens for micro-hardness and micro-structural testing

For further investigations, microhardness and microstructural determinations, specimens were taken as is shown in Figure 4.

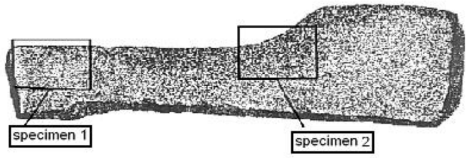


Figure 4 – Places for hardness & microstructure examinations from damaged water pipe, made of gray cast iron, not etched

The upper side of specimen from Figure 4 was in contact with soil. At the top of specimen is visible a thin graphitic layer. The outer side of pipe had been in contact with moist soil. According to macro examination of failed pipe wall, the metal thickness practically is not changed, see carefully Figures 2 and 4. By visual inspection of damaged water pipes, a corroded surface, where the graphitic corrosion was discovered by other more precise techniques, does not appear different from gray iron, and this fact is of course disadvantage. In other words, the graphitic corrosion at grey cast iron pipe often visually appears to be fine other then some general corrosion, when they are present at the surface.

3.3.2. Micro-hardness testing

At uncorroded wall the hardness was kept at the starting level:

- in the range from 219 - 358 HV1 – see Figure 5a)
- or 224 - 390 HV1 – see Figure 5b).

In corroded zones the hardness values are nearly 50 HV1, even less, see Figure 5b).

Hardness values are measured by using a HV1 scale, according to SRPS ISO 4516/1993. The observed corroded layer was about 2 mm.

Results of measured micro-hardness values are given in Figure 5a) and b).

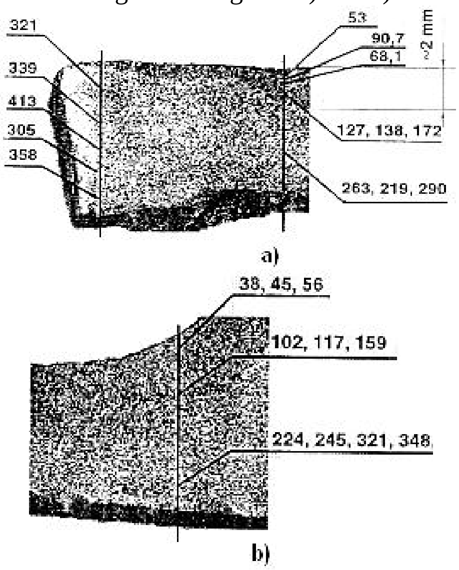


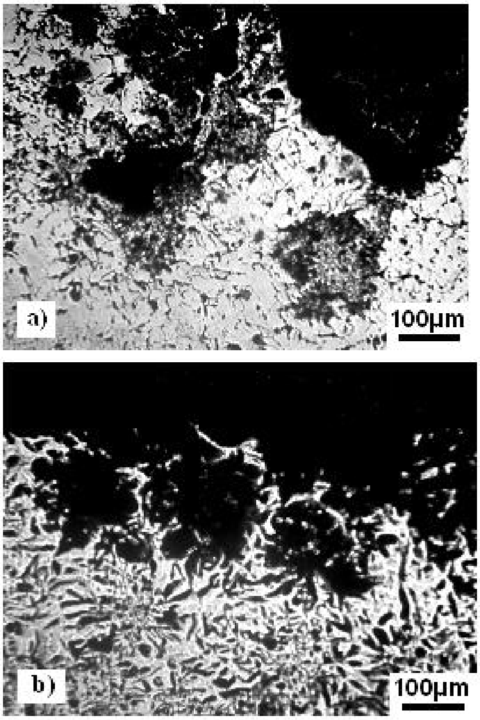
Figure 5a) and b) – Hardness changes at damaged pipe

3.4. Microstructure investigation

A high degree of hardness degradation, is in close accordance with the macrostructure changes, see carefully Figure 5. Microstructure degradation is further investigated and part of obtained results are shown in Figure 6.

According to these micro- structural investigations, the graphitic corrosion is started at the surface and develops through the wall of cast iron water pipe. Metallographic examination shows a porous structure and different etching characteristics of the remaining metal. The graphite mass is porous and very weak.

In examined iron pipes, the white-iron structure at the surface is not found. This is an important think because the chilled structure is frequently present in foundry practice, when gray iron castings are produced.



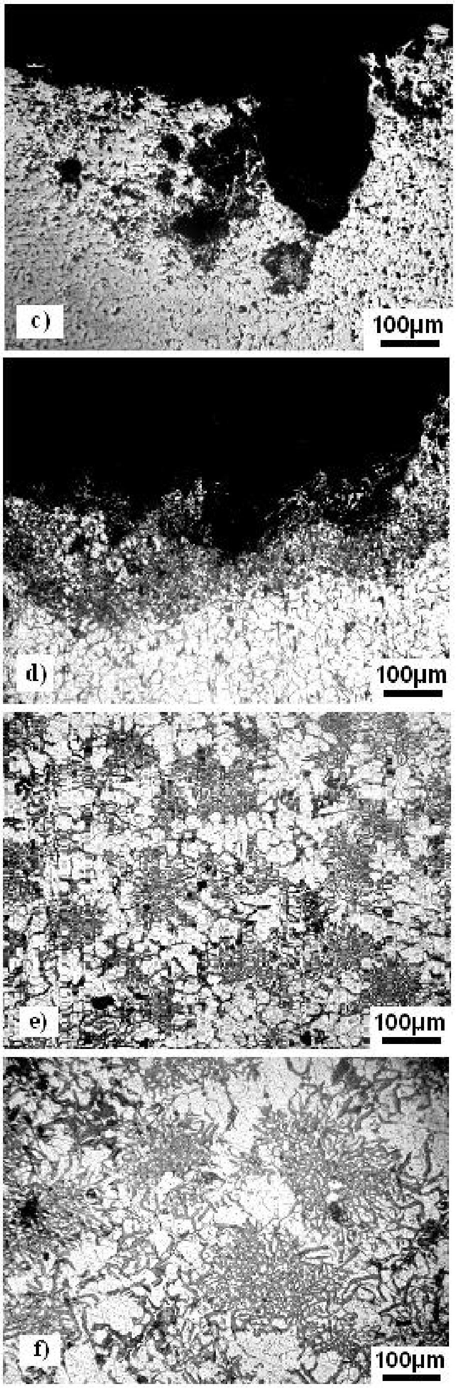


Figure 5 – Microstructural changes in gray iron pipe, for water supplying, at: a), b), c) d) near surface; and e), f) in the middle of tube wall; nital etching

4. DISCUSSION

Graphitization in foundry production is a process of forming the graphite during solidification of casting. But, graphite might be also formed after a years of production. Here is registered the graphite appearance in pipes, for water supplying, made from gray cast iron. The total amount of carbon in this case is not taken into account for giving an explanation in graphitic corrosion appearance.

As it was well known in foundry production, the mechanical properties of cast iron are determined by it's structure. Cast iron usually contains a great amount of large, straight graphite plates, dividing the metal matrix and lowering the mechanical properties. The flakes of graphite reduce the strength and ductility of cast iron [6-14].

It also known that trace elements, like oligo-elements, which are not normally considered in routine analyses, can exert a profound influence upon the characteristics of cast iron.

5. CONCLUSION

The pipes for water supplying in this paper were made from cast iron SL 250 and they were seriously corroded.

Although the gray iron castings posses a pretty well corrosion resistance here is registered and explained the so called graphitic corrosion.

Graphitization made only at the outer side of tube wall, as a corrosion product in contact of gray iron with the dumped soil after about 50 years in service.

As a consequence of graphitic corrosion, the hardness degradation has happened (from 250 HV1 to ≈ 40 HV1), as it was measured at the damage surface.

Mechanical and metallographic investigations have proved the whole degradation piping system.

Corrosion has long been identified as a major cause of failure in cast iron and other metallic pipes. In each case analyzed above, corrosion pits and graphitic corrosion were associated with the failure of the pipes. In the case of the Belgrade pipes it was possible to determine the graphitic corrosion was directly associated with the failure . The results also indicate that the failure process is more complex than has previously been believed.

The graphitization and the hardness degradation seen here indicate that the pipe itself was partly the cause of the failure, rather than external conditions or forces. Utilities with similar, low quality pipes may wish to schedule them for early replacement or rehabilitation.

The number of failures presented here is quite small. While the failure processes in these pipes has been identified, it would be incorrect to assume that the same processes take place in all grey cast iron pipe failures.

REFERENCES:

[1] AWWA (American Water Works Association) (1975). USA Standard for Thickness Design of Cast-Iron Pipe. USAS A21.1-1967/AWWA H1-67, Denver, Colorado.

[2] Makar J.M., 2000, A preliminary analysis of failures in grey cast iron water pipes, Engineering Failure Analysis 7, pp.43-53.

[3] Zamanzadeh, M., et. al.,1990, Analysis of Failures in Water Mains, Materials Protection, August, pp. 50 – 53.

[4] ASA (American Standards Association), 1953. American Standard Specifications for cast-iron pipe centrifugally cast in metal molds, for water or other liquids. A21.6-1953/AWWA C106-53

[5] Talbot, A.N., 1926, Strength Properties of Cast Iron Pipe Made by Different Processes as Found by Tests, Journal of the American Water Works Association, Vol. 16, July, pp.1-44.

[6] Reed-Hill R.E.: Physical Metallurgy Principles, New York 1973, D. Van Nostrand Co, 661- 698.

[7] Таран Ју. Н.: Строение сплавов железо-углерод, у књизи: Металловедение и термичес- каја обработка, Москва 1983, Металлургија, стр. 76-83.

[8] Šuman H.: Metalografija, Beograd 1968, Zavod za izdavanje udžbenika Srbije, str. 452-466.

[9] Smallman R.: Modern Physical Metallurgy, London 1970, Butterworths, pp. 456-461.

[10] Kočovski B.: Teorija livarstva, Beograd 1972, BIGZ, str. 58-90.

[11] Karsay S.: Production de la fonte GS I, Point de la technique a ce jour, Montreal 1976, QIT - Fer et Titane Inc.

[12] Kočovski B.: Livena gvožđa, Bor 2006, Tehnički fakultet, str. 30-81.

[13] Kovačević Z., Karastojković Z., Janjušević Z.: Graphitic corroion and hardness degradation in water pipes made from gray cast iron, 40th International October Conference on Mining and Metallurgy, Soko Banja 2008, Proceedings Book, pp. 359-29.

[14] Karastojković Z., Janjušević Z., Kovačević Z., Sarić V., Čubrilović S.: Korozija toplovoda, Integritet i vek konstrukcija, Vol. 7, No 2, 2007, pp. 129-132.