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NATIONAL BUREAU OF STANDARDS REPORT

9923

FATIGUE FAILURE OF ELECTROFORMED PRINTING PLATES

To

Electrolytic Section
Bureau of Engraving and Printing
Washington, D. C.

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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NATIONAL BUREAU OF STANDARDS

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[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D. C. 20234.
[2] Located at Boulder, Colorado 80302.
[3] Located at 5285 Port Royal Road, Springfield, Virginia 22151.

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FATIGUE FAILURE OF ELECTROFORMED PRINTING PLATES

By

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Engineering Metallurgy Section
Metallurgy Division

To

Electrolytic Section
Bureau of Engraving and Printing
Washington, D. C.

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U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

Fatigue Failure of Electroformed Printing Plates

Material Submitted: Nine strips removed from electroformed-nickel currency printing plates that had cracked in service were submitted for examination. An investigation was requested because plate failures were being experienced at exceptionally low mileages.

All of the strips contained cracks that were adjacent to and parallel to the bend line in plate Vee bends - bends necessary for adaptation of the plates to the press cylinder. The cracks observed varied in length from approximately one inch in one plate to three-fourths of the plate width in others. A typical view of the general location of the cracks with respect to the plate bend line is shown in Figure 1. Strip identifications and pertinent plating and service life data are given in Table 1. The Bureau of Engraving and Printing (BE&P) requested NBS to determine whether cracking could be attributed to detrimental material conditions or to mechanical factors. BE&P also requested that the mechanical properties of the materials be established for their records and possible future reference.

Visual Examination: All of the strips had grooves made by teeth on plate fastening clamps. The grooves varied in depth and continuity from plate to plate. It was observed that the grooves on the strips from the lowest mileage plates, 40400 and 40421, were shallower than those on the strips from the highest mileage plates, 40364 and 40381.

A cursory examination of the 0.563 inch nominal diameter punched holes in the plate strips indicated a generally greater "out-of-roundness" of the holes in the low mileage plates compared with that in the high mileage plates. In punching the holes, burrs were raised on the reverse face of the plates. These burrs were not removed after punching.

Macroscopic Examination: Figure 2a is a view of the reverse face of a plate section containing a fracture. It shows fretting in the bend line, arrow a, and a continuous line resulting from a polishing action, arrow b. The fracture path is between these lines. Figure 2b is a view of the fracture surface of the section shown in Figure 2a. It has the characteristic features of a fracture surface resulting from fatigue. Its appearance is typical of that observed in all of the fractured plates.

Microscopic Examination: Figures 3a and 3b show the microstructure and fracture profiles of low mileage plate, 40400, and high mileage plate, 40364, respectively. The fine-grained microstructure, Figure 3a, is characteristic of that obtained in a Watts bath and the coarse grained structure, Figure 3b, is characteristic of that obtained in a sulfamate bath. The fracture path shown in Figure 3a is predominantly flat and intergranular while in Figure 3b, it is predominantly transgranular.

Both fractures were initiated by fatigue cracks originating at the obverse (printing) face of the plates. The flat profile of the fracture in Figure 3a is characteristic of material that failed rapidly and in a brittle manner. The fracture of plate 40364, Figure 3b, was accompanied by plastic deformation. The uneven fracture profile is characteristic of a fracture that propagated through shear. Shear fractures are peculiar to material having good ductility.

The photomicrographs of secondary cracks in Figure 4 provide a clue as to the mechanism of crack propagation in the subject plates. Figure 4a shows cracks originating at and propagating from the chromium plate-nickel base interface; some of the cracks having propagated to the plating surface and to a lesser degree into the base metal. When the cracks had penetrated the plating completely, notches were created that acted as stress raisers promoting deep penetration of fatigue cracks into the base metal as shown in Figure 4b.

Chemical Analysis: A conventional chemical analysis was conducted on a sample from strip No. 40418 L. A copy of the report is included as addendum 1. The sample contained 99.9 percent nickel. Carbon, copper, iron, sulfur, silicon and cobalt contents were acceptably low. The chemical composition complied with that specified for Type II anode nickel, Federal Specification QQ-A-677, March 22, 1957.

Macrohardness: Macrohardness measurements obtained in chromium-free areas on strip specimens are as follows:

Strip No.	Hardness, Rockwell 15T	
	Printing Face	Back Face
40364 L	89	88.5
40364 T	88	87.5
40377 L	91.5	91.5
40381 L	92	92
40395 L	91	91.5
40400 L	91	91.5
40418 L	93	92.5
40418 T	92	92
40421 L	91.5	92

The hardness range of 88 to 93 Rockwell 15T obtained on strip printing faces and 87.5 to 92.5 Rockwell 15T on back faces results in a considerable spread in related tensile strength. These hardness values converted to tensile strength indicate approximate equivalent tensile strengths ranging from 77,000 to 116,000 psi. There is no correlation between hardness and related tensile strength and mileage. A high mileage, 365,161, was obtained with the softest plate, No. 40364. However, a high mileage, 271,792, was obtained also with one of the harder plates, No. 40381. The mileages obtained from the remaining plates in the tabulation were a small fraction of these values.

Tensile Properties: Tensile test specimens were obtained from areas parallel to and adjacent to the cracks in strips 40364 L, 40381 L, 40400 L and 40418 L. The specimens were prepared with a 0.250 inch width and 2.00 inch gage length in the reduced section. As-received thickness of the strips was maintained in the machined tensile test specimens. Tensile properties obtained are given in Table 2.

The tensile strengths given in Table 2 are absolute values and therefore more reliable for purposes of comparison than those obtained from a hardness relationship. Plate 40364, which yielded a superior mileage, had the lowest yield strength and ultimate tensile strength, and a percent elongation (ductility) roughly twice as great in comparison with the other plates. However, plate 40381 which also provided a comparatively high mileage had tensile properties more closely related to that of the low mileage plates listed in Table 2.

Discussion and Conclusions: Failure of the subject plates is attributed to fatigue. It appears that cracks could have been initiated in the chromium plating adjacent to plate bend lines when the bends were formed. These cracks created notches that acted as stress raisers. The presence of polishing and fretting on the printing plates indicates that there was relative motion between plates and press cylinder during press operation. This motion was attended by cyclic bending stresses of such magnitude as to favor the propagation of fatigue cracks starting from the root of the cracks in the chromium plating and progressing through the nickel base.

With respect to material properties, analysis of samples revealed an acceptable chemical composition and microstructure. From the material examined it is felt that differences in material properties can be ruled out in seeking the reasons for the comparatively short life of some of the plates. The same ruling applies to differences in the electrolyte used, sulfamate or Watt's bath. Plate 40364, which had a long service life, was made in a sulfamate bath. It had a comparatively low hardness, low yield strength, low tensile strength and good ductility. Plate 40381 which also had a long service life, was made in a Watt's bath. It had comparatively high hardness, high yield and tensile strengths and only fair ductility. It is considered that efforts to improve printing plate service life should be concentrated on plate fabrication procedures, on plate alignment and on press cylinder adjustments and lubrication.

Recommendations: In line with NBS observations and discussions with Bureau of Engraving and Printing personnel the following recommendations are made:

1. If possible, look for elimination in cracking of the chromium plating by forming plate bends before chromium plating of the printing plates rather than after.

2. Check printing plate bends for conformance with mating cylinder lips and make what adjustments are possible to minimize relative motion between the printing plate and the press cylinder.

3. Keep plate clamp teeth sufficiently sharp and tighten clamps so that all plates are adequately and uniformly gripped on the printing cylinder.

4. Consider whether plate fastening hole "out-of-roundness" and burrs raised by hole punching have a detrimental effect on plate seating.

5. Continue Bureau of Engraving and Printing lubrication experimentation.

6. Roll shallow grooves approximately 0.015 inch deep into the obverse face of the currency plates. The grooves should be approximately 0.25 inch wide and blend gently into the plates. They should be so located that the groove median should coincide with the observed path made by fatigue cracks in the leading and trailing ends of the plates, respectively.

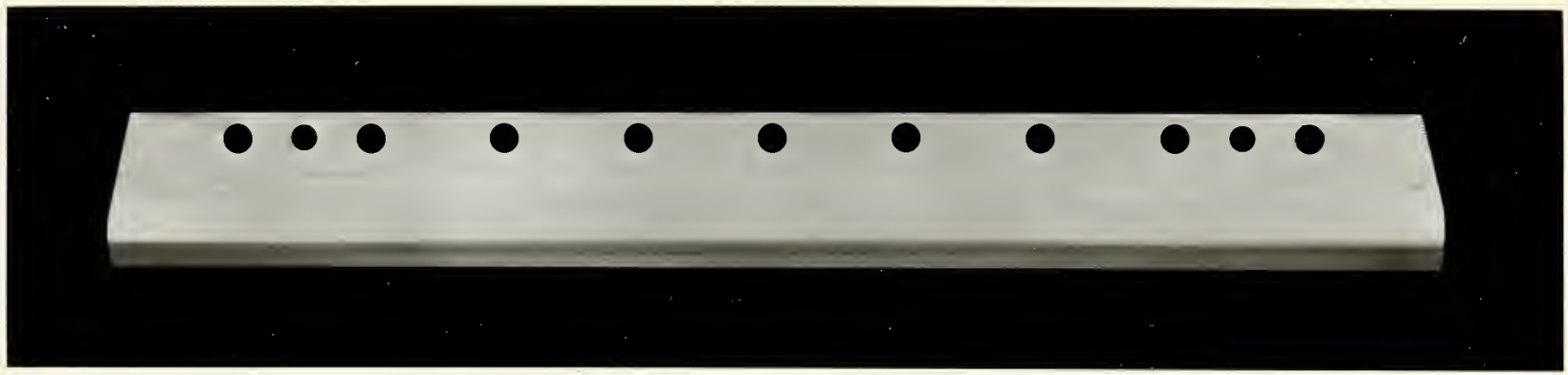
Table 1. Identification of Electroformed Plate Test Strips

Strip Number [1]	BE&P Plating Tank	Bath Type	Plate Mileage (Impressions Obtained)
40364 L	W	Sulfamate-Nickel	365,161
40364 T	W	" "	365,161
40377 L	3	Watts-Nickel	66,964
40381 L	3	" "	271,792
40395 L	3	" "	26,626
40400 L	3	" "	24,805
40418 L	3	" "	36,543
40418 T	3	" "	36,543
40421 L	3	" "	25,249

[1] Suffixes L and T for the numbers indicate that the strips were cut from the leading end or the trailing end, respectively, of a given numbered plate.

Table 2. Tensile Properties of Electroformed Plate Material

BE&P Strip No.	Specimen Number	Yield Strength 0.20% Offset psi	Ultimate Tensile Strength psi	Elongation in 2 inches %
40364 L	1	45,500	70,800	20.0
40364 L	2	45,700	71,300	21.5
	Avg.	45,600	71,050	20.5
40381 L	1	64,400	94,200	12.5
40381 L	2	65,100	97,300	12.5
	Avg.	64,750	95,750	12.5
40400 L	1	63,900	94,400	13.0
40400 L	2	70,700	103,900	10.0
	Avg.	67,300	99,150	11.5
40418 L	1	74,500	107,700	10.1
40418 L	2	67,800	100,000	10.8
	Avg.	71,150	103,850	10.5



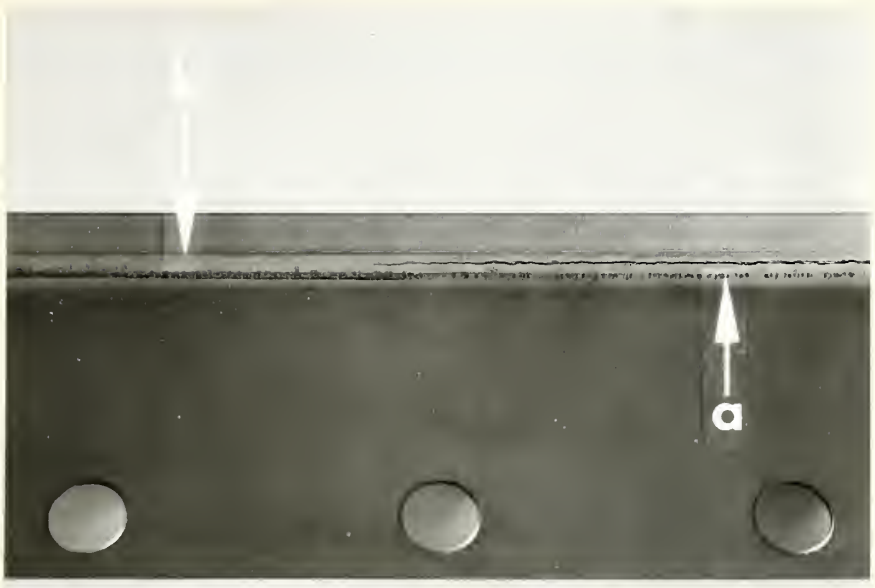
a

b

Figure 1. Strip from printing plate No. 40395. The location of the cracks with respect to the plate bend line is typical of that observed in all of the strips examined.

a. Obverse face. X 1/4

b. Reverse face. X 1/4



a

b

Figure 2a. Reverse face of a section of strip No. 40418 L. Arrow, a, points to fretting in the bend line. Arrow, b, points to a continuous line that resulted from a polishing action. Note that the fracture path is between these lines. X 2/3

Figure 2b. Fracture surface of the fracture shown in Figure 2a. The surface is characteristic of that resulting from fatigue. X 4

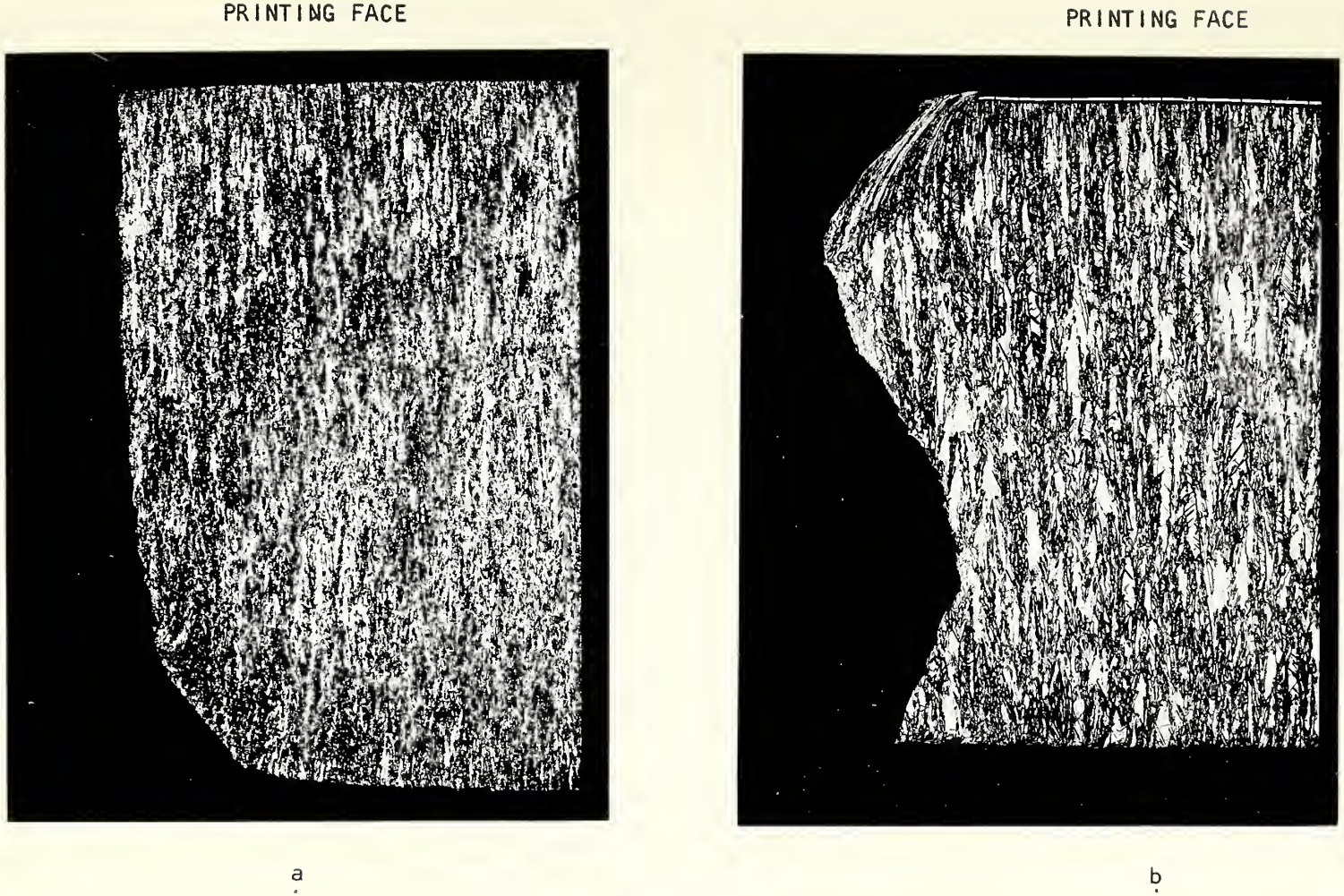
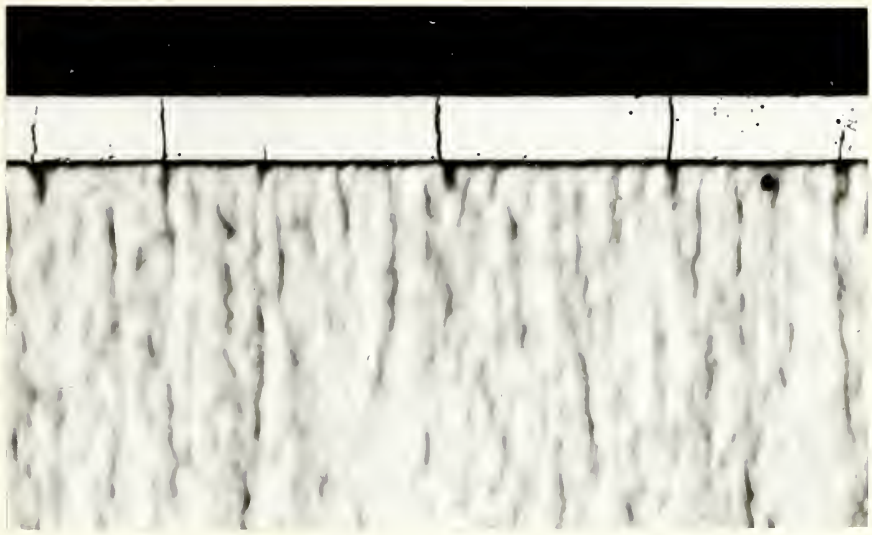


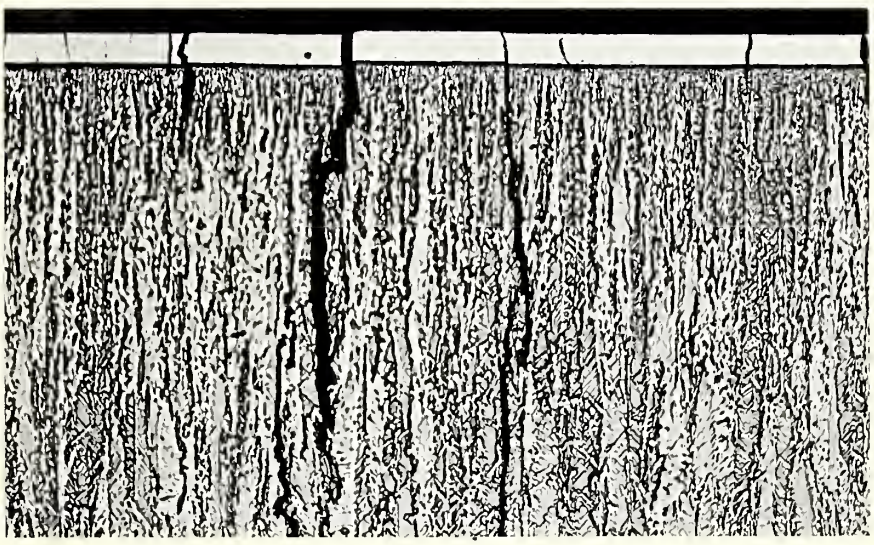
Figure 3. Microstructures and fracture profiles representative of two plates. Fractures were initiated at the obverse (printing) face (at the upper left hand corner in both photomicrographs). Etched with Carapella's reagent. X 100

a. Plate 40400 produced in Watts bath.

b. Plate 40364 produced in sulfamate bath.



a



b

Figure 4. Typical secondary cracks adjacent to a fracture.

a. Cracks in the chromium plate (white) appear to have been initiated at the interface of the plate and nickel base. Etched with Carapella's reagent. X 1000

b. Cracks in the chromium plate have propagated to the plating surface and into the nickel base. Etched with Carapella's reagent. X 500

Addendum 1

VALUE ENGINEERING COMPANY
Materials Evaluation Laboratory
2316 Jefferson Davis Highway
Alexandria, Virginia 22301

CERTIFICATE OF TEST RESULTS

Material Nickel (Strip No. 40418 L) No. of Samples 1
Submitted By National Bureau of Standards Date Submitted 8/16/68
Tests Performed Chemical analysis

CHEMICAL ANALYSIS

Al		Mg		Pb		Zn	
C	0.0072	Mn		S	0.004	Co	0.006
Cr		Mo		Si	< 0.002		
Cu	0.004	Ni	99.9	Sn			
Fe	0.008	P		Ti			

Analysis Performed By ..... In accordance with .....

TENSILE TEST

Sample No.	Yield Strength, psi	Tensile Strength, psi	Per Cent Elongation in...Inches	Per Cent Reduction In Area

Test Conducted By ..... In accordance with .....

HARDNESS

Sample or Position No.	Hardness	Sample or Position No.	Hardness

Test Conducted By ..... In accordance with .....

Comments .....

Approved By H. P. Weinberg
H. P. Weinberg
Laboratory Director

ML-1

Date August 22, 1968

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