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RESEARCH MEMORANDUM

SURVEY OF MICROSTRUCTURES AND MECHANICAL PROPERTIES OF
OVER-TEMPERATURED S-816 TURBINE BUCKETS

FROM J47 ENGINES

By S. Floreen and R. A. Signorelli

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

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March 20, 1957



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RESEARCH MEMORANDUM

SURVEY OF MICROSTRUCTURES AND MECHANICAL PROPERTIES OF OVER-
TEMPERATED S-816 TURBINE BUCKETS FROM J47 ENGINES

By. S. Floreen and R. A. Signorelli

SUMMARY

A group of buckets overtemperated in service were given an extensive metallographic examination. Most of the buckets showed an overaged microstructure. Similar microstructures were also found in new buckets and in new buckets heated at 1500° F for 50 hours. Therefore, an overaged microstructure is not proof of overtemperature.

Several of the overtemperated buckets had partially solutioned microstructures, which may be taken as evidence of overtemperature operation.

The stress-rupture lives of specimens obtained from overtemperated buckets ranged from 66 to 216 hours when tested at conditions giving a 100-hour life for S-816 bar stock. The partially solutioned buckets had longer lives than the overaged buckets.

A considerable variation in hardness and microstructure was found in the new buckets. These variations are probably due to fabricating variables and could cause variation in bucket performance in service.

INTRODUCTION

An overtemperated bucket is one that has been heated in service to a temperature greater than the allowable maximum operating temperature. In most engines in service today the bucket temperature is not measured, but the tailpipe temperature is measured. Studies have shown that when the tailpipe temperature reaches the operating limit of about 1275° to 1300° F in steady-state operation, a region in the buckets reaches a temperature of 1500° F. Hence, an overtemperated bucket may be defined as one that has been heated in excess of 1500° F.

Overtemperature was sometimes observed by pilots but was usually noticed during engine overhaul by indirect evidence such as warped or cracked nozzle guide vanes. One practice has been to inspect the buckets and discard all those showing visible damage such as cracking, warping, or necking. Other buckets from the engine, however, often showed no visible damage. If overtemperature was suspected, four undamaged buckets were removed from the engine and examined microstructurally in order to determine whether they had been overtemperated.

Heating S-816 above 1500° F is known to produce microstructural changes. Spheroidization and solution of carbides have been taken as evidence of overtemperature operation, and buckets showing these changes have been classified as overtemperated. Similar changes in microstructure, however, might also take place during normal engine operation. Therefore, there is some question of whether or not microstructural examination can distinguish between overtemperature and nonovertemperature operation.

This investigation evaluates the microstructural method of detecting overtemperature in S-816 buckets. A metallographic examination was made of new and overtemperated buckets. New buckets were also heated and then microexamined to estimate the effect of normal operation. As a further check on the effects of overtemperature, stress-tupture tests were conducted on a group of the overtemperated buckets.

PROCEDURE

Buckets Investigated

Eight new buckets and twenty buckets classified as overtemperated were used for this investigation. Table I lists all the buckets and how they were investigated. The eight new buckets were selected at random from Air Force stock at the NACA Lewis laboratory.

The overtemperated J47 buckets were furnished by the Air Force from their Oklahoma City Depot. Buckets 1 and 2 were from engine A, which exceeded a tailpipe temperature of 1832° F on acceleration. (Maximum tailpipe temperature is 1275° to 1300° F.) Buckets 3 and 4 were from engine B, which oversped 104 percent of rated speed with a tailpipe temperature greater than 1490° F. The remaining 16 buckets overtemperated in service were of unspecified background.

Four of the buckets of unspecified overtemperature history were necked. A photograph showing an example of this necking is presented in figure 1. The necked buckets were 5, 6, 13, and 14 (table I).

Metallographic Survey

Buckets were sectioned for microexamination and hardness measurements as shown by the sketch in figure 2. All eight new buckets and twelve overtemperated buckets including the four buckets from engines A and B, and two necked buckets were investigated by this method. In addition, small sections were cut from various parts of two of the new buckets and heated for 50 hours at 1500° F and then inspected metallographically.

Stress-Rupture Tests

Stress-rupture specimens were machined from eight overtemperated buckets as shown by figure 3 and tested in stress rupture at a temperature of 1500° F and stress of 23,600 pounds per square inch. This temperature and stress would give a nominal 100-hour life for S-816 bar stock in the standard heat-treated condition. As shown in figure 3, a region adjacent to the stress-rupture specimen was photomicrographed in order to furnish a correlation of rupture life with microstructure.

RESULTS

Metallographic Survey

The microstructure of heat-treated S-816 is presented in figure 4(a). Aside from the residual columbium-tantalum-type carbides, the carbides that precipitate in aging are very fine. When subjected to increasingly higher temperatures, these fine carbides tend to coalesce and spheroidize, producing what is termed an overaged microstructure as illustrated in figure 4(b). At still higher temperatures, these carbides tend to redissolve into the matrix until the alloy becomes predominantly a solid solution with the exception of the very stable columbium-tantalum carbide precipitate.

The microstructures of the new buckets were in most cases typical of those found in heat-treated S-816 bar stock. Several regions were found, however, where the microstructure appeared slightly overaged, as shown in figures 5(a) to (e). A cold-worked region was also found in one of the new buckets (24) as shown in figure 5(f).

The microstructures found in the overtemperated buckets are presented in figure 6. In general, the microstructure varied from the leading edge to the trailing edge of these buckets. The leading edge usually shows the greatest degree of overaging, as exemplified by the hyphenated or spheriodized structures found in this region, while the trailing edge shows much less overaging. The middle of the bucket

generally shows very little overaging. The microstructure also varies somewhat from the hub to the tip of the buckets. That is, the leading edge at the hub is slightly different from the leading edge at the tip, and so on. In most cases, however, these variations are of much smaller magnitude than those from the leading edge to the trailing edge.

A considerable variation in microstructure was found between buckets 5 and 6, which were almost completely solutioned, and the remaining overtemperated buckets. This solutioning indicates that the overtemperature must have been quite severe. Buckets 5 and 6 were necked which further indicates a severe overtemperature. All the remaining overtemperated buckets investigated metallographically had overaged microstructures. The variations in this overaging may be shown by comparing buckets 12 and 4. Bucket 12 shows a large amount of carbide precipitation, while bucket 4 shows very little. The remaining buckets show more overaging than bucket 4, but less than 12. This moderately overaged microstructure might therefore be considered the typical microstructure of the overtemperated buckets. A cold-worked region was also found in one of the overtemperated buckets as indicated by the region at the trailing edge of bucket 3.

The microstructures produced by heating sections of the new buckets for 50 hours at 1500° F are shown in figure 7. These specimens had moderately overaged microstructures quite similar to those found in most of the overtemperated buckets.

The hardness data for all the buckets are presented in table II. There were few variations in hardness, but two of the new buckets, 22 and 23, each had a hardness range of Rockwell C-21 to 35. The remaining buckets had hardness values typical of S-816 bar stock, and no distinction could be made between the new and the overtemperated buckets on the basis of hardness values.

Stress-Rupture Tests

The results of the stress-rupture tests are presented in table III. The rupture life of the overtemperated buckets ranged from 66 to approximately 216 hours with an average life of 133 hours.

The microstructures of the specimens before testing are shown in figure 8 in order of increasing rupture life. The specimens moderately overaged had shorter rupture lives than those partially solutioned.

DISCUSSION OF RESULTS

The results showed that an overaged microstructure similar to those found in the overtemperated buckets can be produced by heating sections

from new buckets at 1500° F for 50 hours. This temperature roughly corresponds to full-power operation for the engine and is not an overtemperature. It seems very likely, therefore, that buckets that had been run at normal operating temperatures may appear overtemperated. Furthermore, overaged structures were also found in some regions in the new buckets.

An overaged microstructure, therefore, is not positive evidence of overtemperature operation. Only when partial solutioning occurs does overtemperature produce a unique microstructure. The partially solutioned buckets examined, however, would have been discarded during inspection because they showed visible necking. Partial solutioning might occur with a high temperature and low stress, such as during a hot start, with no visible damage to the bucket. In this instance, microexamination would detect overtemperature.

The survey of the overtemperated buckets showed that the leading edge of these buckets was usually overaged while the midchord was not. Hence, it might be thought that overtemperature could be detected by variation in microstructure of a bucket. This detection might be possible if overtemperature always involved a high temperature for a short time and if all the buckets had uniform microstructures when new. Such is not the case, however. Overtemperature could occur with a wide variety of time-temperature conditions, and the new buckets did not have uniform microstructures. Hence, it does not appear likely, particularly with the present variation in microstructure of new buckets, that overtemperature can be reliably detected by a variation in microstructure between the leading edge and the midchord of a bucket.

As far as rupture life is concerned, the moderately overtemperated buckets (overaged) ranged in life from 66 to 216 hours, which is within the scatterband of rupture life for S-816 bar stock. Hence, it is difficult to estimate the effect of overtemperature on the strength for these buckets. The partially solutioned buckets, however, had longer rupture lives (212 and 216 hr) than the overaged buckets (fig. 8).

One of the significant results of this investigation was the variations in microstructure and hardness of the new buckets. Several of these buckets showed signs of overaging, while others had a cold-worked region. Two buckets each had hardness values ranging from Rockwell C-21 to 35. In view of such variations, it would appear that scatter in bucket performance may be partially due to fabricating variables. Certainly, if there were less variation, a more uniform performance in service might be expected. Therefore, the problem of fabricating variables and how to control them seems worthy of more study.

SUMMARY OF RESULTS

Twelve buckets overtemperated in service were inspected metallographically. In addition, eight overtemperated buckets were tested in stress rupture. Eight new buckets were also examined metallographically in the as-received condition and after heating at 1500° F for 50 hours. The following results were obtained:

1. An overaged microstructure is not definite proof of overtemperature since similar microstructures were found in both new buckets and those heated at 1500° F. Partial solutioning, however, may be taken as evidence of overtemperature.

2. The rupture lives of the overtemperated buckets ranged from 66 to 216 hours when tested at conditions giving a nominal 100-hour life for S-816 bar stock. Partially solutioned specimens had longer lives than overaged ones.

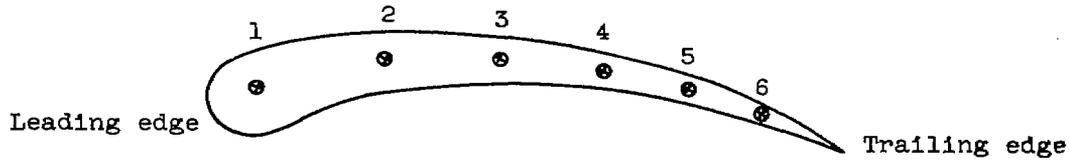
3. Signs of overaging and cold work were found in some of the new buckets. Hardness ranging in a single bucket from Rockwell C-21 to 35 was also found in two of the eight new buckets examined. These variations, probably due to fabricating variables, could cause scatter in bucket performance in service.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, December 5, 1956

TABLE I. - BUCKETS INSPECTED

Bucket	Manufacturer	Condition	Examination
1	A	Overtemperature; engine A Overtemperature; engine A Overtemperature; engine B Overtemperature; engine B Overtemperature; necked	Micro survey
2	A		
3	B		
4	C		
5	D		
6	C	Overtemperature; unspecified history ↓ Overtemperature; necked ↓ Overtemperature; unspecified history ↓ New	Stress rupture
7	A		
8	A		
9	E		
10	A		
11	F		
12	A		
13	B		
14	D		
15	B		
16	E	New	Micro survey + heat treatment (1500° F for 50 hr)
17	F		
18	F		
19	A		
20	F		
21	A		
22	A		
23	A		
24	A		
25	B		
26	B		
27	A		
28	F		

TABLE II. - ROCKWELL C HARDNESS VALUES FOUND IN BUCKETS



Bucket	1	2	3	4	5	6	Bucket	1	2	3	4	5	6
1 { Tip Mean Hub	29 30 27	27 29 28	27 28 28	27 27 27	28 27 27	23 24 24	12 { Tip Mean Hub	27 27 27	26 27 26	26 26 25	28 26 26	31 27 26	31 28 26
2 { Tip Mean Hub	25 25 25	25 25 24	26 25 24	28 26 25	30 27 26	31 28 27	21 { Tip Mean Hub	27 28 27	28 27 27	28 26 27	29 25 27	28 26 28	24 25 29
3 { Tip Mean Hub	28 31 32	29 29 30	30 29 30	31 30 29	33 33 31	35 35 33	22 { Tip Mean Hub	29 30 24	28 27 24	26 25 23	28 24 21	30 27 25	30 35 27
4 { Tip Mean Hub	27 25 26	26 25 27	25 25 26	26 25 27	25 25 27	22 25 27	23 { Tip Mean Hub	25 21 24	27 23 21	29 23 23	27 26 24	25 29 25	23 35 26
5 { Tip Near tip Mean Hub	30 22 23 27	30 24 24 27	29 24 24 26	29 24 24 27	29 24 25 27	25 23 23 28	24 { Tip Mean Hub	30 27 27	29 28 28	27 29 28	27 28 28	25 28 27	24 27 26
6 { Tip Near tip Mean Hub	27 23 23 26	28 24 24 27	27 24 25 28	27 23 25 28	26 22 25 27	25 21 23 27	25 { Tip Mean Hub	27 27 29	28 25 28	29 24 27	28 25 28	27 25 31	25 26 34
7 { Tip Mean Hub	25 26 25	25 25 27	24 26 27	25 24 25	24 24 27	21 25 27	26 { Tip Mean Hub	24 24 24	25 24 23	27 23 23	28 25 25	28 27 27	28 27 29
8 { Tip Mean Hub	30 30 28	27 28 27	26 27 27	26 27 27	27 28 28	23 27	27 { Tip Mean Hub	23 26 24	24 25 24	25 26 23	26 26 24	25 26 25	26 30 25
9 { Tip Mean Hub	27 30 30	27 27 28	28 27 27	28 28 28	27 29 30	32 33 33	28 { Tip Mean Hub	28 29 30	28 30 30	29 30 30	30 30 29	30 29 30	29 27 30
10 { Tip Mean Hub	25 27 27	26 28 27	25 27 27	25 27 28	25 27 28	25 29 27	Hardnesses from region cut next to stress-rupture specimen						
11 { Tip Mean Hub	31 33 31	29 27 27	26 26 27	25 27 26	28 28 27	29 28 27	13	24	25				
							14	24	24				
							15	28	28				
							16	25	26				
							17	28	29				
							18	29	29				
							19	25	26				
							20	31	31				

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TABLE III. - RUPTURE LIVES OF OVERTEMPORATED BUCKETS

[All specimens tested at 1500° F and 23,600 psi.]

Bucket	Rupture life, hr
13	216.2
14	211.5
15	84.9
16	66
17	68.7
18	200.5
19	68.6
20	152.7
Av., 133.3	

CR-2

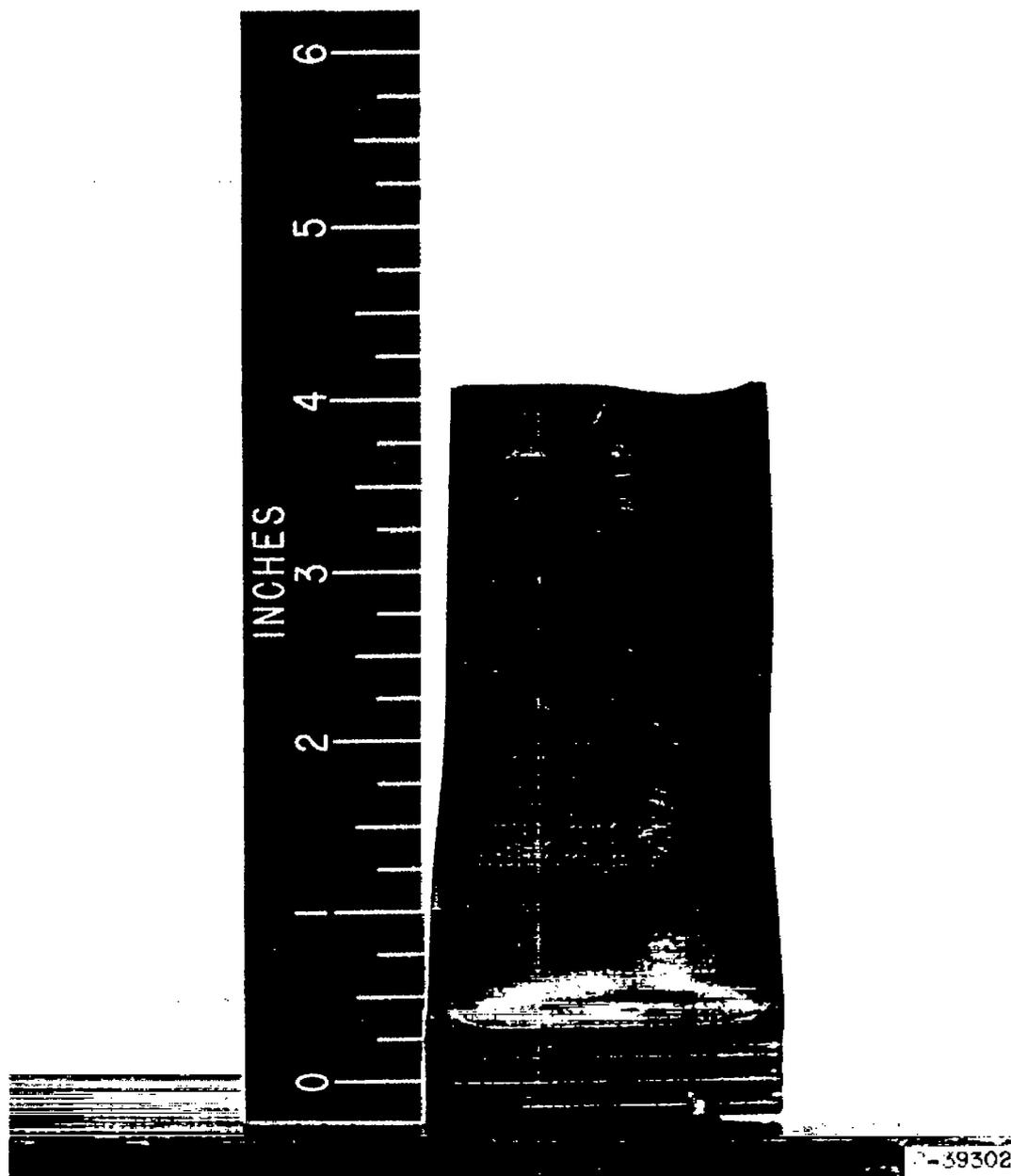


Figure 1. - Necked bucket.

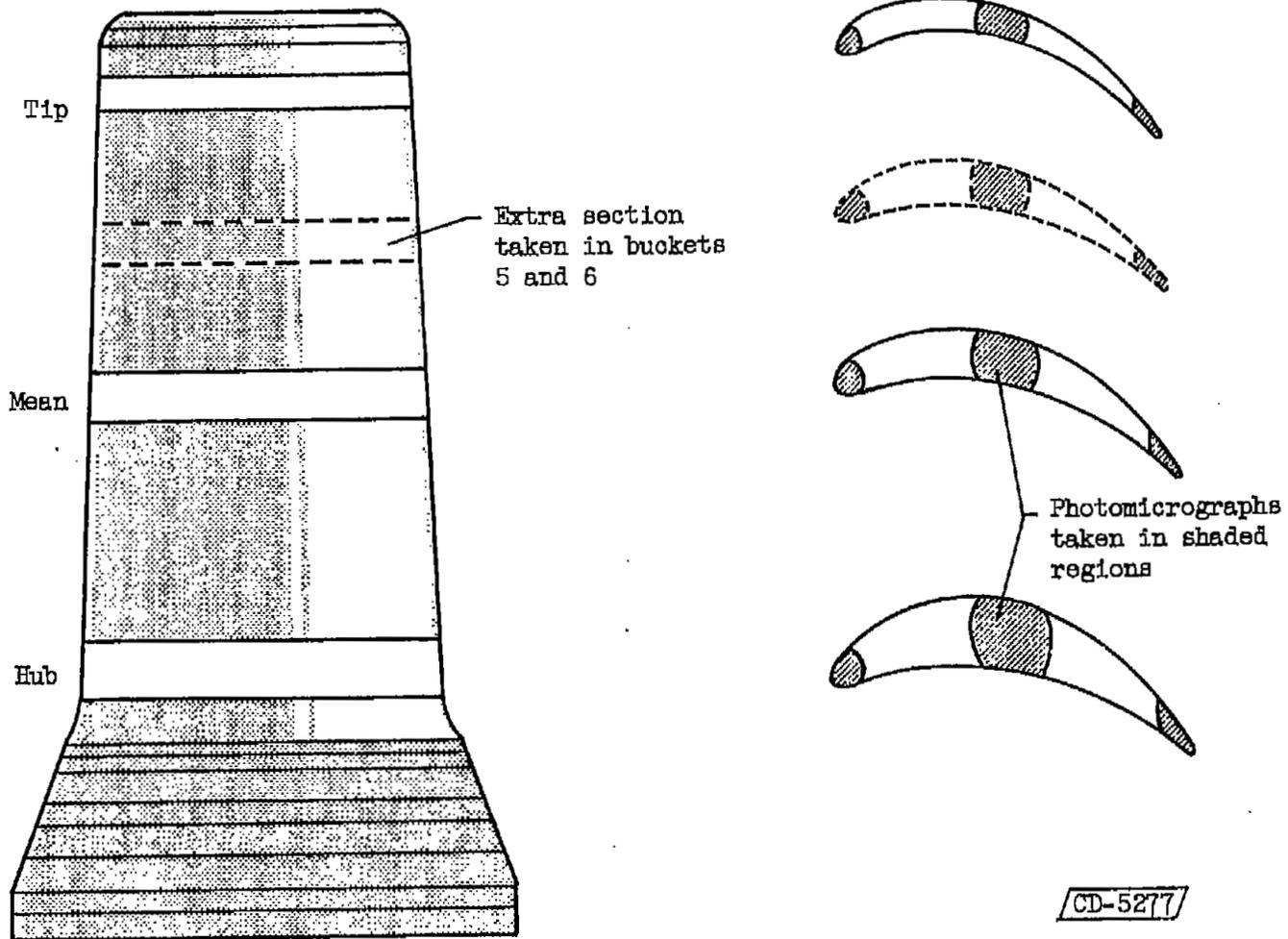
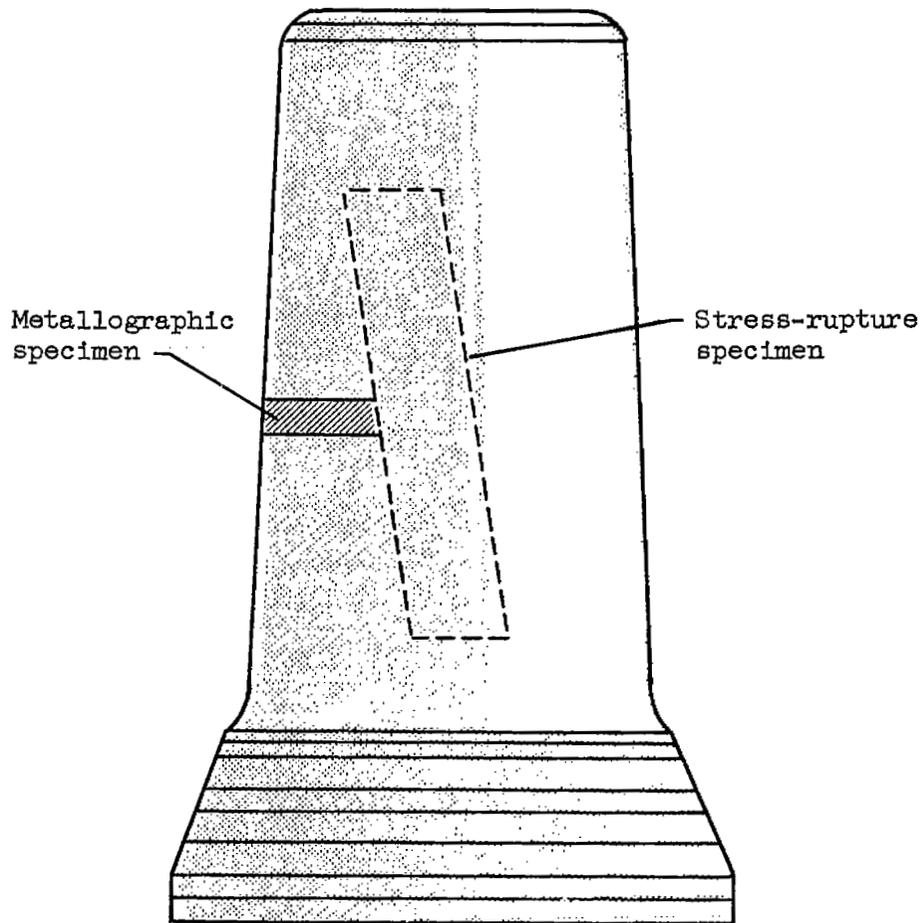


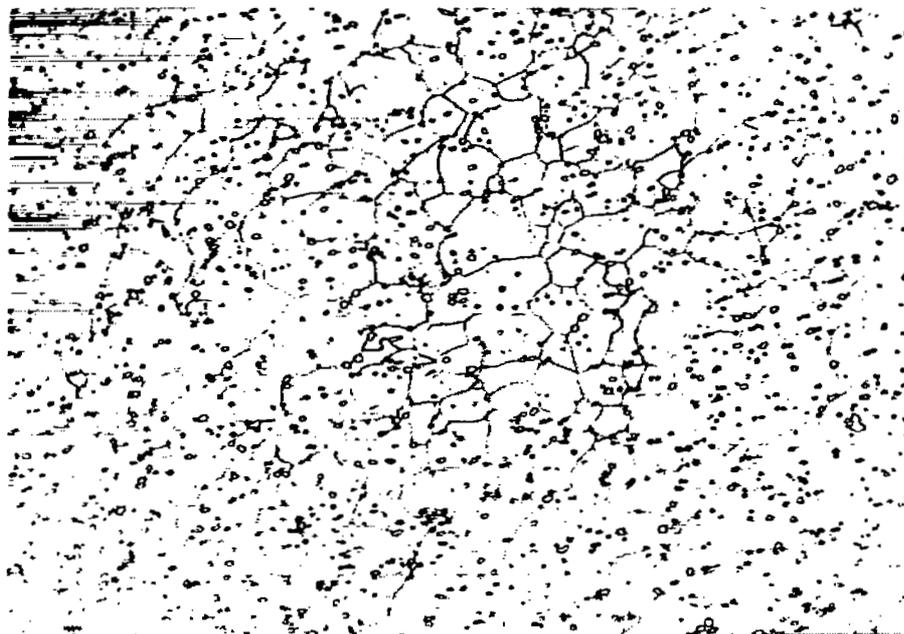
Figure 2. - Sketch showing how buckets were sectioned and inspected.



CD-5276

Figure 3. - Sketch showing how stress-rupture specimen and metallographic specimen were cut from buckets.

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X250.



C-43457

X1000.

(a) Normal. Reduced 6 percent in printing.

Figure 4. - Microstructure of S-816.

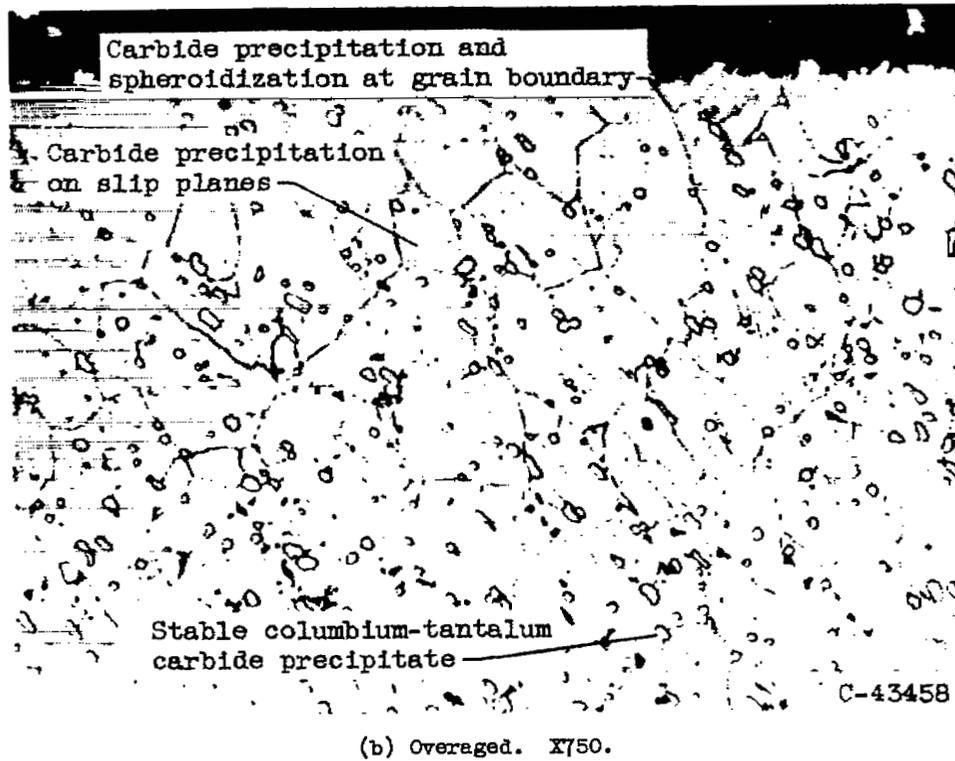
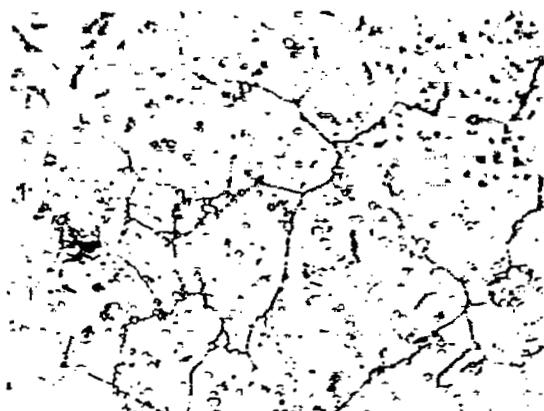


Figure 4. - Concluded. Microstructure of S-816.

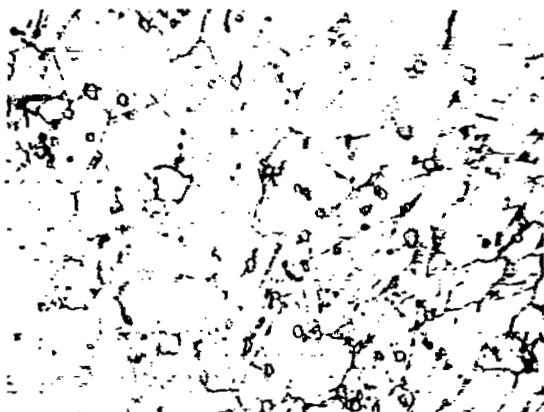
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(a) Bucket 21, mean middle.



(b) Bucket 21, hub trailing edge.



(c) Bucket 22, mean trailing edge.



(d) Bucket 24, tip leading edge.

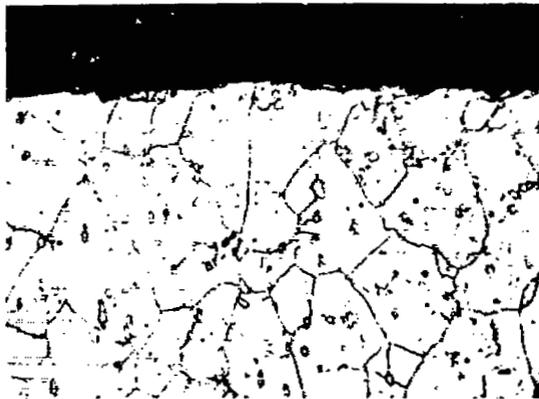


(e) Bucket 25, hub trailing edge.

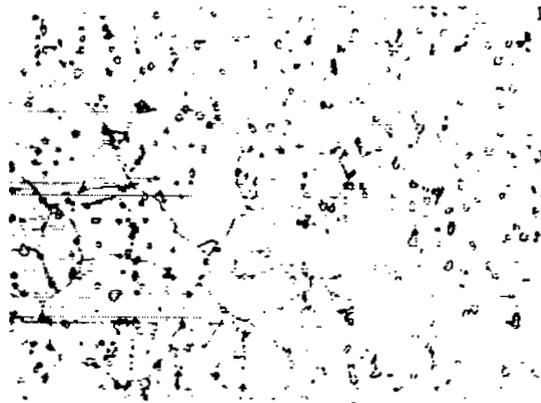


(f) Bucket 24, hub trailing edge.

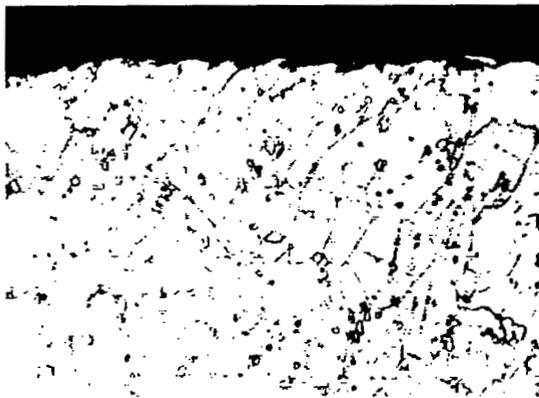
Figure 5. - Microstructures found in some new buckets. Reduced 44 percent in printing. X750.



Tip



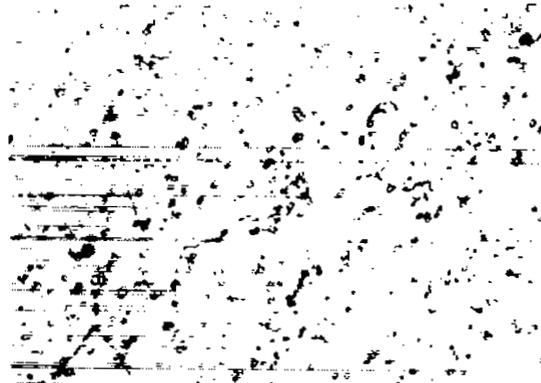
Mean



Hub



Leading edge

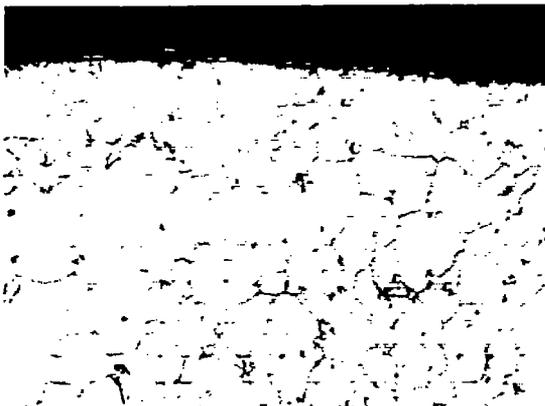


Middle

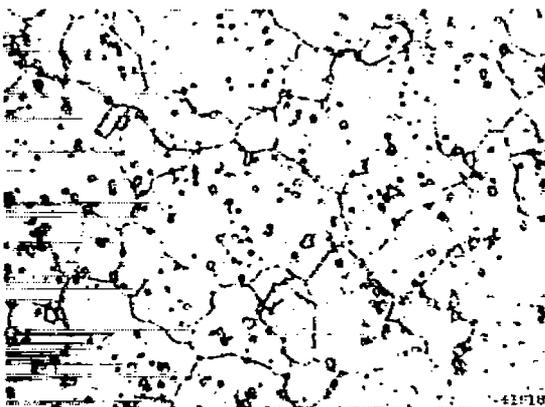
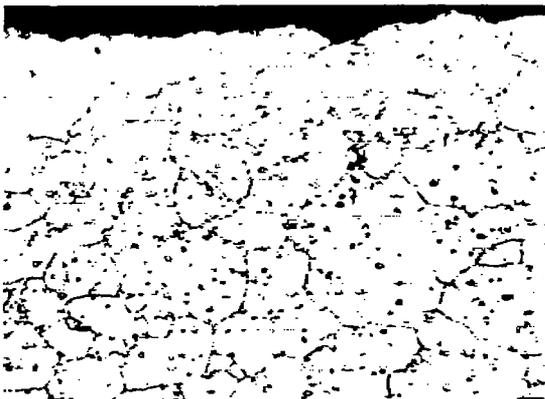
(a) Bucket 1. Reduced

Figure 6. - Microstructures
Etch, aqua regia plus

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CR-3

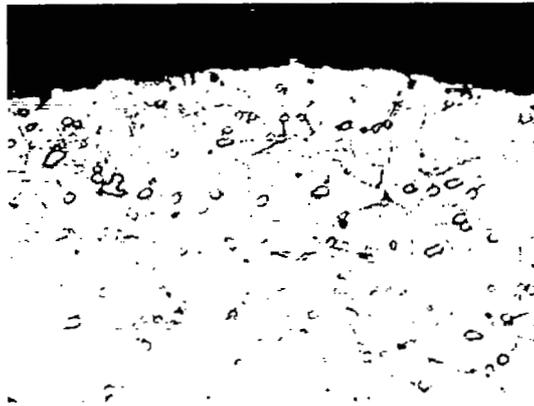


Trailing edge

44 percent in printing.

of overtemperated buckets.
glycerine. X750.

Tip



Mean

Hub

Leading edge

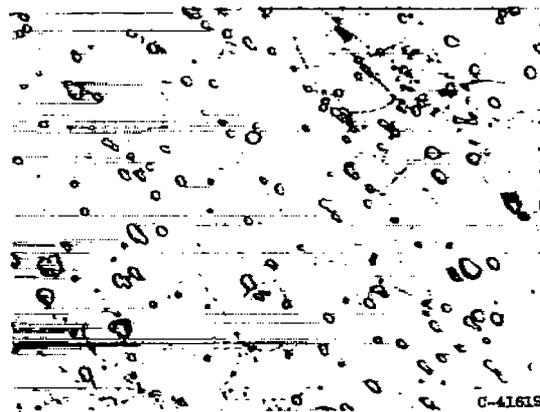
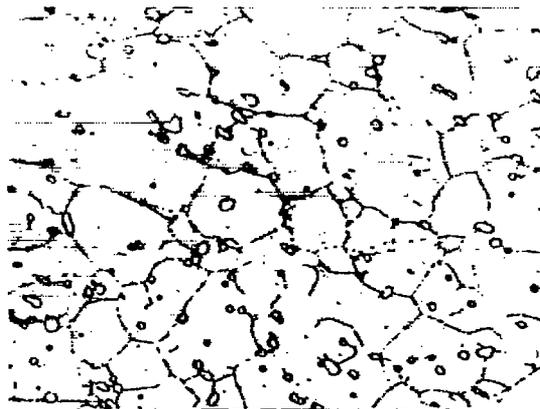
Middle

(b) Bucket 2. Reduced

Figure 6. - Continued. Microstructures Etch, aqua regia plus glycerine.

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CR-3 back

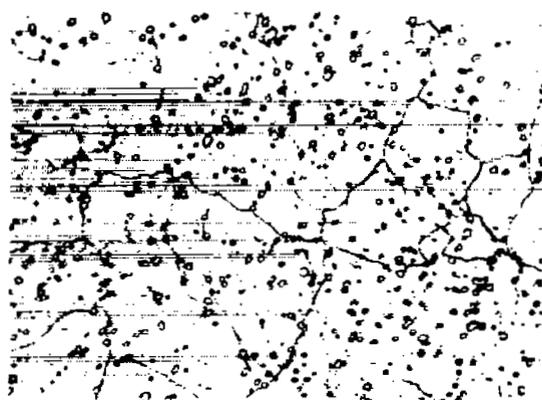
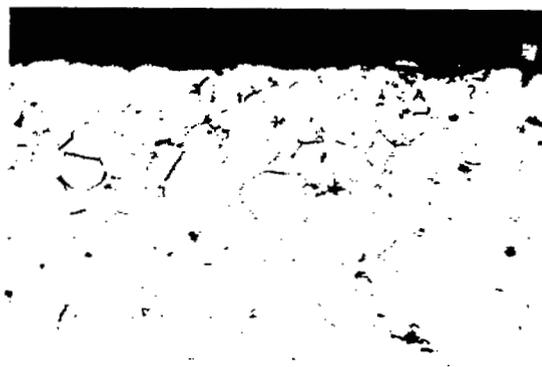


Trailing edge

44 percent in printing.

of overtemperated buckets.
X750.

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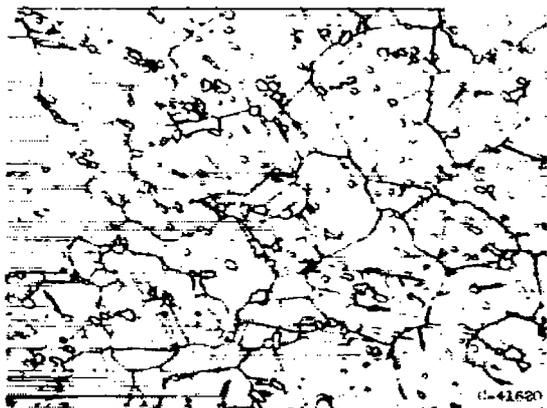
Leading edge

Middle

(c) Bucket 3. Reduced

Figure 6. - Continued. Microstructures Etch, aqua regia plus glycerine.

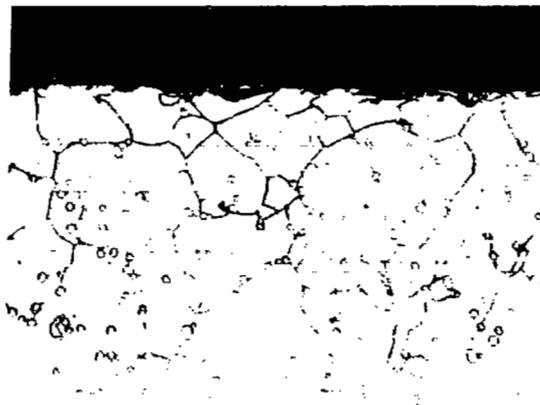
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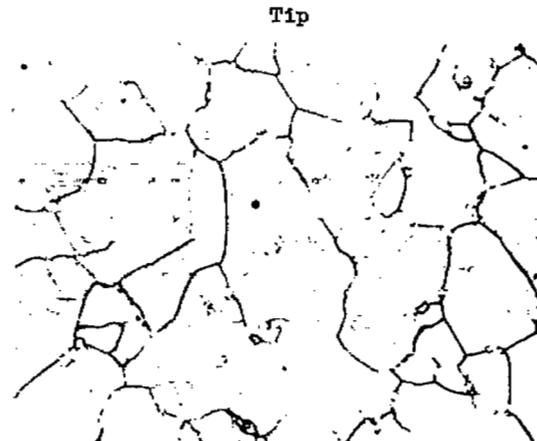
Trailing edge

44 percent in printing.

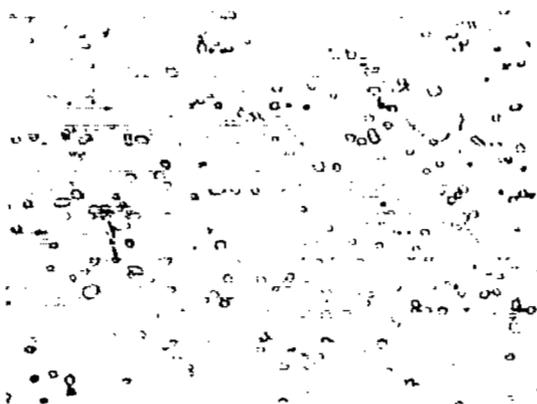
of overtemperated buckets.
X750.



Leading edge



Tip



Mean



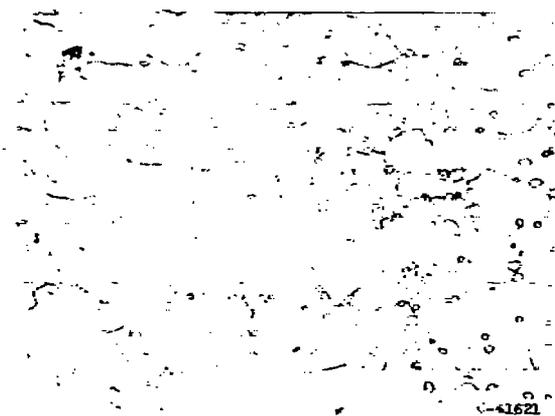
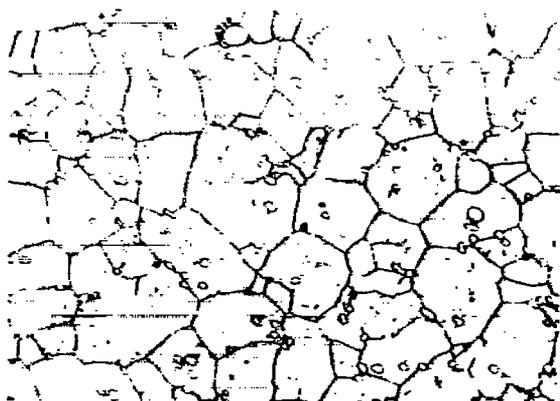
Hub

Middle

(d) Bucket 4. Reduced

Figure 6. - Continued. Microstructures Etch, aqua regia plus glycerine.

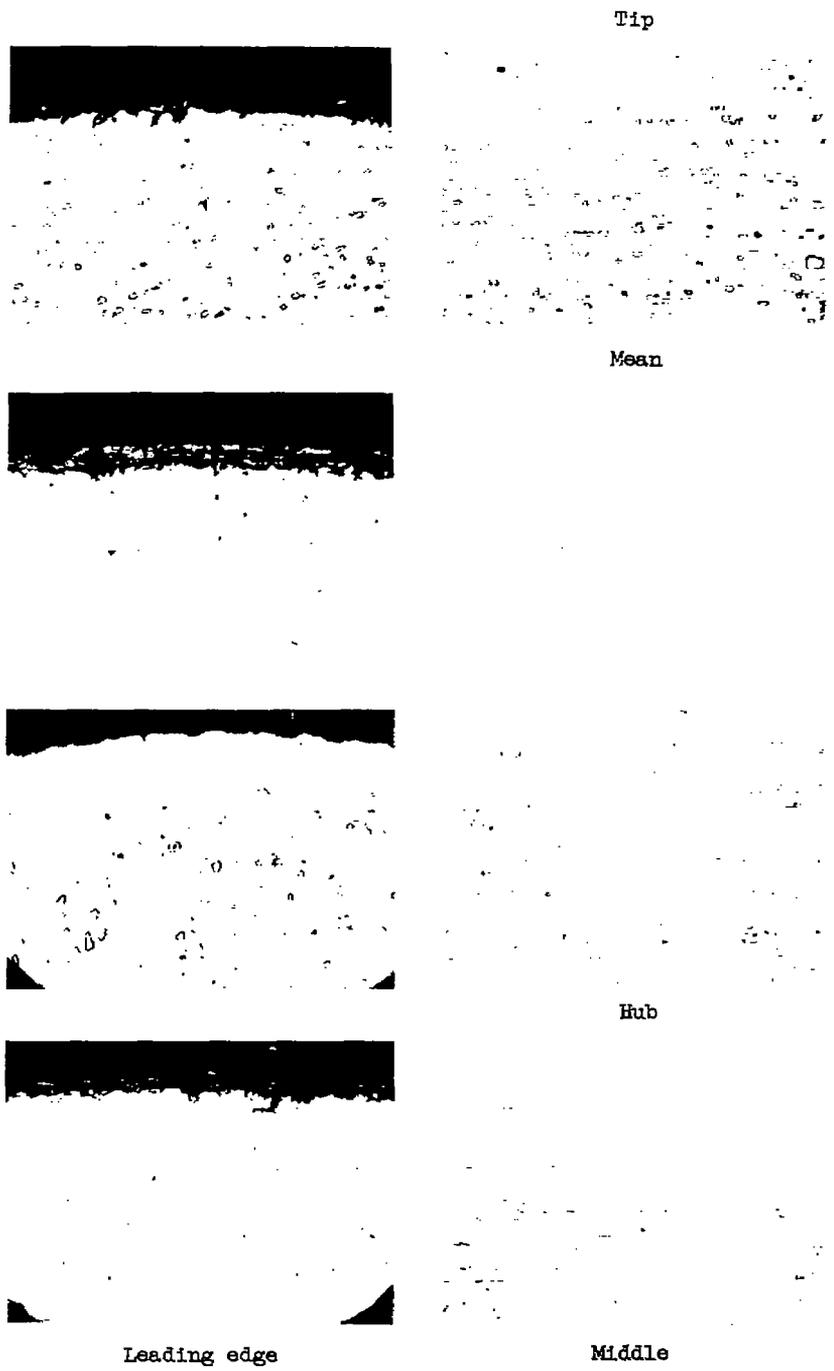
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Trailing edge

44 percent in printing.

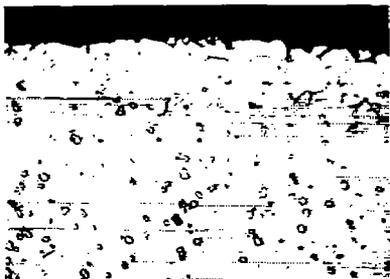
of overtemperated buckets.
X750.



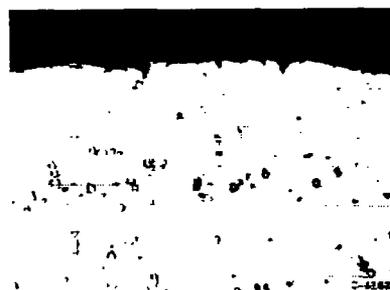
(e) Bucket 5. Reduced

Figure 6. - Continued. Microstructures Etch, aqua regia plus glycerine.

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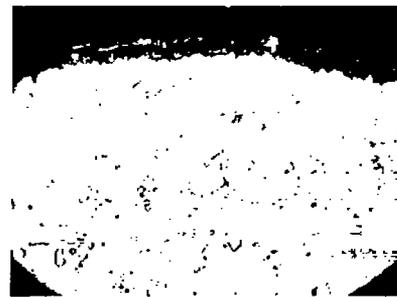
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Trailing edge

59 percent in printing.

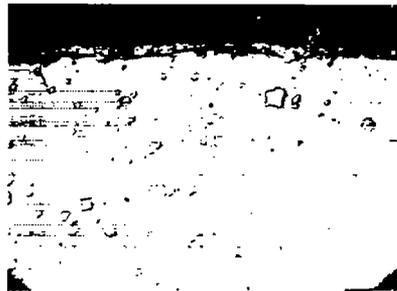
of overtemperated buckets.
X750.



Tip



Mean



Leading edge



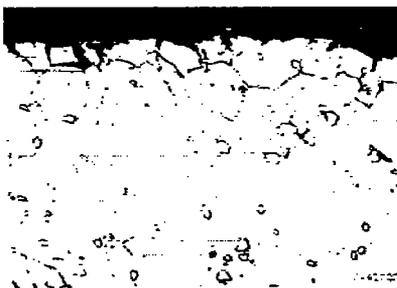
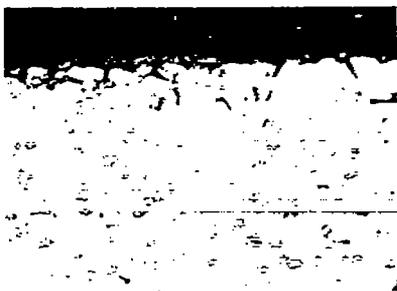
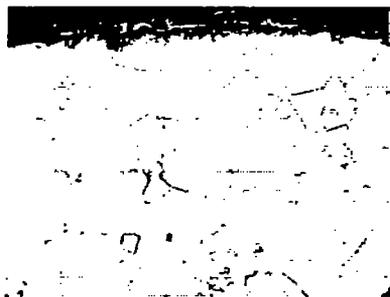
Hub

Middle

(f) Bucket 6. Reduced

Figure 6. - Continued. Microstructures
Etch, aqua regia plus glycerine.

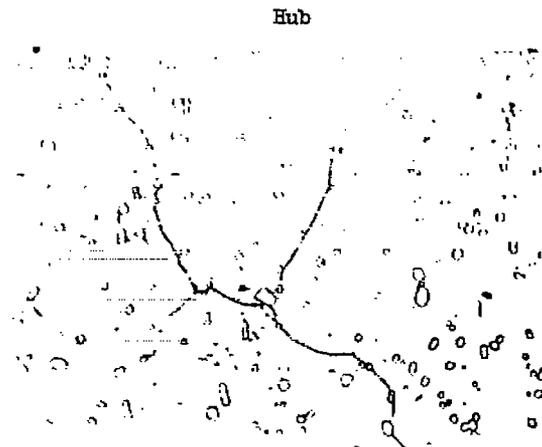
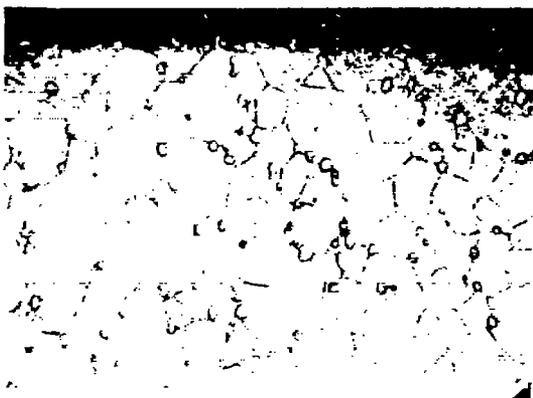
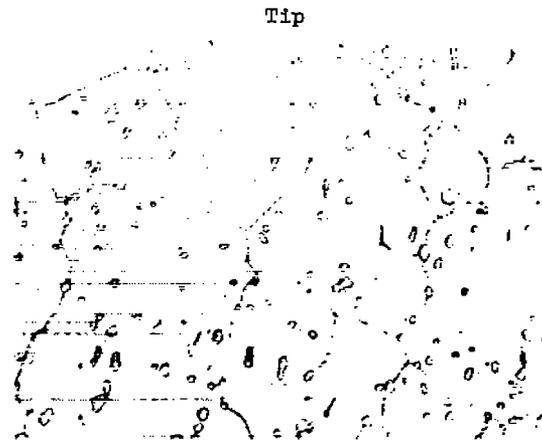
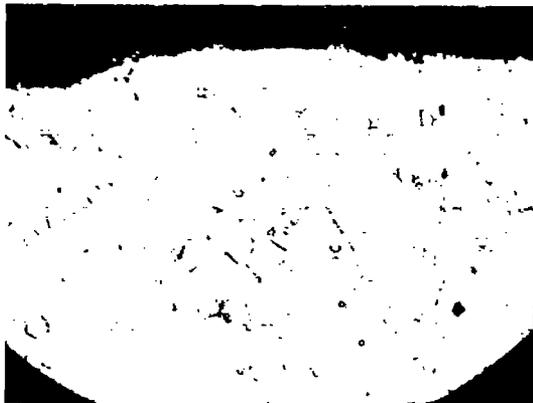
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Trailing edge

59 percent in printing.

of overtemperated buckets.
X750.



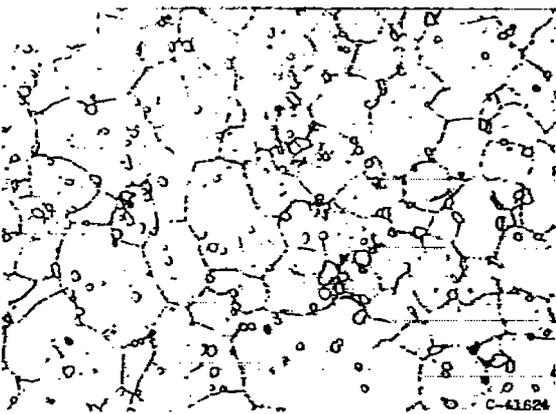
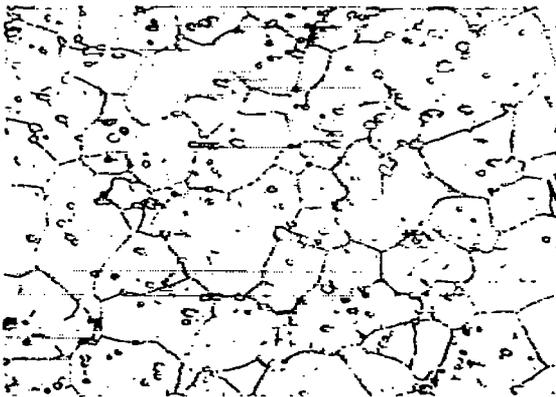
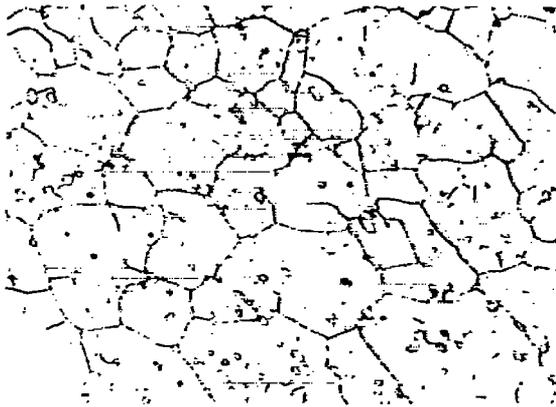
Leading edge

Middle

(g) Bucket 7. Reduced

Figure 6. - Continued. Microstructures
Etch, aqua regia plus glycerine.

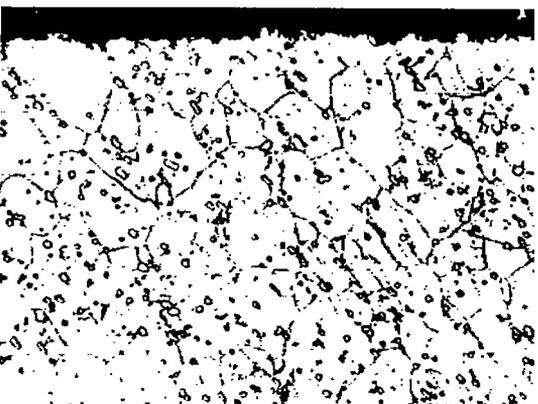
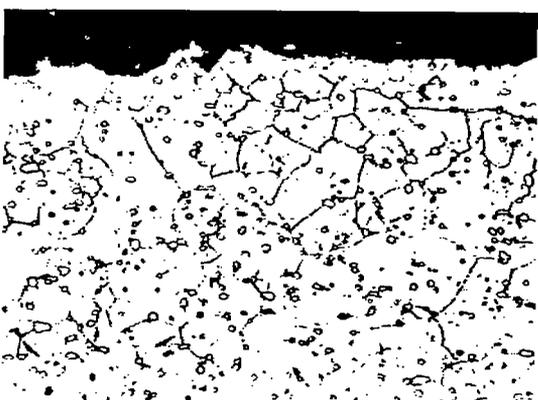
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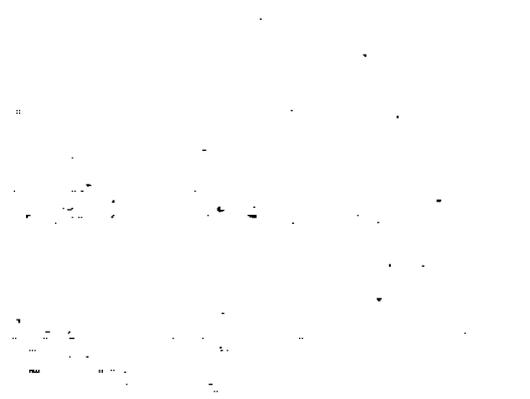
Trailing edge

44 percent in printing.

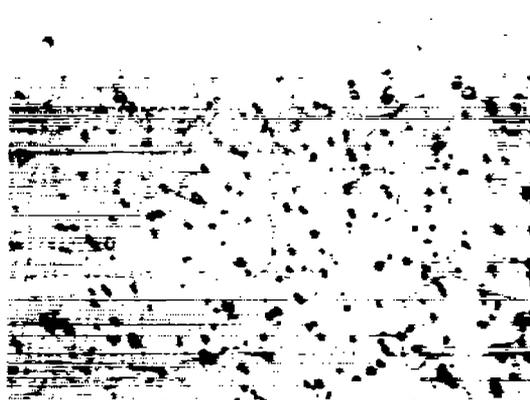
of overtemperated buckets.
X750.



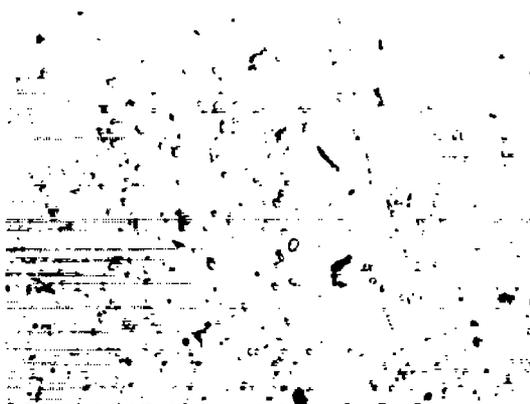
Leading edge



Mean



Hub

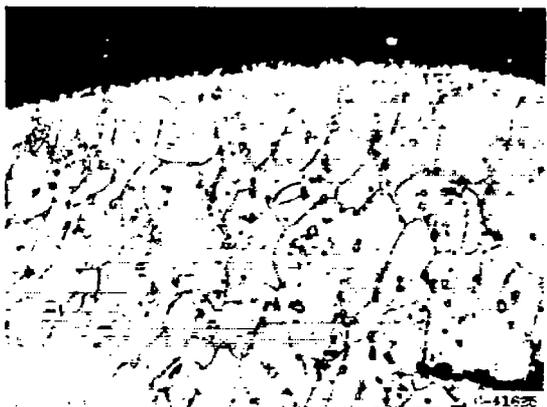
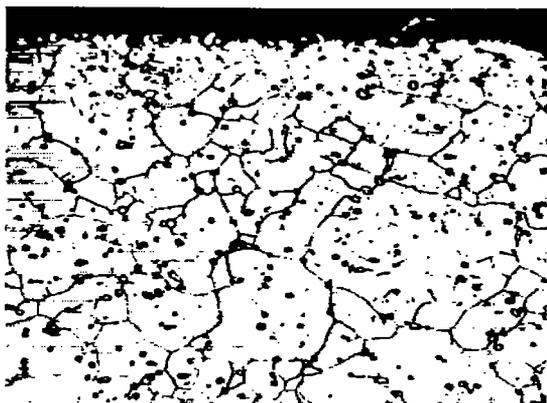
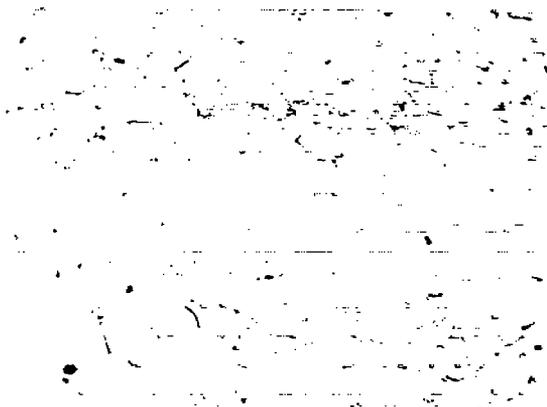


Middle

(h) Bucket 8. Reduced

Figure 6. - Continued. Microstructures
Etch, aqua regia plus glycerine.

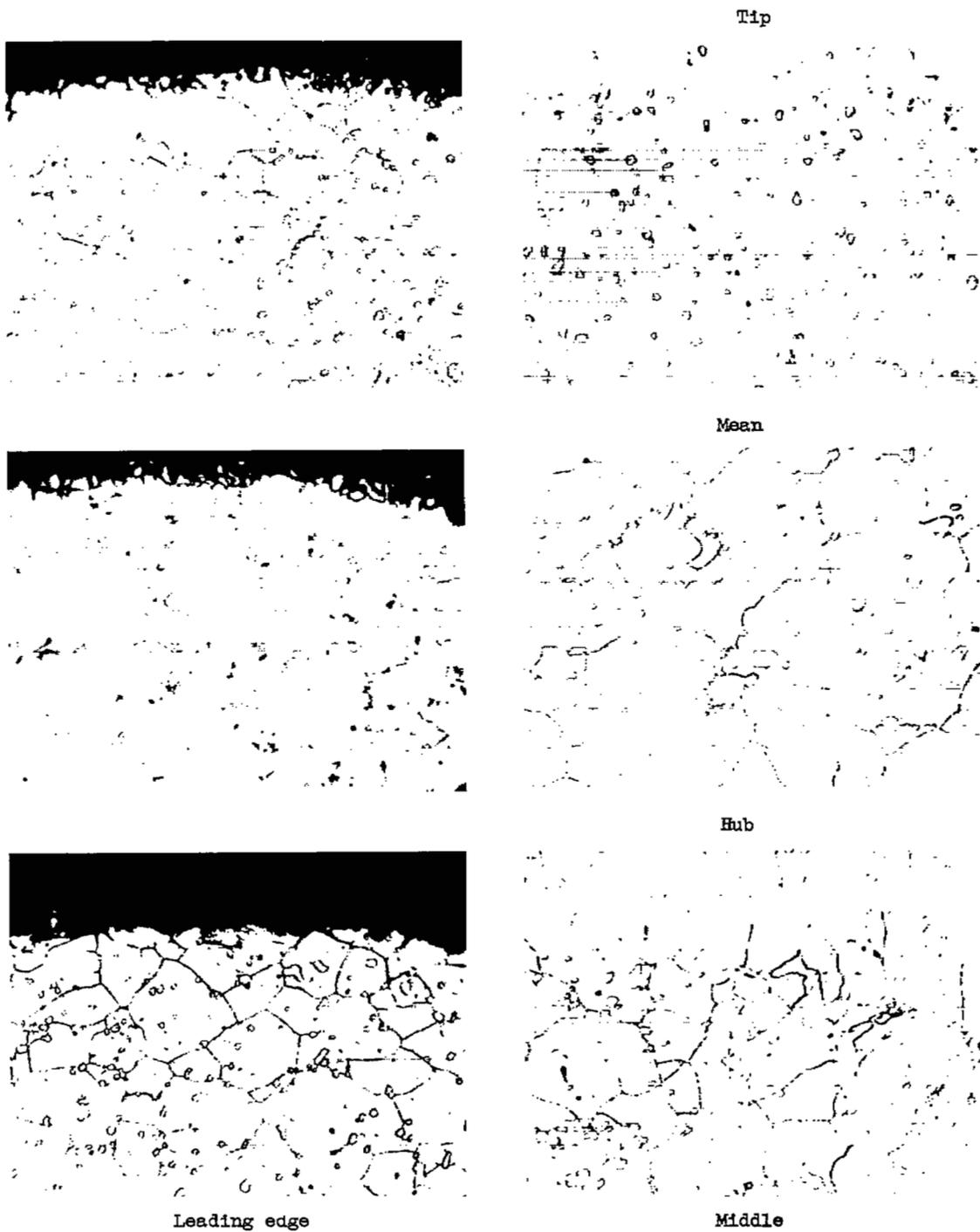
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Trailing edge

44 percent in printing.

of. overtemperated buckets.
X750.



Leading edge

Middle

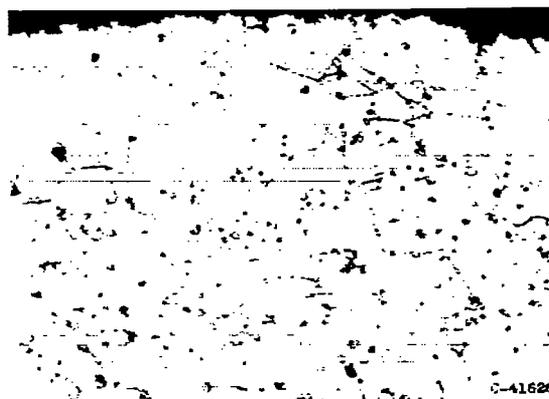
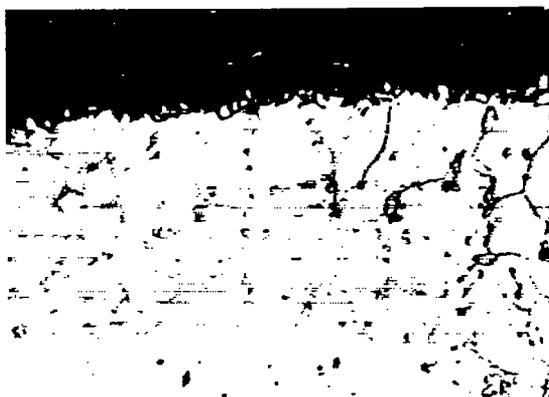
(1) Bucket 9. Reduced

Figure 6. - Continued. Microstructures
Etch, aqua regia plus glycerine.

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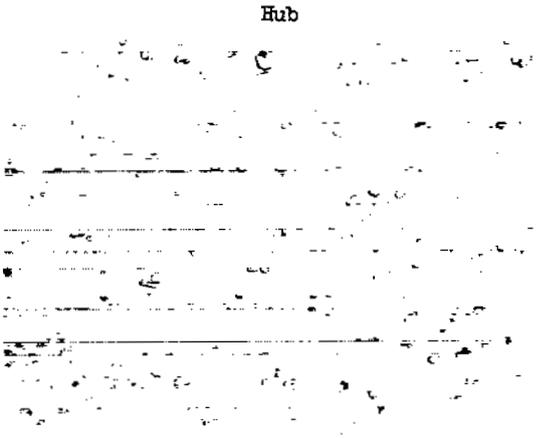
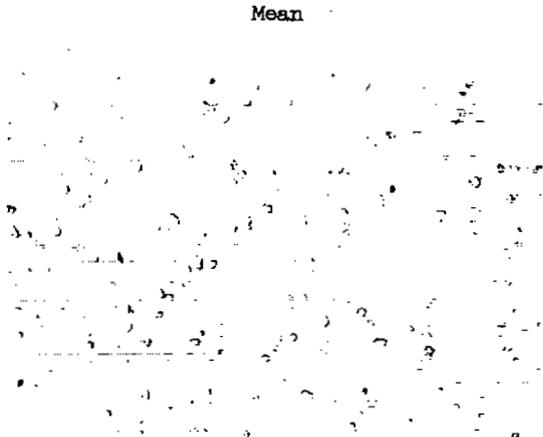
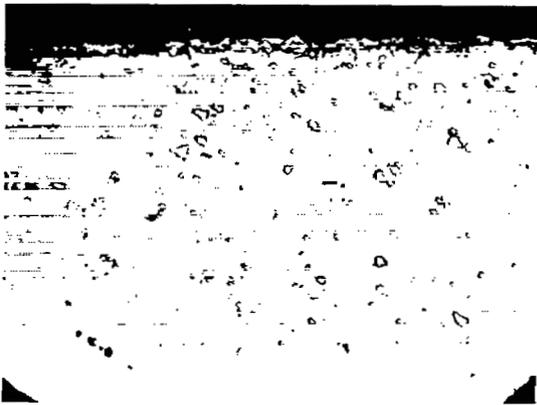
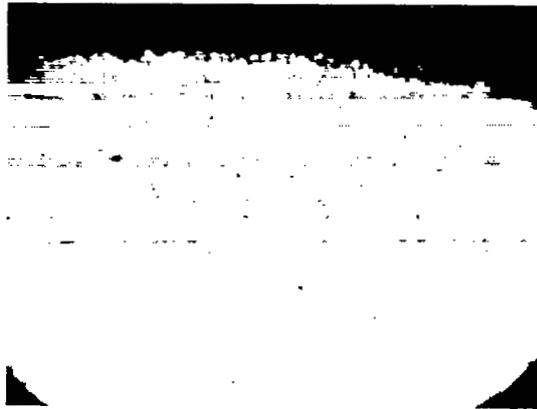
CR-5



Trailing edge

44 percent in printing.

of overtemperated buckets.
X750.



Leading edge

Middle

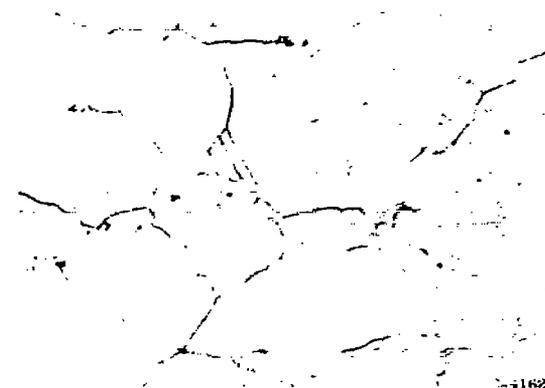
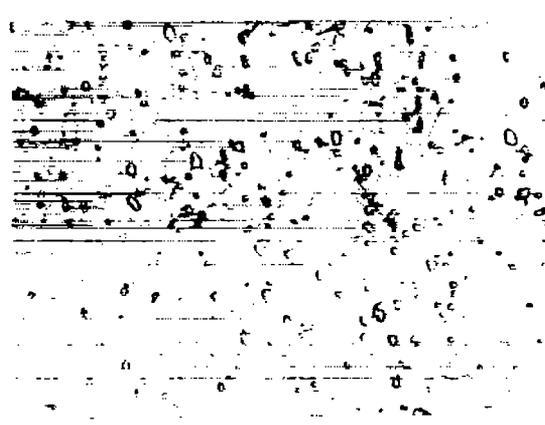
(j) Bucket 10. Reduced

Figure 6. - Continued. Microstructures
Etch, aqua regia plus glycerine.

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CR-5 back



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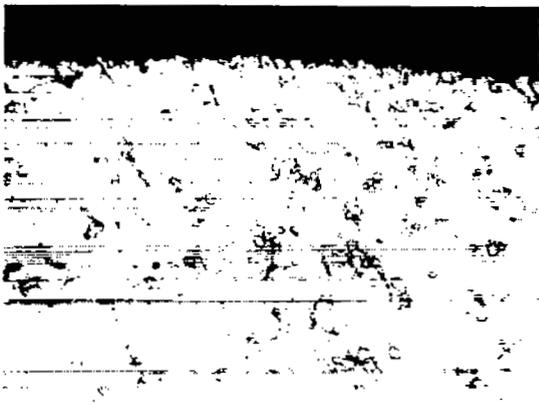
Trailing edge

44 percent in printing.

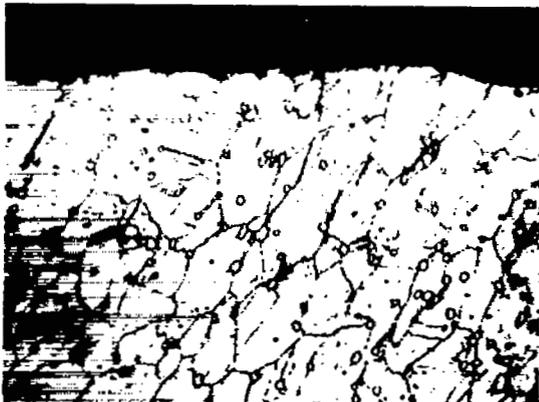
of overtemperated buckets.
X750.



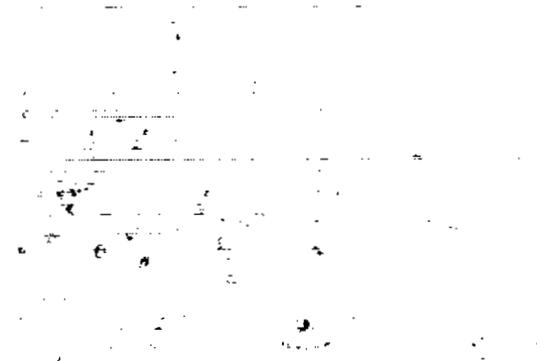
Tip



Mean



Leading edge



Hub

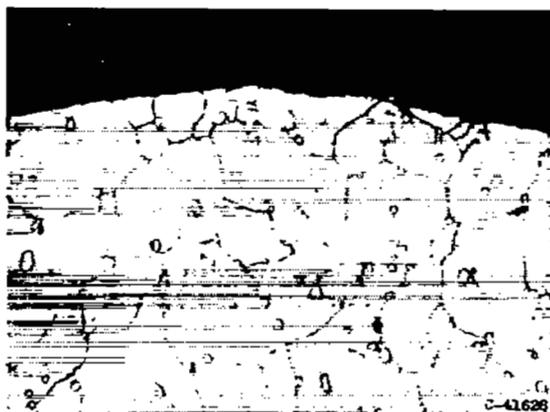
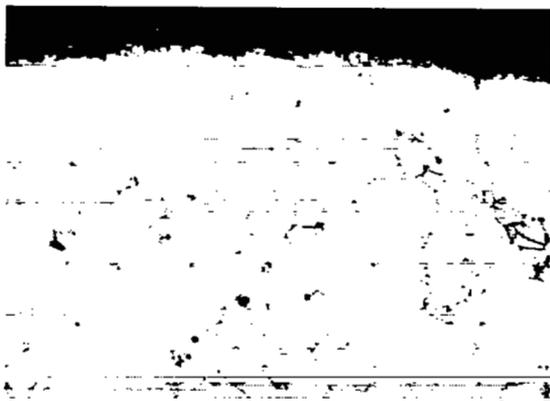
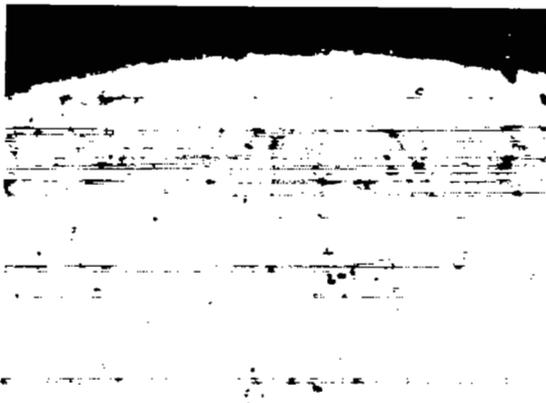


Middle

(k) Bucket 11. Reduced

Figure 6. - Continued. Microstructures Etch, aqua regia plus glycerine.

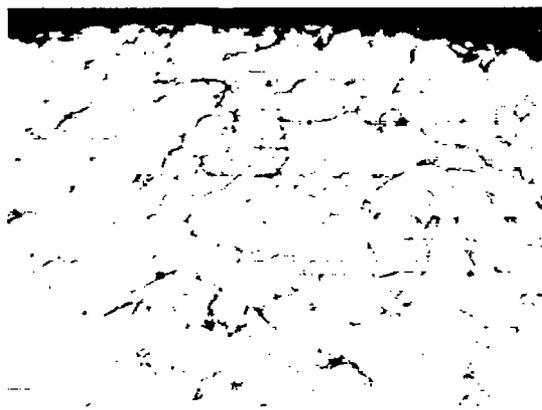
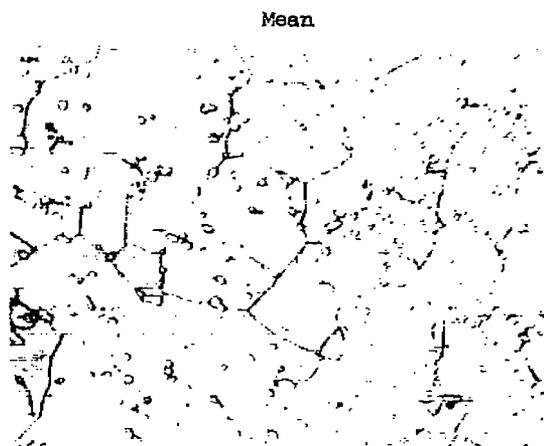
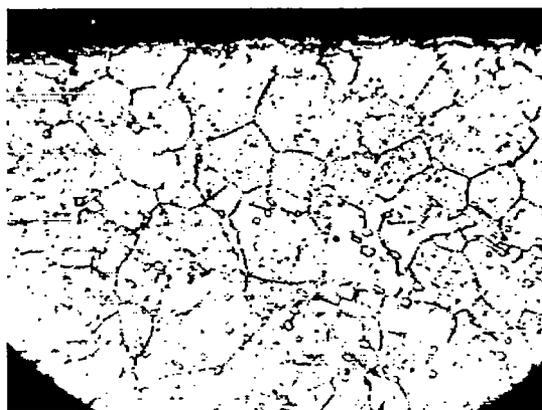
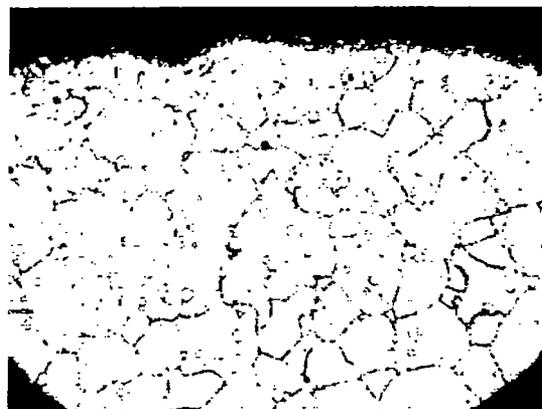
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Trailing edge

44 percent in printing.

of overtemperated buckets.
X750.



Leading edge

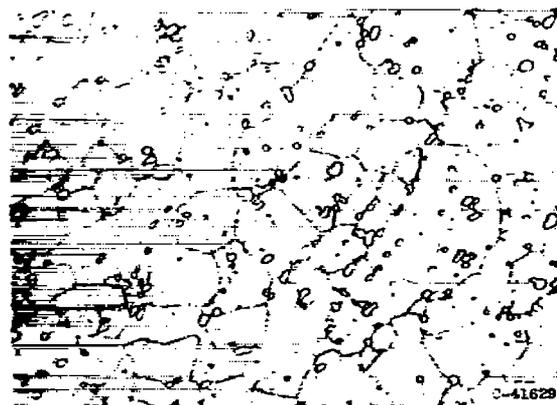
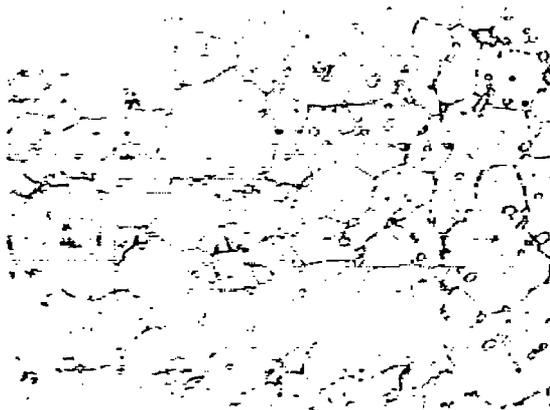
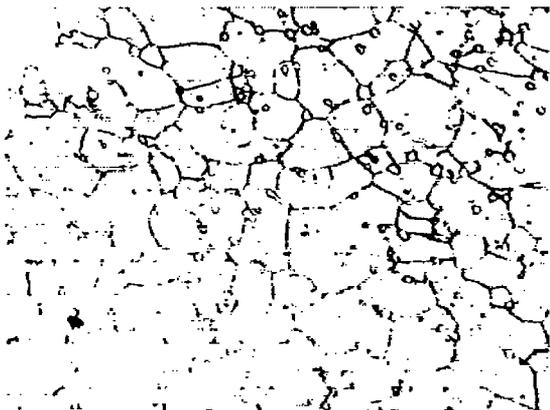
Middle

(1) Bucket 12. Reduced

Figure 6. - Concluded. Microstructures
Etch, aqua regia plus glycerine.

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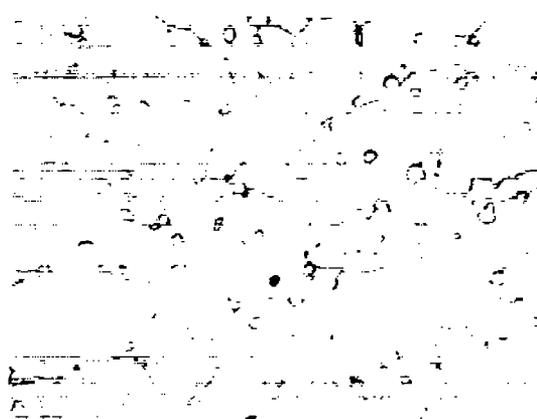
Trailing edge

44 percent in printing.

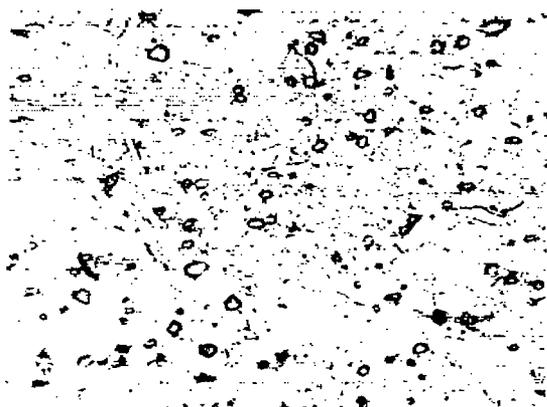
of overtemperated buckets.
X750.



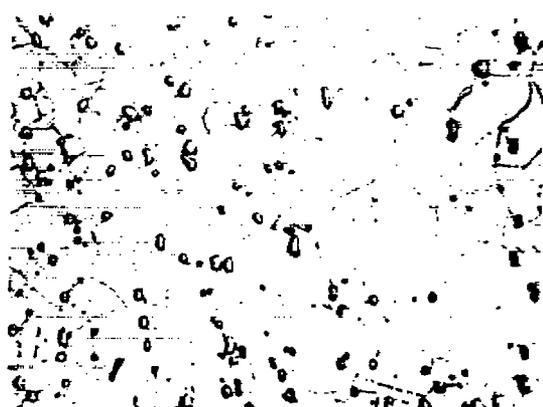
(a) Bucket 22, mean leading edge.



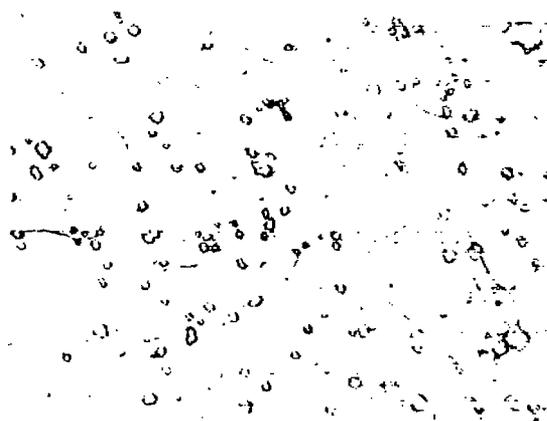
(b) Bucket 22, mean middle.



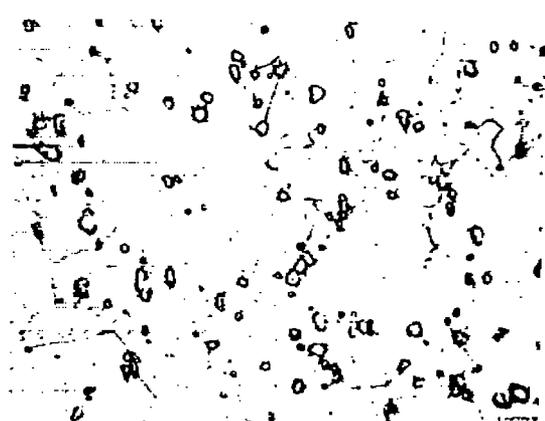
(c) Bucket 22, mean trailing edge.



(d) Bucket 23, mean leading edge.



(e) Bucket 23, mean middle.



(f) Bucket 23, mean trailing edge.

Figure 7. - Heat-treated specimens. Reduced 44 percent in printing.
X750.

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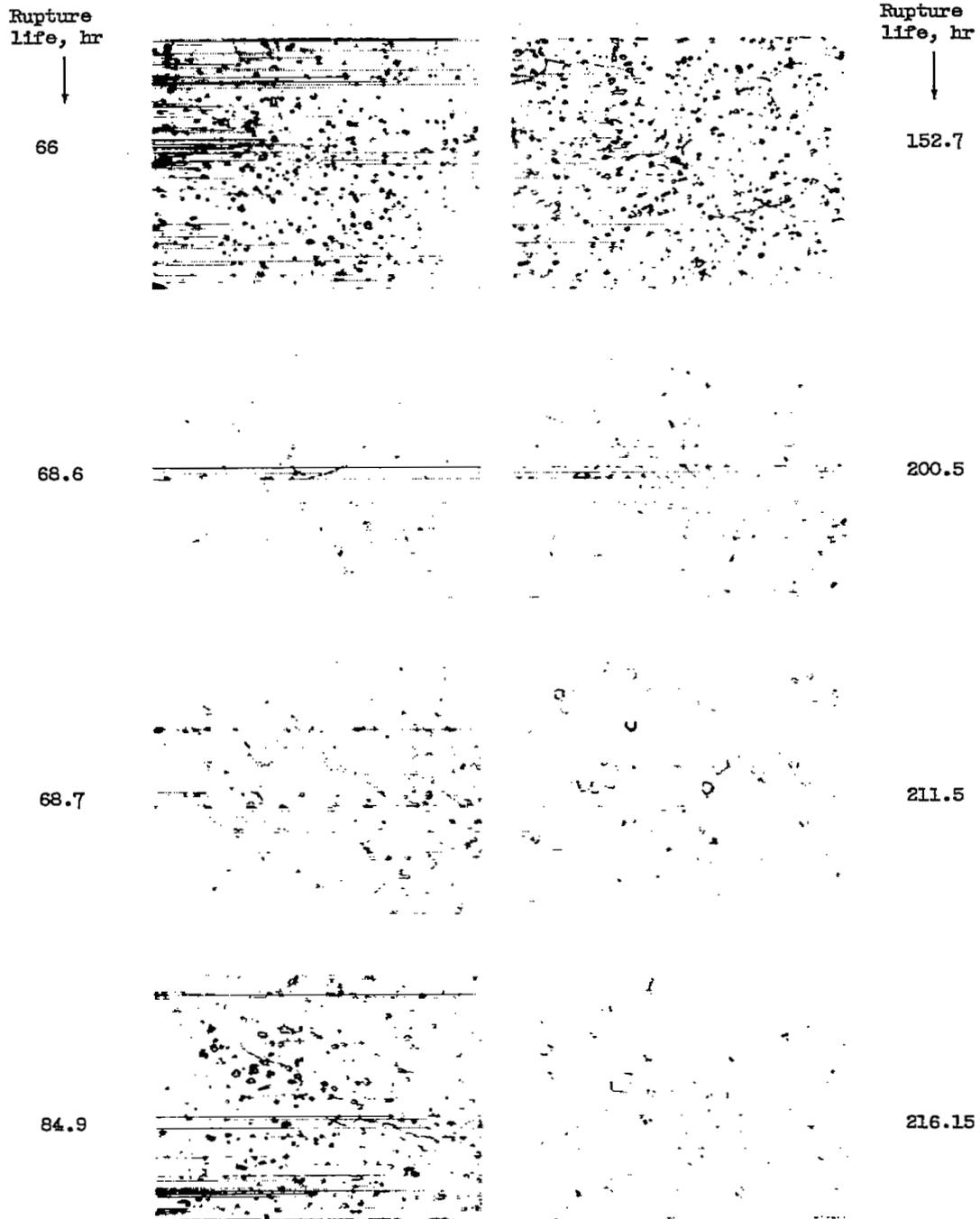


Figure 8. - Stress-rupture specimens arranged in order of increasing rupture life. Reduced 63 percent in printing. X750.

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