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Examination of Failed Components From District of Columbia Incinerator No. 5

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Mechanical Properties Section
Metallurgy Division
National Bureau of Standards
Washington, D. C. 20234

March 2, 1973

Failure Analysis Report

Prepared for
Construction and Repair Division
Department of Environmental Services
Government of the District of Columbia 20019

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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary

NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

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SUMMARY

The Department of Environmental Services of the Government of the District of Columbia submitted a number of components from Incinerator Number Five to the NBS Mechanical Properties Section for examination. These included grates, trunnions, trunnion pins, trunnion sockets, "spacers", and chain links from the residue ash conveyor system. According to the Department of Environmental Services, many of the incinerator components were failing within a relatively short time after installation.

Examination of both new and used components (excluding the chain links) revealed that all of the used components, had undergone significant mechanical property and micro-structural changes when compared to the material of the new components. Some of the used components also exhibited some distortion and loss of material. The changes in the used components could be attributed to exposure of the materials to temperatures which were excessive for the materials employed.

The new and used grate material did not meet contract specifications for tensile properties and hardness. Where specifications were available, the other components did meet mechanical property specifications.

The materials met chemical composition specifications where specifications were given.

Fractures in the trunnions and the trunnion pins appeared to have been due to tensile overload, and the fractures in the chain links appeared to have been due to impact or tensile overload.

Examination of Failed Components from District of Columbia Incinerator No. 5

1. INTRODUCTION

1.1 Reference

Government of the District of Columbia, Department of Environmental Services, Construction and Repair Division. Request by Mr. Edward M. Halley, Jr., Chief, Bureau of Construction and Repair. Job. No. 206-001.

1.2 Parts Submitted

The D.C. Department of Environmental Services submitted a number of parts from Incinerator No. 5 for examination. These parts are listed below and are shown as received in figures 1 through 4.

1. One new grate with both trunnions and trunnion pins in place (figure 1a).
2. One used grate with one trunnion and the mating trunnion pin in place (figure 1b).
3. One new trunnion and trunnion pin (figure 2).
4. One used, fractured trunnion and trunnion pin assembly (figure 2).
5. One used, fractured trunnion (figure 3).
6. One new trunnion socket (figure 2).
7. One used trunnion socket (figure 2).
8. One new "spacer" (figure 3).
9. One used "spacer" (figure 3).
10. Two fractured chain links from the residue ash conveyor system (figure 4).
11. One used, intact chain link attached to one two-piece connecting unit from the residue ash conveyor system (figure 4).

In addition, a copy of the Government of the District of Columbia, Department of Sanitary Engineering Bid Proposal and Specifications for Invitation No. C-7038-S for Incinerator No. 5 was furnished. Any reference made hereafter to "specification" or "specifications" not specifically identified refers to this document.

1.3 Background Information

Information in this section was furnished by Mr. Alan Cassel of the D. C. Department of Environmental Services. Incinerator No. 5, which is of recent construction, contains a number of grates (such as that shown in figure 1a) on which trash is burned. The grates are "hinged" at the trunnions and are raised at regular intervals moving the burning trash from one grate to another. Combustion is promoted by the blowing of air through the grates from below. This air stream is also supposed to cool the grates to keep them from becoming overheated. The rate of air flow should control the rate of combustion and the temperature of the grates. Grates, trunnions, trunnion pins, and trunnion sockets have been failing in a relatively short time, sometimes within two to three months of the time they are put into service.

A number of links of the conveyor chain from the residue ash conveyor system had fractured, again in a relatively short time. This system is used to remove ash remaining after the trash is burned from the incinerator for disposal. According to the information furnished to us, the chain is not subjected to hot ash and its temperature never reaches that of boiling water (212° F).

2. PURPOSE

The D. C. Department of Environmental Services requested the NBS Mechanical Properties Section to conduct a failure analysis of the submitted parts as follows:

1. Tensile tests (ultimate tensile and yield strengths and elongation) on specimens from the new grate, the used grate, and one of the fractured chain links.

2. Hardness measurements on material from both grates, the trunnions, the trunnion pins, and the chain links.

3. Chemical composition determinations for material in one grate, one trunnion, one trunnion pin, and one chain link.

4. Metallographic examination of material from both grates, one trunnion, one trunnion pin, and one chain link.

5. Fractographic examination of one of the fractured trunnions, one of the trunnion pins, and one of the chain links.

In addition, if the material currently used for the grates appears to be unsatisfactory, recommendations of better materials were requested.

3. EXAMINATIONS, TESTS, AND ANALYSES PERFORMED

3.1 Visual Examination

The various components were examined visually for apparent damage. A limited number of dimensional comparisons were made between new and used components.

3.2 Tensile Tests

Two tensile specimens each were machined from the used grate, the new grate, and one of the fractured chain links to sizes and types in accordance with ASTM Standard E8-69. One specimen was taken from each grate bottom with the longitudinal axis of the specimen parallel to the bottom of the grate. The other grate specimens were taken near the top in the same vertical plane as the specimens taken at the bottom. Specimens from the bottoms of the grates were designated U1 and N1 for the used and new grates, respectively. Specimens from the tops of the grates were designated U2 and N2 for the used and new grates, respectively. Chain link specimens were designated C1 and C2. The tensile tests were run at cross head speeds of 0.01 to 0.016 inch per minute.

3.3 Metallographic Examination

Metallographic specimens were prepared from cross sections through the top and bottom of both the new and used grates, new and used trunnions, new and used trunnion pins, new and used trunnion sockets, and one of the fractured chain links.

It was deemed advisable to examine metallographically more specimens than had been originally proposed because of the results of the hardness measurements which indicated that there were differences in the mechanical properties between essentially all of the new parts and the corresponding used parts. Cross sections for examination from the used grate bottom were taken through attached "globules" so that the material in these globules could be examined as well as the grate material.

3.4 Chemical Analyses

One sample each was selected from the new grate bottom, a new trunnion, a new trunnion pin, and one of the fractured chain links for chemical analysis. Surface scale, paint, and the apparent decarburized layer (on the chain link sample) were removed from the surfaces of the sample before they were submitted to a commercial laboratory for chemical analysis. Analyses were made using spectrographic techniques.

In addition, qualitative analyses were made on cross sections through the two globules from the bottom of the used grate on which the hardness measurements were made. This was carried out with the non-dispersive X-ray analyzer used in conjunction with the scanning electron microscope.

3.5 Hardness Measurements

Brinell hardness measurements (BHN) were made on the metallographic specimens. Knoop microhardness measurements (KHN) were made at 200 grams load on two cross sections through "globules" of material attached to the bottom of the used grate. Knoop microhardness measurements were also made on a cross section through one of the fractured chain links near the surface because of the presence of what appeared to be a decarburized layer at the surface.

3.6 Fractographic Examination

The fracture surfaces of the two failed chain links, the failed trunnions and the failed trunnion pins were examined visually and macroscopically in an attempt to determine the mode(s) of fracture.

4. RESULTS OF EXAMINATIONS, TESTS, AND ANALYSES

4.1 Visual Examination

4.1.1 Grates

The used grate was covered with a fairly heavy scale at and near the bottom and on most of the inside surface. The new grate had an apparently superficial layer of rust on most of the surface except for the area which had been painted. There was considerable distortion in the bottom "grille" work and along both sides of the used grate (figures 1b and 5) as compared with the new grate (figure 1a). There were various bits of material attached to the grille of the used grate (figure 5). Some of this material could be easily removed, but most of it was firmly attached to the grate, and some of the material was in globular form appearing as though it had melted and resolidified on the grate bottom.

The widths of the dividing members of the grille work measured 0.75 inch for the new grate compared to 0.50 inch for the used grate. These values are an average of measurements made on 15 dividing members of each grate. The widths of the side panels of both the new and the used grates measured essentially the same, about 3/4 inch.

One of the trunnion pins from the used grate had apparently fractured, and it and the companion trunnion were separated from the grate.

4.1.2 Trunnions

In addition to the three trunnions attached to the grates (figures 1a and 1b), there were two used and one new trunnion submitted for examination (figures 2 and 3). The outer surfaces of the two new trunnions attached to the new grate were painted. The new trunnion not attached to a grate was not painted and had a small amount of what appeared to be superficial rust on the surface, but otherwise appeared to be similar to the attached trunnions.

The one trunnion attached to the used grate was covered with scale, and there was a light grey deposit adjacent to the head of the trunnion pin. This trunnion-trunnion pin assembly appeared to be bent relative to the grate. The other trunnion-trunnion pin assembly for this grate was missing, and apparently at least the pin had fractured. Some of the

light grey deposit was also located in the cavity in the used grate where the assembly had been. Both of the used unattached trunnions had fractured. One of them exhibited very little rust and there was still considerable bright metal showing. The appearance of this trunnion compared to the appearance of the other used trunnions indicated that this trunnion may have been in use for a relatively short period of time, or was in an area of the incinerator which was not subjected to the heat of the burning trash. Both the other unattached used trunnion and the attached used trunnion were covered with a fairly heavy scale.

The outside diameters of all the trunnions except for the used one attached to the used grate were essentially the same and measured about 2.95 inches. The diameter of the used trunnion attached to the used grate measured 2.90 inches.

4.1.3 Trunnion pins

Of the two trunnion pins attached to the new grate, only the heads were visible, and these were painted. The new unattached trunnion pin was not painted and had a small amount of superficial rust. The shaft of the pin was straight. The heads of the two used trunnion pins were covered with scale. The unattached pin had apparently fractured (figure 2) close to the point of attachment to the grate, and the shaft was bent. The shaft of the attached trunnion pin also appeared to be bent.

4.1.4 Trunnion sockets

One new and one used trunnion socket were submitted for examination (figure 2). The used socket was covered with a heavy scale. The new socket was painted only in places and was covered with a superficial rust where there was no paint. The diameter of the hole of the new socket measured 3.0 inches and that of the used socket measured 3.1 inches. The widths of the tops of the sockets (measured parallel to the center line of the hole) were 0.99 inch for the new one and 0.67 inch for the used one. There was much less difference in the widths at the bottom where the measurements were 0.98 inch for the new socket and 0.97 inch for the used socket.

4.1.5 "Spacers"

The used "spacer" was covered with a heavy scale and exhibited considerable distortion. The new one was partially covered with paint, and the unpainted areas were covered with a superficial rust. Enough material had been lost from one area of the used "spacer" so that the side of the "spacer" intersected one of the two bolt holes. This can be seen in figure 3.

4.1.6 Residue ash conveyor system chain links

Both of the fractured chain links had patches of a grey, powdery substance on their surfaces. In the areas not covered with this substance, the link surfaces were covered with scale. One of the fractured links had separated into at least two pieces, and only the piece shown in figure 4 (link in the center of the photograph) was submitted. One of the two fracture surfaces shown in the figure was about 75% covered with what appeared to be the same grey substance found on the link surfaces. The intact link was covered with scale and there was no evidence of the grey substance visible to the eye. There was no apparent distortion in any of the links, but in the fractured link which had not separated, the fracture faces had separated slightly.

4.2 Tensile Tests

4.2.1 Grates

The results from the tensile tests of material from the grates are presented in the first four rows of Table 1. The material in the grates was specified to have the following tensile properties:

Ultimate tensile strength	100,000 psi minimum
Yield strength	70,000 psi minimum
Elongation	3 % minimum

Of the four specimens tested, only the one from the new grate bottom had an ultimate tensile strength above the specified minimum, although the specimens from the new grate top and the used grate top had ultimate tensile strengths within 4 1/2% of the specified minimum. The ultimate tensile strength of the specimen from the bottom of the used grate was quite low.

Only the specimen from the top of the new grate had a yield strength (0.2% offset) above the specified minimum, although the specimens from the bottom of the new grate and the top of the used grate had yield strengths within about 3 1/2% of the specified minimum. The yield strength for the material from the bottom of the used grate was quite low.

The elongation (in one inch) was above the specified minimum for all specimens except the one from the top of the new grate. However, elongation for the one from the top of the used grate was very high.

4.2.2 Chain links

The results from the tensile tests of material from the chain link are presented in the last two rows of Table 1. The material in the chain links was specified to have the following tensile properties:

Ultimate tensile strength	230,000 psi
Breaking strength	228,000 psi
Yield point	210,000 psi

The yield strengths and the ultimate tensile strengths for both chain link specimens were well above the specified values.

4.3 Metallographic Examination

4.3.1 Grates

The microstructure of cross sections taken from both the top and the bottom of the new grate and the top of the used grate were essentially the same. A typical unetched microstructure representative of these areas is shown in figure 6. The cross section shown was taken from the top of the used grate. The dark, round areas are graphite nodules. The material appears to be relatively free of inclusions and no porosity is evident. An etched microstructure representative of this material (figure 7, cross section through bottom of new grate) shows the graphite nodules in a matrix consisting of essentially all pearlite. This appears to be an as-cast structure.

A different microstructure is exhibited by the material from the bottom of the used grate. An unetched microstructure of a cross section through the bottom of the used grate is shown in figure 8 (at a higher magnification than figures 6 and 7). There is secondary graphite surrounding some of the graphite nodules. An etched microstructure from this cross section (figure 9) shows that the matrix is mostly ferrite with a small amount of spheroidized cementite instead of pearlite. The presence of these constituents indicates that the material was probably heated to temperatures in the range of 1200 to 1300° F for an appreciable period of time.

An etched microstructure of a cross section through one of the globules (no. 2 in Table 3) where it was attached to the grate bottom is shown in figure 10. The material appears to have fused to the grate bottom.

4.3.2 Trunnions

The unetched microstructures of cross sections from the new and the used trunnions are shown in figures 11 and 12, respectively. The dark areas appear to be graphite, or, in some places, cavities where graphite was pulled out during metallographic preparation. These figures may not represent typical concentrations of the graphite, but they do illustrate the relative sizes and shapes of the particles.

Etched microstructures of cross sections through the new and used trunnions are shown in figures 13 and 14, respectively. A dendritic structure of prior austenite is exhibited in both cases. In figure 13, the microstructure consists of cementite (white area), martensite (grey area), and what appears to be unresolved pearlite (dark area, could not be resolved up to X 800). The microstructure of the used trunnion (figure 14) has essentially an as-cast appearance and consists of cementite and tempered martensite.

4.3.3 Trunnion pins

The unetched microstructure of a cross section through the new trunnion pin is shown in figure 15. This is typical for the material in both the new and the used trunnion pins. The steel is very clean and has very few inclusions.

An etched microstructure of a cross section through the new trunnion pin is shown in figure 16. It appears to be a normalized structure consisting of pearlite in a pro-eutectoid ferrite network.

The microstructure of the used trunnion pin (figure 17) consists of spheroidized carbides (probably mostly iron carbide, Fe_3C) in a ferrite matrix. The spheroidized microstructure can be formed from the normalized structure by holding the material at an elevated temperature for a long period of time.

4.3.4 Trunnion sockets

The trunnion sockets were specified to be manufactured from "wear resistant alloyed iron"[1]. Material from both the new and the used trunnion sockets appear similar in the unetched condition. A typical unetched microstructure of a cross section through the new trunnion socket is shown in figure 18. The dark, round particles are graphite nodules.

The etched microstructure of a cross section through the new trunnion socket is shown in figure 19. The microstructure consists of graphite nodules in a matrix containing primarily pearlite (grey) with some massive cementite (white).

The etched microstructure of a cross section through the used trunnion socket is shown in figure 20. The microstructure here consists of graphite nodules in a matrix of ferrite (white), spheroidized carbides (appearing as small dark dots), and a very small amount of pearlite.

4.3.5 Chain links

An unetched microstructure of a cross section taken through a used chain link and intersecting the surface of the link is shown in figure 21. There appears to be some corrosion or scale that has penetrated the surface. A few inclusions can be seen, but the material appears to be relatively clean.

An etched microstructure of a cross section intersecting the surface of the link is shown in figure 22. The microstructure consists primarily of very fine needles of tempered martensite. Near the surface, however, there are areas which appear to have been decarburized. A typical area of decarburization is indicated by arrow A. The phase appearing white in the photomicrograph is ferrite. The depth of the decarburized layer is not uniform. At the surface on the right of figure 22 (arrow B), the microstructure is predominantly martensite. Some of the surface may have been removed by grinding after the links were fabricated or heat treated, or by wear or corrosion in service.

4.4 Chemical Analyses

The results of the chemical analyses are presented in Table 2.

4.4.1 Grates

The grate material was specified to be "high quality, heat resistant ductile iron"[1]. The results of the chemical analysis indicate that the material of the new grate is ductile iron[2].

A qualitative analysis of the material in two globules (designated globules no. 1 and 2 in Table 2) indicates that globule no. 1 consists basically of iron with some aluminum, copper, and silicon present, and that globule no. 2 is nearly all iron with a small amount of aluminum.

4.4.2 Trunnions

The trunnions were specified to be manufactured from "wear resistant alloyed iron"[1]. The chemical analysis indicates that the material of the new trunnion is a nickel-chromium iron which apparently has no commercial designation.

4.4.3 Trunnion pins

No chemical composition specification was available for the trunnion pin material. Analysis indicates that the material of the new trunnion pin is a plain carbon AISI 1050 steel.

4.4.4 Chain links

The specified material for the chain links is "heat treated alloy steel"[1]. The chemical analysis indicates that the material is similar to AISI S5 tool steel.

4.5 Hardness Measurements

The results of the hardness measurements are presented in Table 3. When the measured value is a Knoop number (KHN), a Brinell hardness number (BHN) approximately equivalent to the measured value is given in the last column for comparison. Each tabulated number represents an average of at least three measurements.

4.5.1 Grates

According to specifications[1], the Brinell hardness of the grate material should be approximately BHN 286. There are no significant differences among the hardness values for specimens from both the new grate top and bottom and the used grate top. All of the results are, however, lower than the approximate BHN specified. The specimen from the bottom of the used grate had a hardness considerably lower than that of the other specimens and more than 115 Brinell hardness points below the specified approximate value.

Hardness measurements taken on two globules of material attached to the bottom of the used grate indicate that one was harder than any of the grate material examined, and the second was slightly softer than the adjacent material in the bottom of the used grate.

4.5.2 Trunnions

The material in the trunnions should have an approximate BHN of 300[1]. The hardness values obtained for both new and used trunnions were well above this number. The new trunnion was somewhat harder than the used one.

4.5.3 Trunnion pins

There was no hardness specification available for the trunnion pins. The used trunnion pin was considerably softer than the new one.

4.5.4 Trunnion sockets

No hardness specification was available for the trunnion socket material. The new trunnion socket was significantly harder than the used one, and the trunnion sockets were significantly softer than the trunnions.

4.5.5 Chain links

Hardness measurements made on a cross section through one of the fractured chain links indicated that the hardness of the material away from the edge (surface of the link) was within the specified range of BHN 460 to 512[1]. There was a significant decrease in hardness at the edge which was apparently due to decarburization (see section 4.3.5).

4.6 Fractographic Examination

4.6.1 Trunnions

The fracture surfaces of the fractured trunnions were in poor condition for examination when submitted. They were corroded and showed evidence of mechanical damage. One of the better preserved fracture surfaces is shown in figure 23. The fracture surface has a rough, coarse-featured appearance. There was no evidence found to indicate fatigue or any other relatively slowly propagating crack mechanism contributing to the failure. Fracture was likely due to overload, perhaps caused (at least in part) by a stress concentration brought about by the bending of the softened trunnion pin.

4.6.2 Trunnion pins

The fracture surface of the failed trunnion pin was heavily coated with scale. There appeared to be some reduction in cross-sectional area of the pin adjacent to the fracture, indicating that the fracture may have been caused by a tensile overload.

4.6.3 Chain links

One of the chain link fracture surfaces was largely covered with a grey material which could be easily crumbled and removed from the surface. This material can be seen as the light area on the fracture surface at the bottom center in figure 4. The material looked and felt somewhat like ash. That part of the fracture surface not covered with this substance was covered with what appeared to be a heavy rust. Removal of some of the grey substance revealed corrosion (rust) on that part of the fracture surface covered with the substance as well.

The fracture surface was fairly flat with coarse features. The fracture had occurred in a brittle manner and probably from either impact or overload. If the grey substance on the fracture surface was indeed ash, this chain link was apparently kept in service after the side containing this fracture had failed.

The second chain link fracture surface examined is shown in figure 24. The part of the fracture surface adjacent to the outside surface of the chain link was fibrous in nature (upper part of fracture surface shown in figure 24a). Part way through, the fracture surface makes a sharp change in direction (arrows in figure 24b), and the part of the fracture surface adjacent to the inside surface of the chain link is flat and smoother than the fibrous part. There appears to have been a pre-existing crack (dark part of fracture surface indicated by arrow A, figure 24a). This may have been a quenching crack which formed during heat treatment of the link. It appears that the fracture probably initiated at the outside surface of the link (arrow B, figure 24a), and propagated inward, passing through the pre-existing crack. The fracture in this chain link probably occurred from either impact or overload.

5. DISCUSSION OF RESULTS

5.1 Grates

The results of the chemical analysis and the metallographic examination indicated that the material from the new grate was ductile (nodular) iron. In no case was the measured hardness of the material from either grate as high as that specified, and material from the new grate failed to meet tensile property specifications, although not by a wide margin.

Assuming that the used grate was essentially the same before service as the new grate, the mechanical properties, physical dimensions, and the microstructure of the material from the bottom of the used grate underwent significant changes while in service. The material from the top of the used grate did not undergo these changes and was similar to that of the new grate.

The microstructure of the material from the bottom of the used grate appears similar to that expected from an extended annealing heat treatment between about 1200 and 1350° F. The extent of the decomposition of the cementite indicates that the material was held at a temperature of approximately 1300° F for many hours total. The decrease in hardness and tensile properties, and the changes in dimension and microstructure of the material from the bottom of the used grate could all have been caused by the grate bottom being subjected to excessive temperatures for this material. The distortion in the bottom members could have been produced by thermal cycling to temperatures near and/or above the eutectoid temperature (about 1330° F).

Since the bottom of the grate had undergone changes due to exposure to heat that the top of the grate did not suffer, the grate was apparently subjected to a temperature gradient. The temperature at the grate top was never great enough to have produced any significant effect on the material properties, while the grate bottom was subjected, probably repeatedly, to relatively high temperatures.

The fact that the material from the new grate does not quite meet the mechanical property specification does not appear to be a problem in itself, as the properties are not below the specified minimum values by a large amount. There is reason to believe that even if the material did meet specifications before use, it would still have mechanical properties after use essentially the same as those of the used grate examined, and therefore would likely fail if subjected to similar conditions.

5.2 Trunnions

Chemical analysis of material from a new trunnion indicated that the trunnions were fabricated from a nickel-chromium cast iron which is an alloy cast iron.

There was only a slight difference in hardness between the new and used trunnions, the used one being softer. At this high hardness, little ductility would be expected.

There were, however, significant differences between the microstructures of the new and used trunnions. The presence of tempered martensite and the lack of pearlite in the used trunnion indicates that this trunnion was subjected to temperatures greater than 1330° F, and then cooled rapidly. This change in microstructure is consistant with the changes in the microstructure of the used grate bottom. In both cases, the changes could have been brought about by excessive temperatures.

The fracture surfaces of the failed trunnions were corroded and had suffered "damage" which obscured many of the fracture features. The apparent "damage" may have been mechanical in nature, but it may also have been produced by temperature excursions. Failure appears to have occurred due to overload. The trunnion-trunnion pin assembly still attached to the used grate was bent, as was the used pin which was not attached. If the trunnion pin bending is a common occurrence, stress concentrations could be imposed on the low ductility trunnion causing overload failure. High loads at about 1330° F during heating or cooling could have caused shear fracture with very little ductility in this material.

5.3 Trunnion Pins

Chemical analysis indicated that the material in the new trunnion pin was probably a plain carbon AISI 1050 steel. Hardness measurements indicated that the unattached, used trunnion pin was considerably softer than the new one, and the new trunnion pin was much softer than the trunnions.

Assuming that the used trunnion pins before service were essentially the same as the new trunnion pin, a significant change in microstructure took place in the used trunnion pin. Both the decrease in hardness and the changes in microstructure could have been caused by subjecting the trunnion pins to temperatures considered excessive for this material.

The conversion of the normalized structure of the new pin to the spheroidized carbides in ferrite structure of the used pin would require temperatures in the range of about 1300 to 1330° F for an appreciable time. This could have occurred through a series of temperature excursions and is consistent with the changes found in the used grate bottom and the used trunnion.

The unattached used pin, discussed above in regard to hardness and microstructure, was bent when submitted, and the used trunnion pin attached to the used grate appeared to be bent also. This indicates that the trunnion pins apparently do not have the tensile strength required to function properly, at least at the temperatures to which they were subjected.

5.4 Trunnion Sockets

If the used trunnion socket was essentially the same before use as the new trunnion socket, there was a considerable loss of material at the top of the used socket, and there was a significant decrease in the hardness of the used socket. The hardness of the new trunnion socket was considerably less than that of the trunnions (a trunnion being the mating part to the socket). Both of these changes can be attributed to the trunnion sockets being subjected to temperatures considered excessive for this material.

The significant change in microstructure from graphite nodules in a matrix consisting primarily of pearlite with some massive cementite in the new trunnion socket to mostly spheroidized carbides in a ferrite matrix could have been brought about by exposure to temperatures of from 1200 to 1300° F for an appreciable length of time, or by a number of temperature excursions into this temperature range.

The changes in the used trunnion socket material are consistent with the changes found in the materials from the other components discussed previously.

A considerable amount of a grey, powdery-appearing substance was found in the used trunnions and in the cavity in the used grate where a trunnion-trunnion pin assembly had been. This substance appears to be ash residue. None of this was found in the used socket, but the proximity of the trunnions and the trunnion sockets may make it likely that this substance could get into the sockets with relative ease. If this substance has an abrasive nature, it could cause excessive wear in the relatively softer sockets.

5.5 "Spacers"

The "spacers" were subjected to a visual examination only. There had been a considerable loss of material in the used "spacer" compared to the new one. This could have occurred, as in the other components, because of excessive operating temperatures for the material from which the "spacers" were fabricated.

5.6 Chain Links

The chain link material meets the specifications for chemical composition, tensile properties, and hardness (except for the decarburized surface layer).

The fractures in the two links examined appeared to be the result of impact or overload, and one of the fractures passed through a pre-existing crack. This pre-existing crack is considered very detrimental in that it reduces the effective cross sectional area of the link and it acts as a staff concentrator. The material was quite hard, and as a result, would not be expected to have much ductility or toughness. The decarburized surface layer indicates an improper atmosphere during heat treatment. This layer is considered detrimental in that it results in the outer layer of the links having a relatively low hardness and thus low wear resistance.

5.7 General Discussion

5.7.1 Incinerator components except chain links

The apparent principal problem leading to the failure of the incinerator components has been the exposure of these components to excessive temperatures for the materials from which they were fabricated. This indicates that the operating temperatures were too high for the materials in the area of the incinerator where they were exposed. There are basically two approaches to the solution of the problem: 1) lower the operating temperatures in these areas sufficiently so that acceptable lifetimes for the various components can be attained, or, alternatively, 2) specify materials which will withstand the higher operating temperatures.

The first approach would be the easiest and also the least expensive to implement. According to information supplied to us (section 1.3), the temperature can be controlled, at least in part, by regulating the rate of the air blast through the grates, or making it more uniformly distributed. This solution would be feasible, of course, only if the incinerator will operate properly at the reduced temperature.

The second approach would be more expensive in that all components of the types examined by NBS would have to be replaced with components fabricated from materials capable of withstanding the higher temperatures. In addition to the cost of a complete change of components, the new high temperature materials would likely be much more costly than those currently in use.

Utilizing the first approach, there is a possibility that, even with operating temperatures low enough so that the mechanical properties of the components are unaffected by temperature, the trunnion pins may have insufficient strength to function properly. If this was found to be the case, a stronger material should be used. One way to accomplish this would be to heat treat the material currently in use to a higher strength. If the trunnion pins function properly, the probability of trunnion failure should be reduced.

5.7.2 Chain links

A decrease in the probability of chain link failure could likely be attained by substituting case-hardened components for the currently used through-hardened components. A case-hardened chain link (with no decarburized surface layer) would provide a hard surface layer for good wear resistance. A core softer than that used currently would provide a greater degree of ductility and toughness.

6. CONCLUSIONS

6.1 Incinerator Components Except Chain Links

1. With the exception of the top of the used grate and the possible exception of the used trunnion, all submitted used components examined had suffered considerable impairment of mechanical properties, apparently due to exposure to excessive temperatures for the material.

2. The used grate, used "spacer", and used trunnion socket had suffered significant losses of material, also probably due to exposure to excessive temperatures for the material.

3. The used grate and the used "spacer" exhibited considerable distortion, probably caused by exposure to excessive temperatures for the material.

4. Material from both the new and used grates did not meet tensile property or "approximate" hardness requirements given in the contract specifications.

5. Material from both the new and used trunnions met hardness specifications. (No hardness specifications were available for components other than the grates and the trunnions.)

6. One, and probably a second, trunnion pin was bent indicating that the trunnion pins may not have sufficient strength to function properly at the temperatures to which they were subjected.

7. Material from all used components examined, had undergone significant changes in microstructure (compared to the microstructures of the new components) which can be attributed to exposure to excessive temperatures for the material.

8. The chemical analyses of materials from the new grate and the new trunnion indicated that the materials were ductile cast iron and alloyed cast iron, respectively. (No specification was available for the trunnion pin chemical composition.)

9. The fractured trunnions appear to have failed from overload, perhaps from a stress concentration imposed by the bending of the trunnion pins.

10. The used fractured trunnion pin appeared to have failed due to tensile overload.

6.2 Chain Links

1. Material from the chain link examined met contract specifications for chemical composition and mechanical properties[1].

2. The fractured links appear to have failed from impact or tensile overload.

3. There was a detrimental decarburized layer of non-uniform depth on the surface of the link cross sectioned which decreased wear resistance.

4. There was a grey, powdery substance covering parts of the surfaces of both fractured chain links, and a large portion of one of the fracture surfaces was covered with what appeared to be the same substance.

7. ACKNOWLEDGEMENT

Mr. L. C. Smith of the Mechanical Properties Section performed the metallographic specimen preparation and assisted in some of the tests and examinations.

REFERENCES

1. Government of the District of Columbia, Department of Sanitary Engineering, Bid Proposal and Specifications for Invitation No. C-7038-S, Incinerator Number Five, 1969.

2. Metals Handbook, American Society for Metals, Eighth Edition, Volume 1, 1961.

TABLE 1. RESULTS OF TENSILE TESTS

Specimen no. and identification		Ultimate tensile strength,[1] psi	0.2% offset yield strength,[1] psi	% elongation in one inch[2]
N1	Bottom new grate	113,600	67,500	4.6
N2	Top new grate	95,600	72,000	1.8
U1	Bottom used grate	70,000	49,500	13.7
U2	Top used grate	98,600	68,500	3.0
C1	Used chain	288,300	262,400	8.9
C2	Used chain	284,300	254,500	10.4

[1] Values given to the nearest 100 psi

[2] Values given to the nearest 0.1%

TABLE 2. RESULTS OF CHEMICAL ANALYSES

Quantitative Analyses

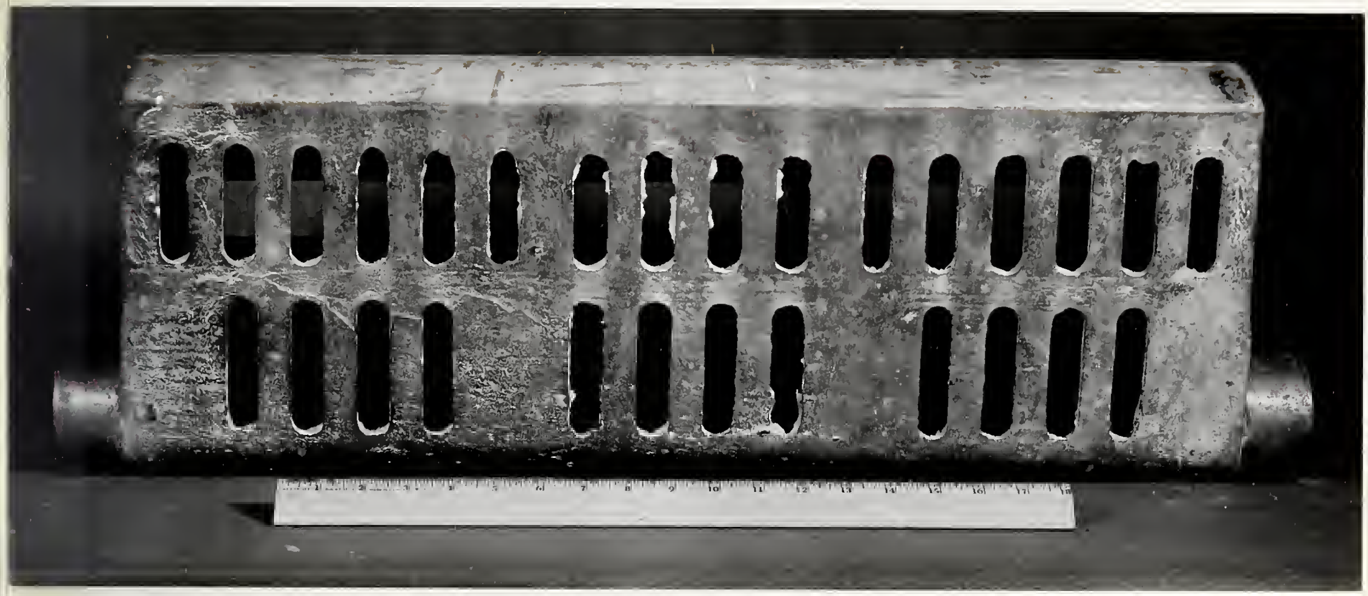
Element	Specimen			
	New grate bottom	New trunnion	New trunnion pin	Used chain link
Carbon (total)	3.57 %	2.96 %	0.50 %	0.63 %
Carbon (graphitic)	2.54			
Manganese	0.46	0.24	0.78	0.73
Phosphorus	0.039	0.015	0.009	0.015
Sulfur	0.006	0.024	0.015	0.016
Silicon	2.26	1.28	0.19	1.58
Nickel		3.85	< 0.05	0.11
Chromium		2.20	< 0.05	0.29
Molybdenum		< 0.05	< 0.05	0.27
Copper		< 0.05	< 0.05	0.16

Qualitative Analyses

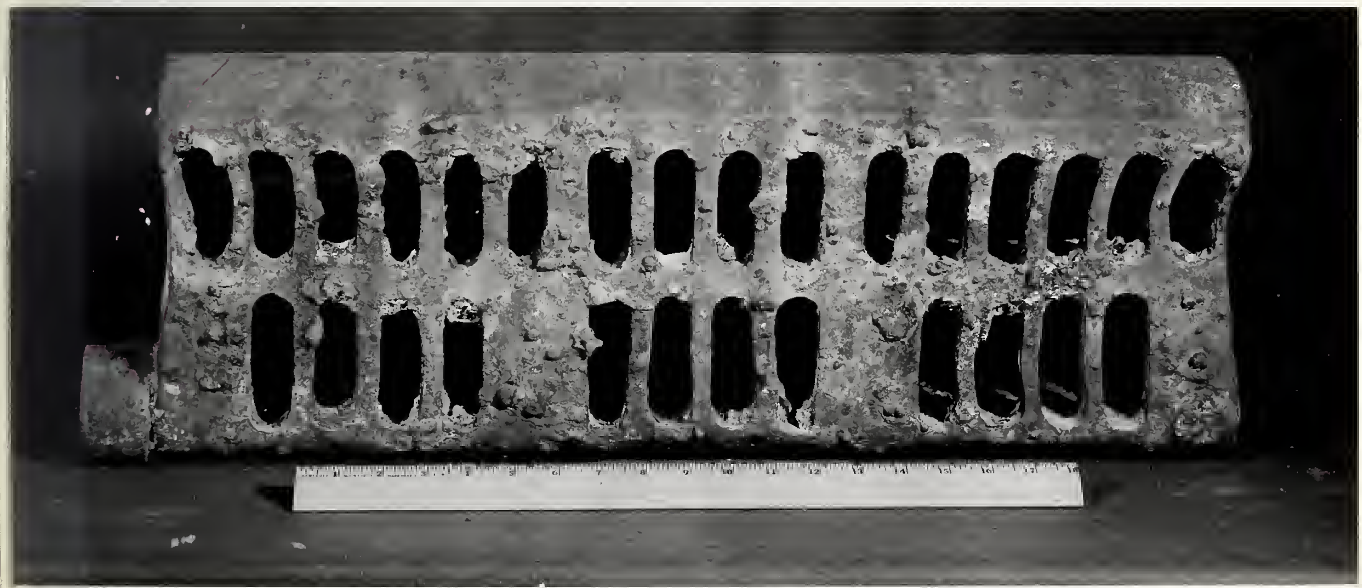
Element Detected	Level of Detection	
	Globule No. 1	Globule No. 2
Iron	very strong	very strong
Aluminum	weak	very weak
Copper	very weak	-----
Silicon	very weak	-----

TABLE 3. RESULTS OF HARDNESS MEASUREMENTS

Components	Hardness BHN	KHN	Approximate BHN Equivalent to KHN
New grate top	269		
New grate bottom	247		
Used grate top	264		
Used grate bottom	170		
Material attached to used grate bottom			
Globule No. 1		340	313
Globule No. 2		167	153
New trunnion	528		
Used trunnion	475		
New trunnion pin	202		
Used trunnion pin	120		
New trunnion socket	340		
Used trunnion socket	243		
Chain link			
Edge		262	240
Interior	502		



a. New grate.



b. Used grate.

Figure 1. Bottom view of grates as received. Smallest scale division equals 1/16 inch.

Figure 2. New trunnion, trunnion pin, and trunnion socket as received at left. Used trunnion, trunnion pin, and trunnion socket as received at right. Smallest division of scale equals 1/16 inch.

Figure 3. New "spacer" at right, used "spacer" at top left, and used, fractured trunnion at bottom left as received. The new trunnion shown for comparison is the same one shown at the left in figure 2. Smallest division of scale equals 1/16 inch.

Figure 4. Two used, fractured chain links at left and center, and one used, intact chain link attached to a two-piece connecting unit as received. Smallest division of scale equals 1/16 inch.

Figure 5. Part of the bottom "grille" work of the used grate showing attached material and distortion. X 2/3

Figure 6. Unetched microstructure of cross section through top of the used grate. The dark round areas are graphite nodules. X 100

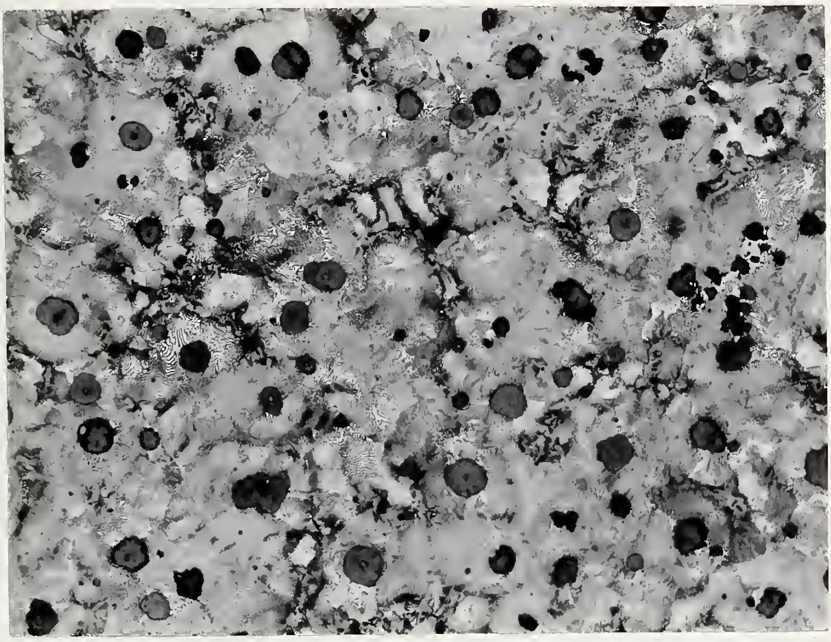


Figure 7. Etched microstructure of cross section through the bottom of the new grate. The dark round areas are graphite nodules. The matrix is essentially all pearlite. Etch: 3% nital. X 100

Figure 8. Unetched microstructure of cross section through used grate bottom showing graphite nodules and secondary graphite. X 200

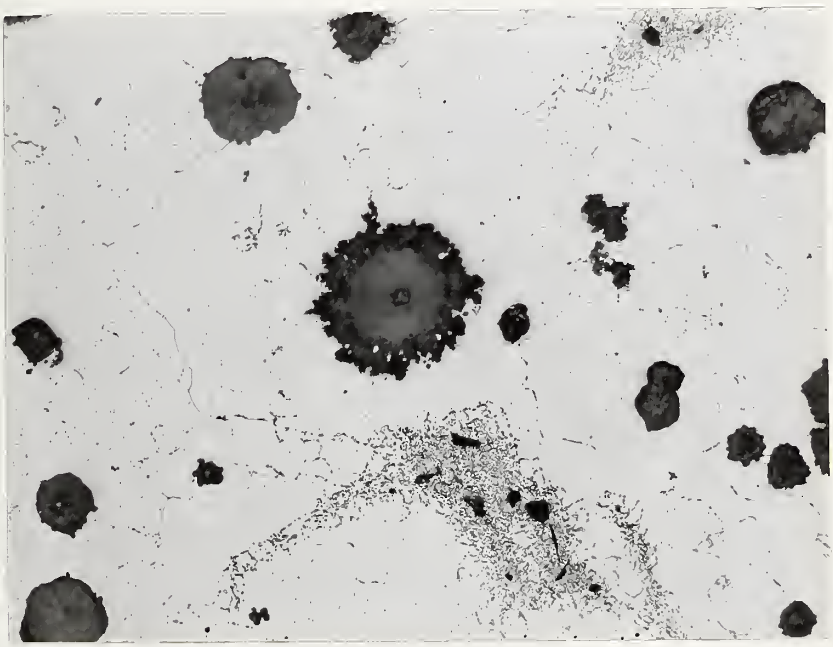


Figure 9. Etched microstructure of cross section through used grate bottom showing graphite nodules, some of which are surrounded by secondary graphite. Matrix is nearly all ferrite with a small amount of spheroidized cementite. Etch: 3% nital. X 200

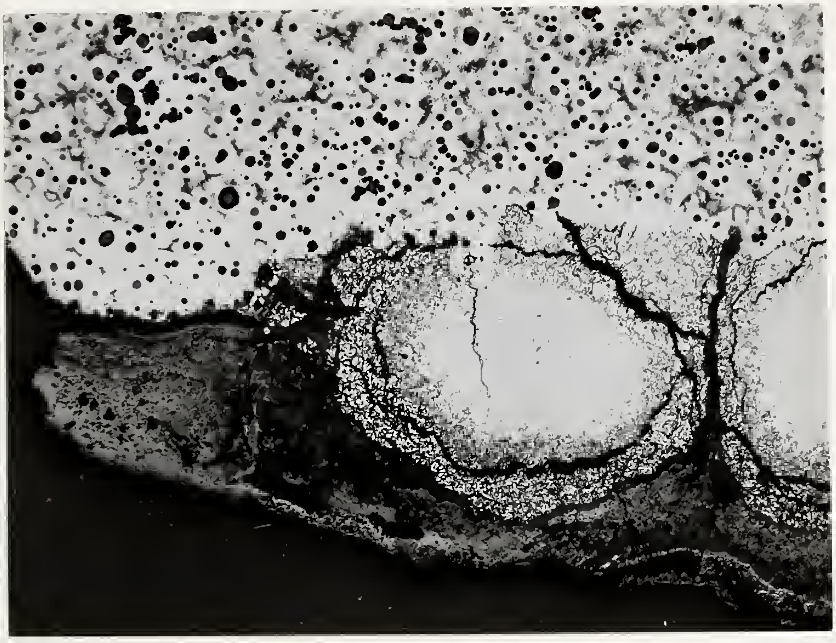


Figure 10. Etched microstructure of cross section through globule no. 2 and the adjacent portion of the grate bottom to which it was attached. Etch: 3% nital. X 40

Figure 11. Unetched microstructure of cross section through the new trunnion. Most of the dark areas are graphite. X 100

Figure 12. Unetched microstructure of cross section through the used trunnion. Most of the dark areas are graphite. X 100

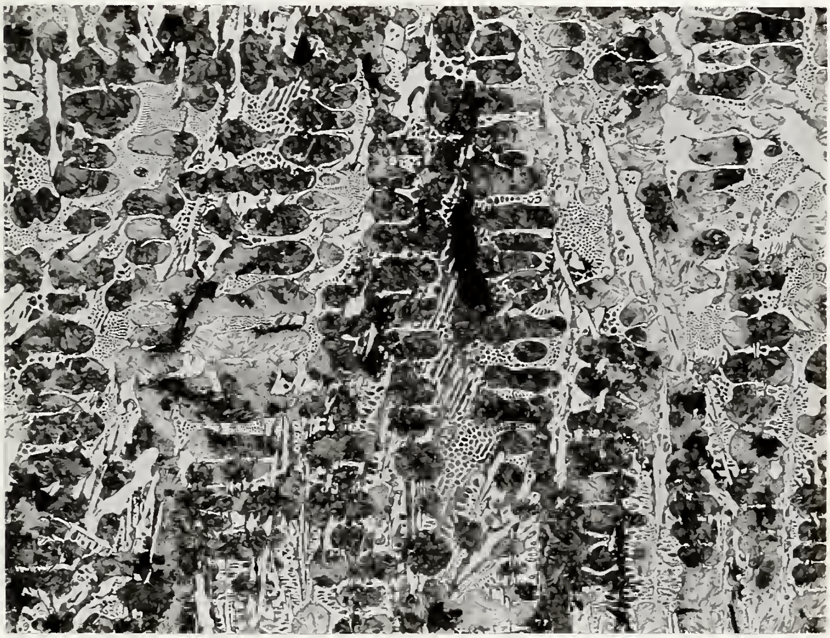


Figure 13. Etched microstructure of cross section through the new trunnion. Microstructure is dendritic and consists of cementite (white), martensite (grey) and what appears to be unresolved pearlite (dark). Etch: 3% nital. X 100

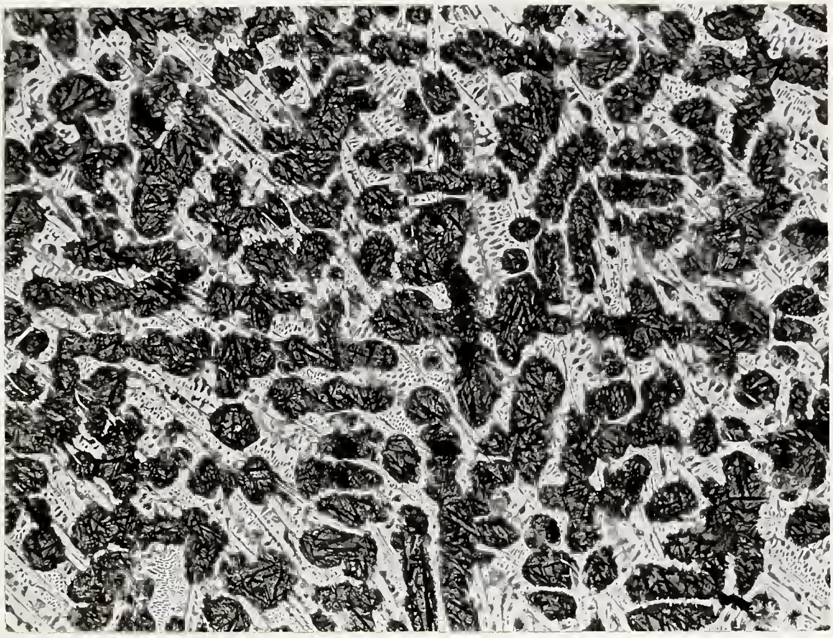


Figure 14. Etched microstructure of cross section through used trunnion. Microstructure is dendritic and consists of cementite (white) and tempered martensite (dark). Etch: 3% nital. X 100

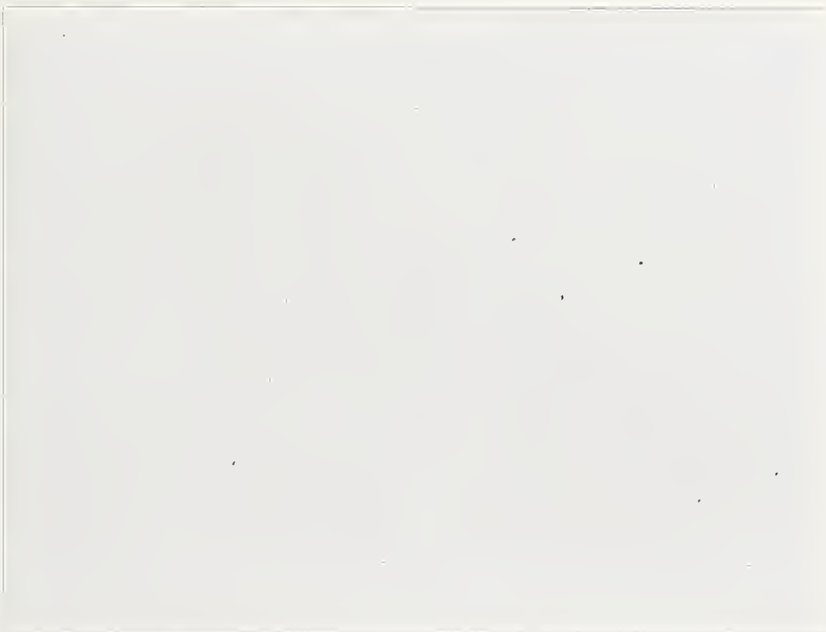


Figure 15. Unetched microstructure of cross section through new trunnion pin. X 100

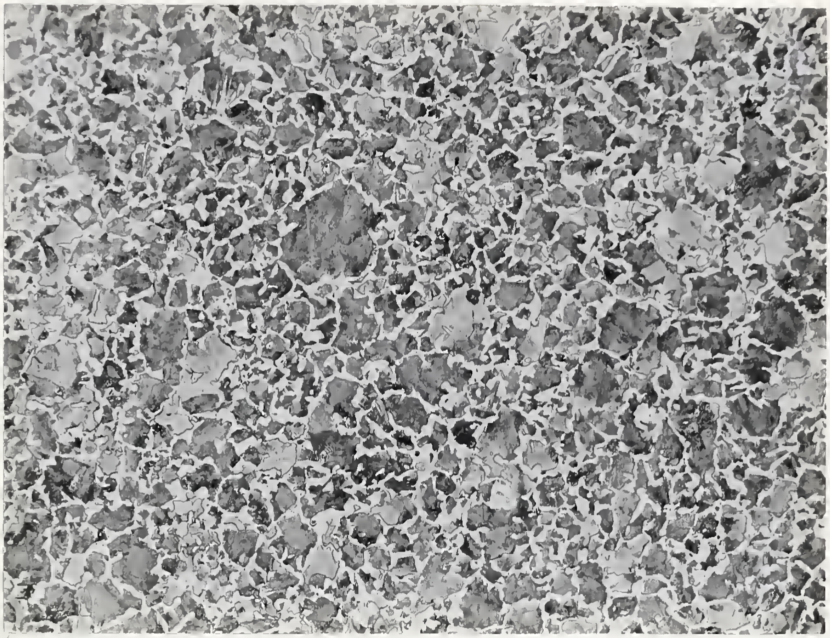


Figure 16. Etched microstructure of cross section through new trunnion pin. Microstructure is "normalized" and consists of pearlite in a pro-eutectoid ferrite matrix. Etch: 3% nital. X 100

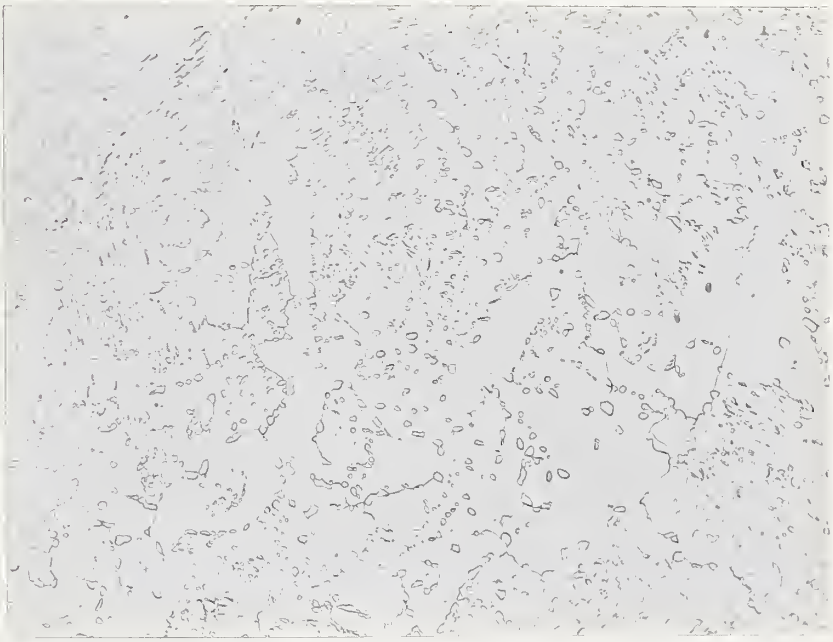


Figure 17. Etched microstructure of cross section through used trunnion pin. Microstructure consists of spheroidized carbides in a ferrite matrix. Etch: 3% nital. X 500

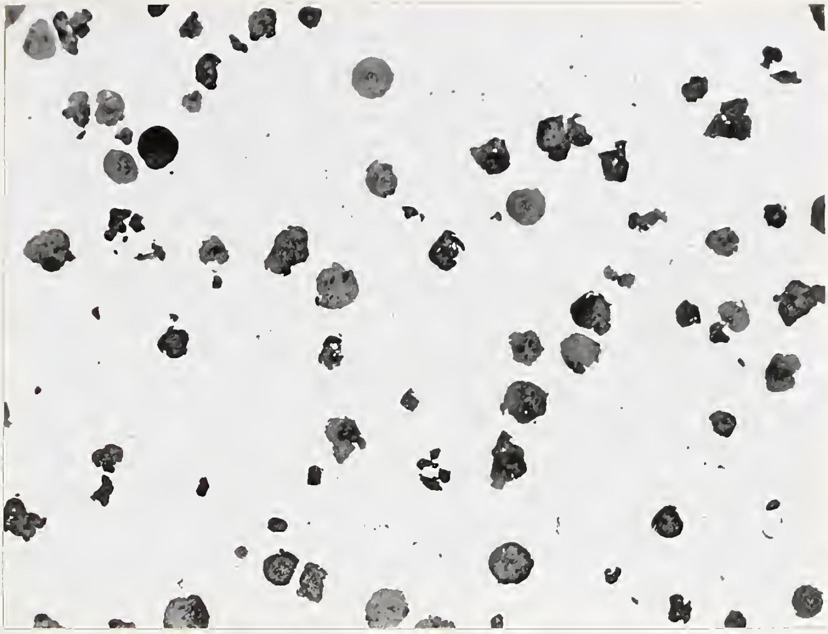


Figure 18. Unetched microstructure of cross section through the new trunnion socket. The dark, round particles are graphite. X 100

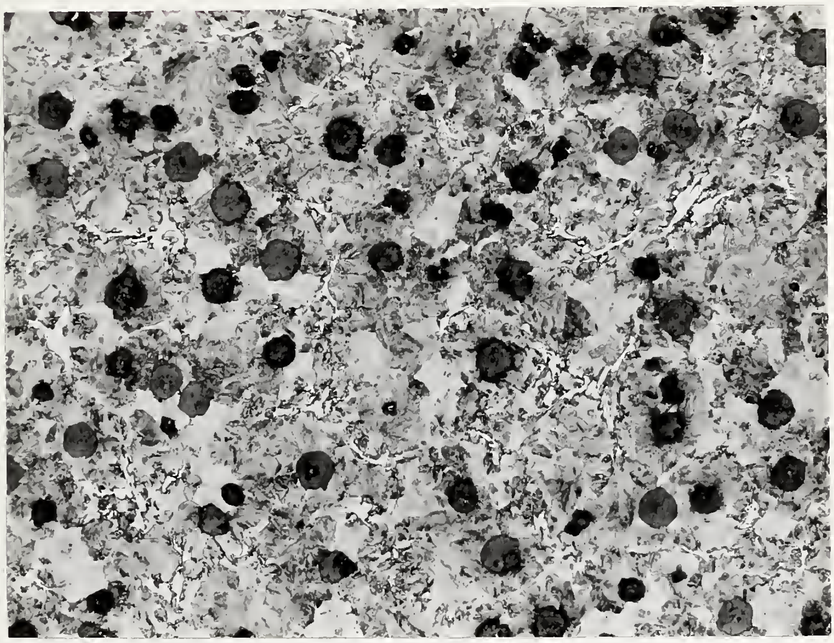


Figure 19. Etched microstructure of cross section through the new trunnion socket. The microstructure consists of graphite nodules (dark), pearlite (grey), and massive cementite (white). Etch: 3% nital. X 100

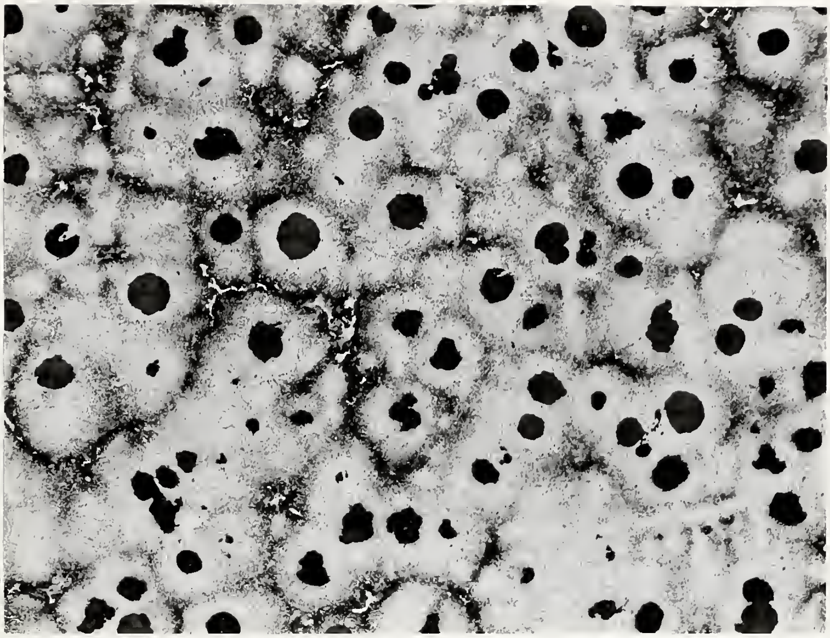


Figure 20. Etched microstructure of cross section through used trunnion socket. Microstructure consists of graphite nodules in a matrix of ferrite (white), spheroidized carbides (appearing as small dark dots), and a small amount of pearlite. Etch: 3% nital. X 100

Figure 21. Unetched microstructure of cross section through used chain link. Cross section intersects the link outside surface about 2/3 from the bottom of the photomicrograph. There is some corrosion product or scale (grey) at the surface. There are a few inclusions (dark) in the material (white). X 100

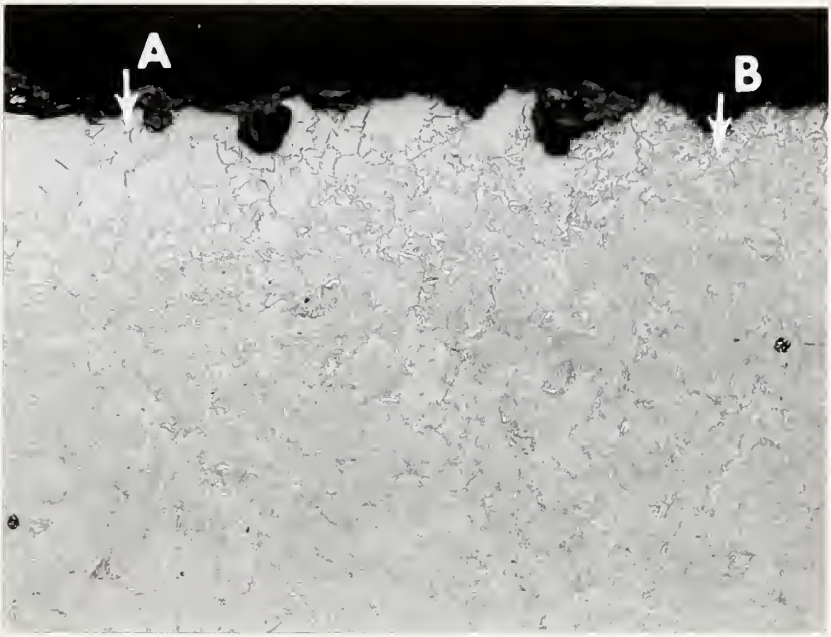


Figure 22. Etched microstructure of cross section through used chain link. Cross section intersects outside surface of link near top of photomicrograph. Interior microstructure is primarily tempered martensite. Arrow A indicates region of severe decarburization (mostly ferrite) near surface. Arrow B indicates region of much less decarburization (mostly martensite). Etch: 3% nital. X 100

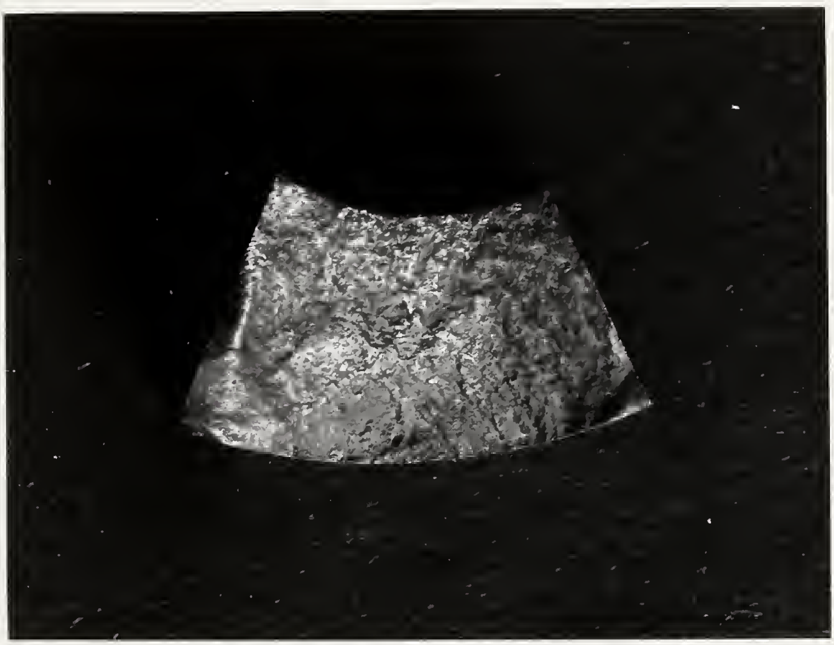
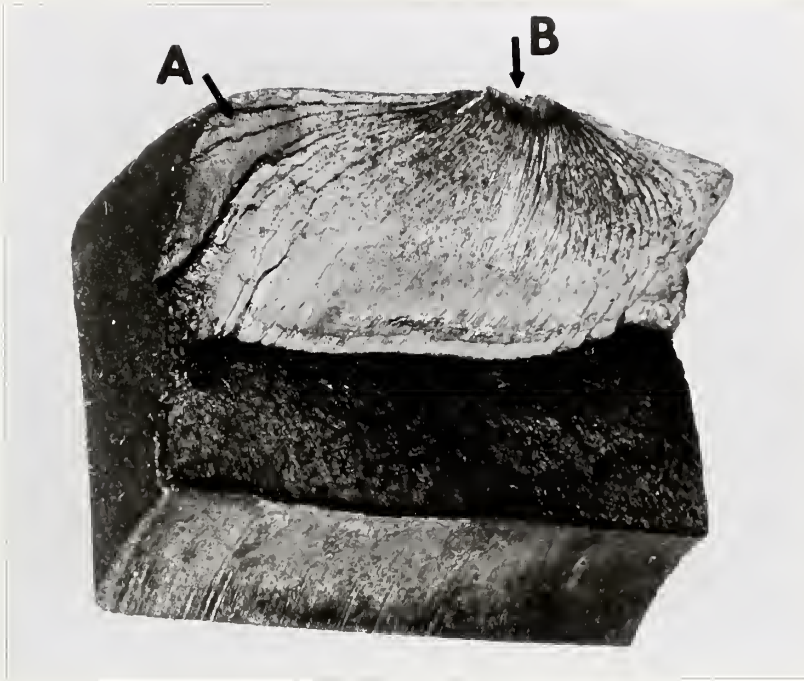


Figure 23. Fracture surface of one of the failed trunnions. X 2



a

b

Figure 24. Fracture surface of one of the failed chain links.

a. Dark area indicated by arrow A is pre-existing crack. Arrow B indicates probable origin of fracture. X 2

b. Arrows indicate change in the fracture plane. X 1

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15. SUPPLEMENTARY NOTES

16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

A number of new and used components including grates, trunnions, trunnion pins, trunnion sockets, "spacers", and chain links from District of Columbia Incinerator No. 5 were submitted for examination by the Department of Environmental Services, District of Columbia. Many of the incinerator components were failing within a relatively short time after installation. Examination revealed that all of the used components except the chain links had undergone significant mechanical property and microstructural changes when compared to the material from the new components. These changes could be attributed to exposure of the materials to temperatures which were excessive for the materials employed. Material from the new and used grates did not meet contract specifications. Two approaches to a possible solution to the problem are discussed.

17. KEY WORDS (Alphabetical order, separated by semicolons)

Ductile iron; incinerator; mechanical properties, microstructures; steel; temperature.

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