NBSIR 74-425

Investigation of G-74 Currency Plate Tensile Properties and Performance

I. J. Feinberg and T. R. Shives

Mechanical Properties Section
Metallurgy Division
Institute for Materials Research
National Bureau of Standards
Washington, D. C. 20234

January 1974

Test Report

Prepared for
Electrolytic Section
Bureau of Engraving and Printing
Department of the Treasury
Washington, D. C. 20226

NBSIR 74-425

INVESTIGATION OF G-74 CURRENCY PLATE TENSILE PROPERTIES AND PERFORMANCE

I. J. Feinberg and T. R. Shives

Mechanical Properties Section
Metallurgy Division
Institute for Materials Research
National Bureau of Standards
Washington, D. C. 20234

January 1974

Test Report

"This document has been prepared for the use of the Electrolytic Section, Bureau of Engraving and Printing, Department of the Treasury, Washington, D. C. Responsibility for its further use rests with that agency. NBS requests that if release to the general public is contemplated, such action be taken only after consultation with the Office of Public Affairs at the National Bureau of Standards.

Prepared for
Electrolytic Section
Bureau of Engraving and Printing
Department of the Treasury
Washington, D. C. 20226

U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

TABLE OF CONTENTS

FIGURES (Continued)

SUMMARY

This investigation revealed that a desirable uniformity in composition, thickness, hardness, microstructure and tensile properties is attained from plate to plate in electroforming. Tests programed to determine whether an increase in plate yield and tensile strengths would afford an improvement in plate service life were inconclusive due to the scatter in the service lives obtained in the limited number of tests conducted at various strength levels. Fatigue cracking, apparently due to excessive vibration and cyclic stressing, was found to be the chief cause of plate failure in the tests. It is unlikely that significant improvements in the service life of G-74 currency plates can be attained until conditions leading to excessive vibration and cyclic stressing in the G-74 presses are remedied.

Investigation of G-74 Currency Plate Tensile Properties and Performance

1. INTRODUCTION

1.1 History

The Bureau of Engraving and Printing (BU E&P) has been concerned about the short service life of a considerable number of currency plates on their G-74 presses. A comprehensive examination was conducted for Bu E&P on plate No. 41812, a plate that failed because of blistering. The results of this examination are given in reference [1]. The failure of G-74 currency plates by blistering was attributed largely to mechanical problems which arise during operation of the presses. It was evident too, from observations in the course of this investigation, that fatigue cracking, the overall chief cause of reduced plate service life, was also largely due to mechanical problems.

1.2 Purpose

The purpose of this investigation was to determine if changes in the mechanical properties of currency plates could increase their service life. A higher plate yield strength had been suggested by NBS as possibly affording an improvement in service life, particularly in reducing the incidence of fatigue cracking [2]. It was further suggested to Bu E&P that a quality control program for the production of electroformed plates that would include the collection of statistical data on mechanical properties be conducted in cooperation with NBS personnel [3]. Bu E&P agreed to both approaches in search of an improvement in plate service life. The results of an examination of a limited amount of material submitted to NBS by Bu E&P under a plan proposed by NBS are herein reported.

2. PLAN OF THE INVESTIGATION

Three general approaches were suggested by NBS and accepted by Bu E&P. These are as follows:

1. Consider the use of a higher yield strength material.

2. Establish a quality control program for the production of the electroformed nickel plates which would include the collection of statistical data on mechanical properties. This would be done in cooperation with NBS personnel.

3. Monitor the mechanical operation of the G-74 presses recording pertinent information such as how often the plates are tightened, mileage[1] when cracks first appeared, final plate mileage, etc.

Implementation of these approaches involved the following:

a. Testing and evaluation data from specially prepared blank plates and from specially prepared face and back plates subjected to mileage tests.

b. Keeping the following constant in the preparation of plates:

    (a) ph of electrolyte
    (b) Electrolyte temperature
    (c) Current density

c. Varying amount of hardening agent (SNSR)[2] of electroforming bath.

d. Limiting tests to one press for face plates; to another for back plates.

e. Observing any mechanical or operational changes that might affect mileage on the presses used.

f. Conducting appropriate chemical analyses, thickness measurements, microscopic observations, and tensile and hardness tests on specimens from blank, face and back plates.

g. Comparing blank plate hardness and tensile properties with face and back plate hardness and tensile properties.

h. Evaluating hardness and tensile property data obtained for face and back plates for possible correlation with mileage and with the nature and location of failures on these plates.

---

[1] Mileage is a term used by Bu E&P to denote the number of complete sheet impressions obtained from an individual plate in currency printing.

[2] SNSR is the abbreviation for the sulfamate nickel stress reducer used by Bu E&P as the hardening agent.

3. MATERIAL

3.1 Plate Preparation

Bu E&P prepared twenty-two plates which included two blanks, eleven currency face and nine currency back plates. Constants and variables in the technique employed in the electroforming of these plates are given in Table 1.

3.2 Material Submitted

The two blank plates were submitted in their entirety and two strips, nominally 0.75 inch wide, were submitted from each of the face and back plates for tests. The strips were stamped with either a letter, T, or a letter, B, and were cut from the respective top or bottom edges of the plates as they were positioned in the electroforming tank. None of the material had been chromium plated, as-received.

Figure 1 is a sketch showing individual note locations and the leading and trailing edges of a currency plate with respect to the positions of these edges on a printing cylinder and the direction of cylinder rotation. Note that T and B, representing the original top and bottom positions of a plate in the electroforming tank, are located at angles of 90 degrees counterclockwise to the leading edge and trailing edge, respectively.

4. EXPERIMENTAL WORK

Experimental work by the Mechanical Properties Section of NBS in this investigation was limited to obtaining data on material properties. Conventional chemical analyses were conducted to determine whether any undesirable impurities were present in the material. Thickness measurements were made to determine if there were any significant localized differences in plate thicknesses. Hardness and tensile properties were obtained to determine what effects variations in the hardener addition used in plate preparation had on these properties. The location and nature of plate damage that terminated the service life of currency face and back plates and the mileages obtained were logged by Bu E&P personnel. Metallographic examinations were made of specimens from blank plates and from selected face and back plates exhibiting significant differences in mileage.

4.1 Tensile Properties

The tensile properties of blank plates 1c and 2c were obtained from ten specimens cut from each plate. The identifications and locations of these specimens are given in Figure 2. The letters L and T in the specimen identifications indicate that the specimens were cut from these blank plates so that their long axes would be aligned parallel or transverse to the direction of plate rotation, respectively, had these plates been regular basso printing plates. Face and back plate tensile properties were attainable by NBS only from specimens cut from the face and back plate strips submitted. These tensile specimens necessarily were cut so that their long axes were transverse to the direction of cylinder rotation. Tensile test specimens were machined using the as-received thickness (approx. 0.030 inch), and a 0.500 inch width and 2 inch gage length in the reduced section. They were tested in accordance with ASTM Designation E8-66.

4.2 Chemical Analysis

Chemical analyses by spectrometric or combustion methods were performed on samples cut from the areas of blank plates, 1c and 2c, shown in Figure 2, and from strips from plate Numbers 42233B and 42248B.

4.3 Thickness and Hardness Measurements

Thickness and hardness measurements were made on each of the ten tensile test specimens cut from both 1c and 2c. Face and back plate thickness and hardness measurements were also made on tensile test specimens cut from strips submitted by Bu E&P.

4.4 Microscopic Observations

Specimens were cut from the areas of plates 1c and 2c, shown in Figure 2, for metallographic examination. Metallographic examinations were conducted on specimens cut from strips of face plates numbered 42233, 42239, 42245 and 42248 and from strips of back plates numbered 7637, 7639, 7645 and 7646.

4.5 Plate Mileage Tests

Currency face plates subjected to mileage tests were mounted on the G 74-101 press and currency back plates on the G 74-104 press. The pressures in each press were adjusted according to normal Bu E&P procedures to obtain satisfactory printing impressions. Normally a higher pressure is required in printing face notes than in printing back notes. Both presses were run at speeds to obtain 7000 sheets per hour.

5. INVESTIGATION RESULTS AND DISCUSSION

5.1 Chemical Analysis

Results of the chemical analyses of samples from plates 1c, 2c, 42233 and 42248 are given in Table 2. The analyses indicate a similarity in the composition of the four samples. Impurity contents are low with the exception of cobalt (0.65 to 0.94%). The NBS Corrosion and Electrodeposition Section does not consider the cobalt contents as being detrimental.

5.2 Thickness Measurements

The results of thickness measurements on the blank plates, face plate strips, and back plate strips are given in Tables 3, 4, and 5, respectively. A considerable number of the measurements in all three groups were outside the tolerance limits. However, most of the measurements that fell outside of the tolerance limits did so by an amount small enough to fall within the measurement error. The thickness measurements of only two strips, 42233T and 42235T, were considered to be out of tolerance to an appreciable amount.

Thickness measurements were made in widely distributed areas of blank plates, 1c and 2c, to determine whether there were any localized differences. The differences found are not considered to be significant. Table 4 shows the spreads in thickness between bottoms and tops of plates. If the Bu E&P 0.03000 ± 0.00025 limits are used as a criterion, then the differences between bottom and top thicknesses of some of these plates would be outside of tolerance limits, but again the amounts are within experimental error. Moreover, NBS has no evidence that similar spreads, which then could be a matter of concern, were present in adjacent plate note areas.

5.3 Hardness Measurements

The results of Rockwell 15T (R15T) hardness measurements on the blank plates, face plate strips, and back plate strips are given in Tables, 6, 7, and 8, respectively. A two point spread (88-90 R15T) was observed in plate 1c and a three point spread (88-91 R15T) in plate 2c. Probably the only appreciable localized hardness differences found in the respective plates in comparing individual hardness readings with average values were a high reading (90 R15T) adjacent to the E_3-A_3 notes of plate 1c and a low reading (88 R15T) adjacent to the A_4-E_2 notes of plate 2c. In comparing hardness values found in both plates no significant pattern of localized differences covering a large area was observed. Interestingly,

an increase in the hardener addition from 25 ml for plate 1c to 50 ml for plate 2c resulted in only about a one point, R15T, increase in the average hardness of the latter. Tables 6 and 7 indicate that an increase of the hardener additions from 20 ml to 75 ml resulted in an increase in the hardness of strips from about 89 R15T to about 91.5 R15T.

Figure 3 shows, graphically, the effects of the hardener addition on the hardness of strips from face and back plates. There is an apparent exponential increase in hardness with increase in the hardener addition. However, paucity of data points and scatter in the available data are great and therefore preclude the derivation of a reliable curve which would indicate the amount of hardener addition needed to achieve a given hardness.

5.4 Microscopic Observations

Blank plate microstructures are shown in Figure 4 and face and back plate microstructures in Figure 5. The columnar grains in each view are normal for electroformed nickel. A 50 ml SNSR addition in the electroforming process produced a finer grain size than did a 25 ml addition, as shown in Figure 4. Similarly, 75 ml additions produced finer grain sizes than 20 or 25 ml additions, as shown in Figure 5. Microscopic examination of face and back plate strip specimens revealed no structural discontinuities that could affect the mileages of the plates from which they were cut.

5.5 Tensile Properties

Tensile properties of the blank plates are given in Table 9. Analysis of these data indicated no appreciable directional differences; i.e., the tensile properties of specimens oriented parallel to the A_1-D_2 direction were found to be generally quite similar to those oriented at a right angle to the A_1-D_2 direction. While yield strength values exhibited greater scatter than did tensile strength values, the scatter of both is considered to be within tolerable limits. No appreciable localized differences in yield strength or tensile strength were found. Ductility as measured by percent elongation and the ratio of yield strength to tensile strength was found to be quite uniform throughout plates 1c and 2c with the exception of the slightly greater ductility found in the H_2-D_2 note areas of both plates, 1c and 2c. Doubling the SNSR addition in electroforming of the blank plates from 25 to 50 ml resulted in average increases of approximately 10% in yield strength, 8% in tensile strength, and 1% in the ratio of yield strength to tensile strength. Elongation decreased by about 27%.

Tensile properties of face plate and back plate strips are grouped in Tables 10 and 11, respectively. These data indicate that the average yield and tensile strengths of bottom (B) strips from both groups are significantly higher than that of top (T) strips. There does not appear to be any significant difference in ductility as determined by averaging the percentages of elongation and the ratios of yield strength to tensile strength values of B and T strips.

The data in both Tables 10 and 11 indicate that generally a progressive increase in yield strength and tensile strength and a progressive decrease in ductility of the plate strips resulted from progressive increase of the SNSR addition in electroforming.

5.6 Plate Performance in Mileage Tests

5.6.1 Mileage versus SNSR additions and tensile properties

The mileage of individual face and back plates are given in Tables 10 and 11, respectively. Face plate mileages ranged from a low of 129,163 to a high of 834,963. Omitting the low mileages obtained for plate no's. 7640 and 7642, adjusted back plate mileage ranged from a low of 205,811 to a high of 732,396.[1] An average mileage of 501,874 was obtained for face plates on the G 74-101 press and an adjusted average mileage of 361,737 for back plates on the G 74-104 press. The high face plate mileage, 834,963, was obtained from a plate having a 75 ml SNSR electroforming bath addition, whereas the high back plate mileage, 732,396, was obtained from a plate having a 25 ml SNSR bath addition.

There appears to be no advantage in increasing yield strength and tensile strength through increase of the SNSR addition in plate preparation. The data in Table 12 indicates a similarity in the average mileages obtained from face plates made with 25 and with 75 ml SNSR additions. The 75 ml addition resulted in significantly higher yield strength and tensile strength. Table 12 also indicates that a significantly greater average yield strength and tensile strength were obtained from back plates made using a 75 ml bath addition. In this case, average mileages obtained from the 25 ml addition plates were approximately 50% greater than those obtained from the 75 ml addition plates.

---

[1] The low mileages obtained for plate no's. 7640 and 7642 were due to mechanical malfunction (rigging ball-up). They were not considered to be representative of mileages that could be obtained if the malfunction had not occurred and were accordingly omitted.

5.6.2 Nature and location of failures in mileage tests

Figures 6 and 7 are sketches intended to indicate the nature and approximate location of failures of face and back plates, respectfully. This information has been obtained from pertinent record sheets submitted by Bu E&P.

Fatigue cracking was the chief cause of face plate failure. Fatigue cracking occurred between the bottom margins of the H_2, D_2, H_4 and D_4 notes and the trailing edges of these plates and also along the trailing edge pitch line of these plates. There was only one instance, each, of a dimple, of rippling and blistering, and of a ball-up (rippling) failure. Face plate failures were largely concentrated adjacent to the H_2 and D_2 notes.

Fatigue cracking was also the chief cause of back plate failure. Fatigue cracks occurred along the leading edge pitch line adjacent to the E_3-A_3 notes and between the top margins of the E_3 and A_3 notes and the leading edge pitch line of the back plates. Fatigue cracking also occurred adjacent to the G_4, H_4 and C_2 notes and adjacent to the trailing edge pitch line, as shown in Figure 4. There were three instances of back plate ball-up and rippling failure.

Above average mileage was obtained from three face plates that failed due to fatigue cracking and below average mileage from five face plates all of which failed by fatigue cracking. Above average mileage was obtained from one face plate that blistered and another that dimpled. Above average mileage was obtained from three back plates that failed due to fatigue cracking and below average mileage from four back plates that failed due to this cause. Premature failure of two back plates occurred when the printing cylinder rigging became loose and caused a ball-up on these plates.

6. CONCLUSIONS

Chemical analyses indicated a similarity in the composition of samples from four plates that were analyzed. No detrimental impurities were found and it appears from these analyses that a desirable uniformity in composition is attained from plate to plate in electroforming.

All material examined microscopically was observed to be sound from the standpoint of microstructure. While the observations made were limited in scope, it is considered that uniform, good quality is achieved in plate production from day to day.

Judging from thickness measurements made on the blank plates, and measurements covering ten separate note areas on each plate, sufficient uniformity in plate thickness, in the note areas, is attained in electroforming.

Doubling the SNSR addition in the electroforming of blank plates from 25 to 50 ml resulted in an average increase of only one R15T hardness point (89 R15T to 90 R15T). Increasing the SNSR addition from 20 ml to 75 ml resulted in the small increase in the average hardness of strips from 89 R15T to about 91.5 R15T. It may be assumed that increases in average hardness of a similar magnitude occurred in the note areas of the plates from which the strips were obtained. It is understood that Bu E&P made hardness measurements at the centers of the face and back plates from which related strips were submitted to NBS. The hardness values obtained by Bu E&P at plate centers were generally one to two Rockwell 15T points higher than those obtained by NBS on related plate bottom and top strips. The hardness differences could be due either to a difference in the techniques employed in hardness measurement or to the possibility that plate bottom and top strip areas are actually lower in hardness than those at the center. Judging from hardness measurements made on the blank plates, no significant pattern of localized hardness difference between note areas of substantial size occurs in the electroforming of plates.

The investigation revealed that generally a progressive increase in the yield and tensile strengths and a progressive decrease in the ductility of plate material resulted from a progressive increase of the SNSR addition in electroforming. Judging from results obtained from blank plates no appreciable directional or localized differences in the yield strength, tensile strength or ductility properties of plates occur in their production.

A tremendous scatter in the results obtained from individual plates was observed in mileage tests. This was true for both face and back plates and for plates in both of these categories that had been produced using the same SNSR addition in electroforming. A broad scatter in plate mileage is a problem occurring in currency printing on all G-74 presses using plates produced by the currently standardized Bu E&P electroforming technique. Apparently, the scatter occurring in the mileage tests in this investigation is a reflection of this inherent problem. The greater plate yield and tensile strengths gained by the increase of the SNSR addition in electroforming apparently resulted in no improvement in plate mileage. However, the mileage tests were severely limited in the number of plates tested in each SNSR addition category. Each category exhibited great scatter.

Accordingly, recognizing that greater attention must be given to the scatter problem in mileage testing, the conclusion that higher plate yield strength and tensile strength afford no improvement in mileage could possibly be reversed if the mileage tests were made more comprehensive by testing a larger number of plates in each SNSR addition category.

Fatigue cracking was the chief cause of plate failure on both presses and blistering a secondary cause. Greater mileages, overall, were obtained for face plates which were run on the G 74-101 press than those obtained from back plates on the G 74-104 press. As previously noted, a greater pressure is exerted in printing face plates than in printing back plates and one might, therefore, expect greater mileage from the G 74-104 press. The explanation for the lower mileages obtained on the G 74-104 press may be that this press is subjected to more cyclic vibration and stressing, the primary causes of fatigue cracking and a probable factor in blistering. Vibration due to bearing wear, cylinder unbalance, gear drive enevenness, faulty mounting, etc., may be greater in this press than on the G 74-101 press. The NBS Vibration Section has suggested that these mechanical conditions be studied in an analysis of the vibration problem [4].

It is the opinion of the authors that no improvement in the mileage of G-74 currency plates can be realized by an improvement of tensile properties until conditions leading to excessive vibration and cyclic stressing in the G-74 presses are remedied.

ACKNOWLEDGMENTS

The metallographic specimens were prepared by Mr. L. C. Smith, Mechanical Properties Section, Metallurgy Division. The photographic prints were also made by Mr. Smith.

REFERENCES

[1] "Examination of Failure of G-74 Currency Face Plates", NBS Report No. 312.01/52, dated October 3, 1972.

[2] Ibid, page 8. Fatigue Properties.

[3] Ibid, page 11. Recommendations.

[4] "Discussion of Bureau of Engraving and Printing Dollar Bill Plate Failures", NBS Vibration Section, Mechanics Division Memorandum by John D. Ramboz, dated December 14, 1972.

Table 1. Constants and Variables in the Technique Employed in the Preparation of Electroformed Currency Plate Material

Type of Plate	Plate No.	North (N) or South (S) Placement in Tank No. 4	ph	Electrolyte Temp. Deg. C.	Current Density, Amp's./sq. ft.	SNSR Addition Ml
Blank	1c	S	4.5	50	50	25
"	2c	S	4.4	50	50	50
Face	42233	N	4.5	50	50	20
"	42235	N	4.5	50	50	25
"	42237	N	4.5	50	50	25
"	42238	S	4.5	50	50	25
"	42239	N	4.5	50	50	25
"	42241	N	4.45	50	50	65
"	42242	S	4.45	50	50	65
"	42244	N	4.48	50	50	75
"	42245	S	4.48	50	50	75
"	42248	N	4.0	50	50	75
"	42249	S	4.0	50	50	75
Back	7637	S	4.5	50	50	20
"	7638	S	4.5	50	50	25
"	7639	N	4.5	50	50	25
"	7640	S	4.5	50	50	25
"	7642	N	4.4	50	50	60
"	7643	S	4.4	50	50	60
"	7644	N	4.4	50	50	50
"	7645	N	4.48	50	50	75
"	7646	S	4.48	50	50	75

Table 2. Chemical Composition of Selected Plates

Element	1c %	2c %	42233B %	42248B %
Carbon	< 0.01	< 0.01	< 0.01	< 0.01
Sulfur	0.005	0.004	0.004	0.004
Iron	0.01	0.01	T < 0.01	T < 0.01
Copper	< 0.001	< 0.001	< 0.001	< 0.001
Zinc	ND < 0.005	ND < 0.005	ND < 0.005	ND < 0.005
Chromium	ND < 0.005	ND < 0.005	ND < 0.005	ND < 0.005
Lead	ND < 0.005	ND < 0.005	ND < 0.005	ND < 0.005
Aluminum	0.009	ND < 0.005	ND < 0.005	ND < 0.005
Cobalt	0.69	0.65	0.94	0.92

T - Trace

ND - Not detected

Table 3. Results of Blank Plate Thickness Measurements

Plate No.	Measurement Location Nearest Notes	Plate Thickness Inch	Bu E&P Tolerance Inch
1c	E_3-A_3	0.0303	0.03000 ± 0.00025
	E_1-A_1	0.0303	0.03000 ± 0.00025
	H_4-D_4	0.0304	0.03000 ± 0.00025
	H_2-D_2	0.0304	0.03000 ± 0.00025
	A_4-E_2	0.0303	0.03000 ± 0.00025
	F_3-G_3	0.0301	0.03000 ± 0.00025
	B_1-C_1	0.0302	0.03000 ± 0.00025
	F_4-G_4	0.0303	0.03000 ± 0.00025
	B_2-C_2	0.0304	0.03000 ± 0.00025
	G_1-H_1	0.0303	0.03000 ± 0.00025
2c	E_3-A_3	0.0302	0.03000 ± 0.00025
	E_1-A_1	0.0304	0.03000 ± 0.00025
	H_4-D_4	0.0302	0.03000 ± 0.00025
	H_2-D_2	0.0304	0.03000 ± 0.00025
	A_4-E_2	0.0303	0.03000 ± 0.00025
	F_3-G_3	0.0303	0.03000 ± 0.00025
	B_1-C_1	0.0302	0.03000 ± 0.00025
	F_4-G_4	0.0303	0.03000 ± 0.00025
	B_2-C_2	0.0303	0.03000 ± 0.00025
	G_1-H_1	0.0303	0.03000 ± 0.00025

Table 4. Results of Face Plate Strip Thickness Measurements

Strip Plate No.	Origin B - Plate Bottom T - Plate Top	Measurement Location on Strip, Nearest Notes	Strip Thickness Inch	Difference Inch	Bu E&P Tolerance Inch
42233	B	D_1-A_2	0.0303	0.0010	0.03000 ±0.00025
42233	T	H_3-E_4	0.0313		0.03000 ±0.00025
42235	B	D_1-A_2	0.0301	0.0007	0.03000 ±0.00025
42235	T	H_3-E_4	0.0303		0.03000 ±0.00025
42237	B	D_1-A_2	0.0300	0.0002	0.03000 ±0.00025
42237	T	H_3-E_4	0.0298		0.03000 ±0.00025
42238	B	D_1-A_2	0.0300		0.03000 ±0.00025
42238	T	H_3-E_4	0.0300		0.03000 ±0.00025
42239	B	D_1-A_2	0.0300	0.0001	0.03000 ±0.00025
42239	T	H_3-E_4	0.0299		0.03000 ±0.00025
42241	B	D_1-A_2	0.0302	0.0005	0.03000 ±0.00025
42241	T	H_3-E_4	0.0297		0.03000 ±0.00025
42242	B	D_1-A_2	0.0300	0.0004	0.03000 ±0.00025
42242	T	H_3-E_4	0.0296		0.03000 ±0.00025
42244	B	D_1-A_2	0.0295	0.0006	0.03000 ±0.00025
42244	T	H_3-E_4	0.0301		0.03000 ±0.00025
42245	B	D_1-A_2	0.0299	0.0005	0.03000 ±0.00025
42245	T	H_3-E_4	0.0294		0.03000 ±0.00025
42248	B	D_1-A_2	0.0301	0.0004	0.03000 ±0.00025
42248	T	H_3-E_4	0.0295		0.03000 ±0.00025
42249	B	D_1-A_2	0.0303	0.0004	0.03000 ±0.00025
42249	T	H_3-E_4	0.0299		0.03000 ±0.00025

Table 5. Results of Back Plate Strip Thickness Measurements

Strip Plate No.	Origin B - Plate Bottom T - Plate Top	Measurement Location on Strip, Nearest Notes	Strip Thickness Inch	Difference Inch	Bu E&P Tolerance Inch
7637	B	D_1-A_2	0.0294	0.0011	0.03000 ±0.00025
7637	T	H_3-E_4	0.0305		0.03000 ±0.00025
7638	B	D_1-A_2	0.0299	0.0003	0.03000 ±0.00025
7638	T	H_3-E_4	0.0302		0.03000 ±0.00025
7639	B	D_1-A_2	0.0303	0.0004	0.03000 ±0.00025
7639	T	H_3-E_4	0.0299		0.03000 ±0.00025
7640	B	D_1-A_2	0.0300	0.0001	0.03000 ±0.00025
7640	T	H_3-E_4	0.0299		0.03000 ±0.00025
7642	B	D_1-A_2	0.0300	0.0001	0.03000 ±0.00025
7642	T	H_3-E_4	0.0299		0.03000 ±0.00025
7643	B	D_1-A_2	0.0300	0.0004	0.03000 ±0.00025
7643	T	H_3-E_4	0.0296		0.03000 ±0.00025
7644	B	D_1-A_2	0.0302	0.0003	0.03000 ±0.00025
7644	T	H_3-E_4	0.0299		0.03000 ±0.00025
7645	B	D_1-A_2	0.0300	0.0001	0.03000 ±0.00025
7645	T	H_3-E_4	0.0299		0.03000 ±0.00025
7646	B	D_1-A_2	0.0300	0.0005	0.03000 ±0.00025
7646	T	H_3-E_4	0.0295		0.03000 ±0.00025

Table 6. Results of Blank Plate Hardness Measurements

Plate No.	Measurement Location Nearest Notes	SNSR Addition Ml	Rockwell 15T Hardness Note Area
1c	E_3-A_3	25	90
	E_1-A_1		88
	H_4-D_4		88
	H_2-D_2		88
	A_4-E_2		89
	F_3-G_3		89
	B_1-C_1		89
	F_4-G_4		89
	B_2-C_2		89
	G_1-H_1		89
	Average		88.8
2c	E_3-A_3	50	90
	E_1-A_1		91
	H_4-D_4		91
	H_2-D_2		90
	A_4-E_2		88
	F_3-G_3		90
	B_1-C_1		91
	F_4-G_4		90
	B_2-C_2		90
	G_1-H_1		91
	Average		90.2

Table 7. Results of Face Plate Strip Hardness Measurements

Strip Plate No.	Origin B - Plate Bottom T - Plate Top	Measurement Location on Strip Nearest Notes	SNSR Addition Ml	Rockwell 15T Hardness Strip	Rockwell 15T Hardness Bu E&P Plate Center Measurement
42233	B	D_1-A_2	20	90	90
42233	T	H_3-E_4	20	89	90
42235	B	D_1-A_2	25	90	90
42235	T	H_3-E_4	25	90	90
42237	B	D_1-A_2	25	90	91
42237	T	H_3-E_4	25	90	90
42238	B	D_1-A_2	25	91	90
42238	T	H_3-E_4	25	89	91
42239	B	D_1-A_2	25	90	91
42239	T	H_3-E_4	25	89	91
42241	B	D_1-A_2	65	91	93
42241	T	H_3-E_4	65	90	92
42242	B	D_1-A_2	65	91	92
42242	T	H_3-E_4	65	90	92
42244	B	D_1-A_2	75	90	93
42244	T	H_3-E_4	75	91	93
42245	B	D_1-A_2	75	91	93
42245	T	H_3-E_4	75	90	92
42248	B	D_1-A_2	75	92	94
42248	T	H_3-E_4	75	92	93
42249	B	D_1-A_2	75	92	92
42249	T	H_3-E_4	75	92	93

Table 8. Results of Back Plate Strip Hardness Measurements

Strip Plate No.	Origin B - Plate Bottom T - Plate Top	Measurement Location on Strip Nearest Notes	SNSR Addition Ml	Rockwell 15T Hardness Strip	Rockwell 15T Hardness Bu E&P Plate Center Measurement
7637	B	D_1-A_2	20	90	90
7637	T	H_3-E_4	20	88	90
7638	B	D_1-A_2	25	89	91
7638	T	H_3-E_4	25	90	91
7639	B	D_1-A_2	25	90	91
7639	T	H_3-E_4	25	89	91
7640	B	D_1-A_2	25	90	90
7640	T	H_3-E_4	25	89	91
7642	B	D_1-A_2	60	91	92
7642	T	H_3-E_4	60	90	92
7643	B	D_1-A_2	60	90	91
7643	T	H_3-E_4	60	90	92
7644	B	D_1-A_2	50	91	92
7644	T	H_3-E_4	50	90	92
7645	B	D_1-A_2	75	91	93
7645	T	H_3-E_4	75	91	93
7646	B	D_1-A_2	75	92	93
7646	T	H_3-E_4	75	91	93

Table 9. Blank Plate Tensile Properties

Blank Plate No.	Specimen Number	Nearest Notes	Yield Strength, (Y.S.) psi	Tensile Strength, (T.S.) psi	Ratio $\frac{Y.S.}{T.S.}$	Elongation in 2 Inches Percent
1c	L1-1	E_3-A_3	55782	83741	0.67	13
1c	L2-1	E_1-A_1	62329	83699	0.74	14
1c	L3-1	H_4-D_4	60135	83784	0.72	14
1c	L4-1	H_2-D_2	57237	82566	0.69	17
1c	L7-1	A_4-E_2	58108	83378	0.70	14
1c	Average		58718	83434	0.70	14
1c	T5-1	F_3-G_3	59732	85034	0.70	14
1c	T5-2	B_1-C_1	58725	84631	0.69	14
1c	T6-1	F_4-G_4	61486	84392	0.73	14
1c	T6-2	B_2-C_2	56250	81842	0.69	15
1c	T7-1	G_1-H_1	58054	83893	0.69	14
1c	Average		58849	83958	0.70	14
1c	Overall Average		58784	83696	0.70	14
2c	L1-1	E_3-A_3	66216	91351	0.72	11
2c	L2-1	E_1-A_1	64094	90805	0.71	11
2c	L3-1	H_4-D_4	66327	90884	0.73	10
2c	L4-1	H_2-D_2	61589	89073	0.69	14
2c	L7-1	A_4-E_2	65646	89932	0.73	10
2c	Average		64774	90409	0.72	11
2c	T5-1	F_3-G_3	66327	91293	0.73	11
2c	T5-2	B_1-C_1	65101	92752	0.70	11
2c	T6-1	F_4-G_4	63542	91319	0.70	10
2c	T6-2	B_2-C_2	66776	89934	0.74	13
2c	T7-1	G_1-H_1	59459	89662	0.66	12
2c	Average		64241	90992	0.71	11
2c	Overall Average		64508	90700	0.71	11

Table 10. Tensile Properties of Face Plate Strips

Strip[1] No.	SNSR Addition Ml	Yield Strength, (Y.S.) psi	Tensile Strength, (T.S.) psi	Ratio $\frac{Y.S.}{T.S.}$	Elongation in 2 Inches Percent	Plate Mileage
42233 B	20	61258	90728	0.68	13	
42233 T	20	56954	82119	0.69	15	
42233 $\frac{B+T}{2}$	20	59106	86424	0.685	14	129163
42235 B	25	59459	85135	0.70	10	
42235 T	25	57843	81046	0.71	14	
42235 $\frac{B+T}{2}$	25	58651	83090	0.705	12	451141
42237 B	25	60473	88108	0.69	11	
42237 T	25	55822	83425	0.67	12	
42237 $\frac{B+T}{2}$	25	58148	85766	0.68	11.5	387555
42238 B	25	62759	90828	0.69	10	
42238 T	25	61644	84932	0.73	12	
42238 $\frac{B+T}{2}$	25	62202	87880	0.71	11	387555
42239 B	25	78472	86389	0.91	11	
42239 T	25	59247	83904	0.71	13	
42239 $\frac{B+T}{2}$	25	68860	85146	0.81	12	825207
42241 B	65	66887	94834	0.70	9	
42241 T	65	60959	87877	0.69	12	
42241 $\frac{B+T}{2}$	65	63923	91356	0.695	10.5	765416
42242 B	65	68151	95890	0.71	8	
42242 T	65	64236	90278	0.71	10	
42242 $\frac{B+T}{2}$	65	66194	93084	0.71	9	546656
42244 B	75	69310	94138	0.74	11	
42244 T	75	73510	98344	0.75	8	
42244 $\frac{B+T}{2}$	75	71410	96241	0.745	9.5	575080
42245 B	75	73129	100000	0.73	8	
42245 T	75	68403	93333	0.73	9	
42245 $\frac{B+T}{2}$	75	70766	96666	0.73	8.5	834963

Table 10. Continued

Strip[1] No.	SNSR Addition Ml	Yield Strength, (Y.S.) psi	Tensile Strength, (T.S.) psi	Ratio $\frac{Y.S.}{T.S.}$	Elongation in 2 Inches Percent	Plate Mileage
42248 B	75	73333	105666	0.69	8	
42248 T	75	74483	101862	0.73	9	
42248 $\frac{B+T}{2}$	75	73908	103764	0.71	8.5	257435
42249 B	75	78378	105743	0.74	8	
42249 T	75	74483	100552	0.74	9	
42249 $\frac{B+T}{2}$	75	76430	103148	0.74	8.5	360445
Average B		68328	94314	0.725	9.7	
Average T		64326	89788	0.71	11.2	
Average $\frac{B+T}{2}$		66327	92051	0.72	10.4	501874

[1] Strip Origins

B - Plate bottom; nearest notes, D_1-D_2.

T - Plate top; nearest notes, H_3-E_4.

Table 11. Tensile Properties of Back Plate Strips

Strip[1] No.	SNSR Addition Ml	Yield Strength, (Y.S.) psi	Tensile Strength, (T.S.) psi	Ratio $\frac{Y.S.}{T.S.}$	Elongation in 2 Inches Percent	Plate Mileage
7637 B	20	70139	87083	0.80	12	
7637 T	20	55369	82148	0.67	16	
7637 $\frac{B+T}{2}$	20	62574	84616	0.74	14	270305
7638 B	25	59310	84897	0.70	13	
7638 T	25	59932	85685	0.70	13	
7638 $\frac{B+T}{2}$	25	59621	85291	0.70	13	312989
7639 B	25	63699	90411	0.70	10	
7639 T	25	61905	86190	0.72	11	
7639 $\frac{B+T}{2}$	25	62802	88300	0.71	10	732396
7640 B	25	64384	87123	0.74	12	
7640 T	25	59247	84315	0.70	12	
7640 $\frac{B+T}{2}$	25	61816	85719	0.72	12	82182[2]
7642 B	60	60403	86577	0.70	-	
7642 T	60	63699	93356	0.68	10	
7642 $\frac{B+T}{2}$	60	62051	89966	0.69	10	82183[2]
7643 B	60	68056	92847	0.73	9	
7643 T	60	62759	87793	0.71	10	
7643 $\frac{B+T}{2}$	60	65408	90320	0.72	10	283373
7644 B	50	63245	87483	0.72	10	
7644 T	50	70408	97143	0.72	9	
7644 $\frac{B+T}{2}$	50	66286	92313	0.72	10	258548
7645 B	75	69655	99448	0.70	8	
7645 T	75	66552	92414	0.72	10	
7645 $\frac{B+T}{2}$	75	68104	95931	0.71	9	205811
7646 B	75	71429	100068	0.71	10	
7646 T	75	68966	94621	0.73	11	
7646 $\frac{B+T}{2}$	75	70198	97344	0.72	10	468736
Average B		65591	90660	0.72	10	
Average T		63204	89296	0.71	11	
Overall Average $\frac{B+T}{2}$		64398	85478	0.72	10	299614
Adjusted Average						361737

[1] Strip Origins
B - Plate bottom; nearest notes, D_1-D_2.
T - Plate top; nearest notes, H_3-E_4.

[2] Values omitted from adjusted average mileage computation because of mechanical failure (rigging ball-up).

Table 12. Average Tensile Properties of Selected Face and Back Plate Strips Versus Plate Mileage

SNSR Addition Ml	Specimens Averaged No.	Averages: Hardness R15T	Averages: Yield Strength, (Y.S.) psi	Averages: Tensile Strength, (T.S.) psi	Averages: Y.S./T.S. Ratio	Averages: Elongation Percent	Averages: Mileage
			Face Plate Strips				
20	1	89.5	59106	86424	0.685	14	129163
25	4	90	61965	85470	0.726	11.6	512864
65	2	90.5	65058	92220	0.70	9.8	656036
75	4	91.25	73128	99955	0.73	8.8	506981
			Average mileage of all plates				451261
			Back Plate Strips				
20	1	89	62574	84616	0.74	14	270305
25	2	89.5	61212	86796	0.705	11.5	522692[1]
50	1	90.5	66286	92313	0.72	10	258548
60	1	90	65408	90320	0.72	10	283373[2]
75	2	91.25	69151	96638	0.715	9.5	337274
			Adjusted average mileage of plates				334438

[1] Low mileage, 81282, of plate No. 7640 due to mechanical failure was omitted in obtaining adjusted average.

[2] Low mileage, 81283, of plate No. 7642 due to mechanical failure was omitted in obtaining adjusted average.

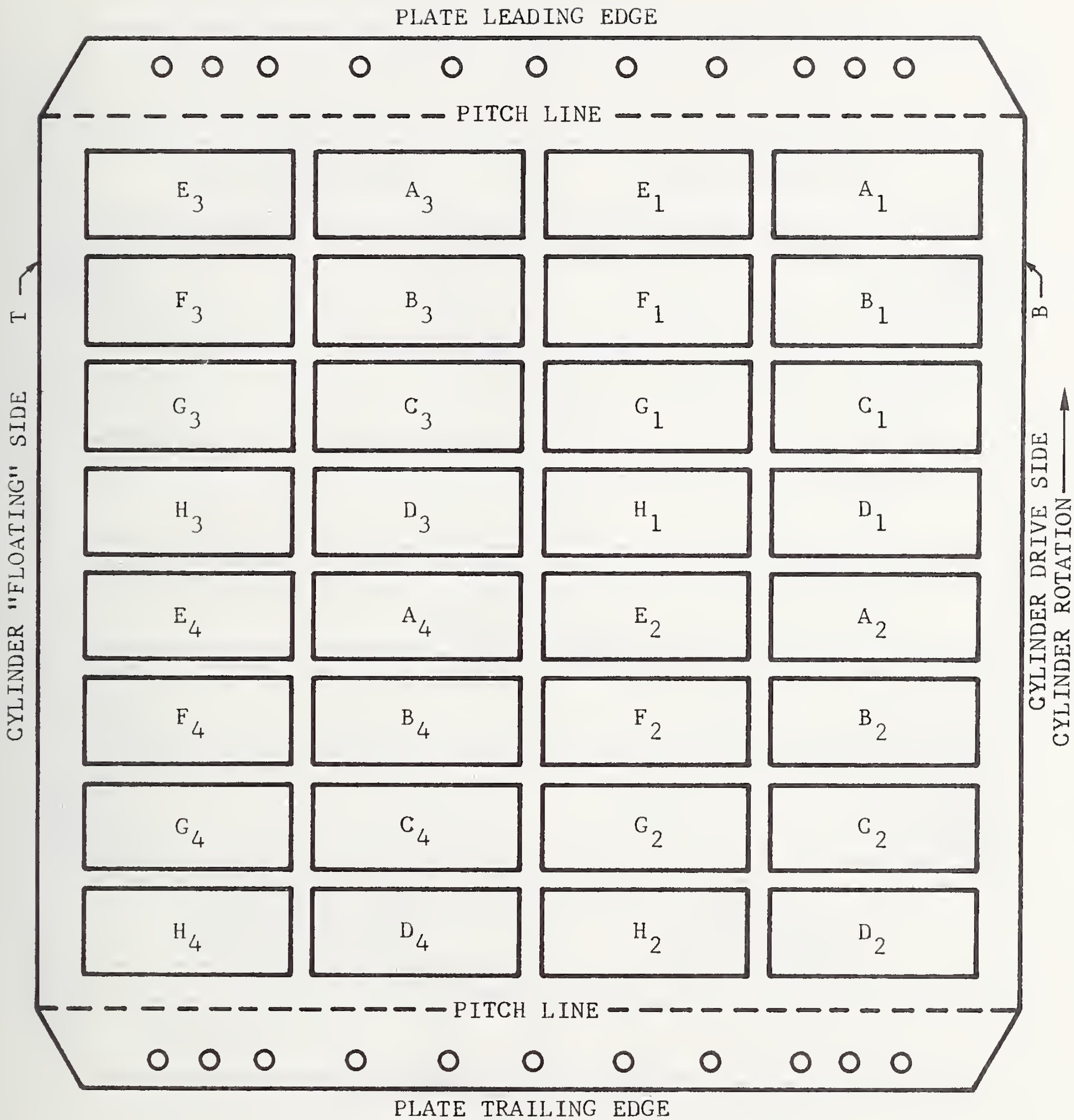


Figure 1. Sketch Showing Individual Note Locations on a Currency Plate, Plate Alignment on a Printing Press and Original Positions of Plate Bottom (B) and Top (T) in Electroforming Tank.

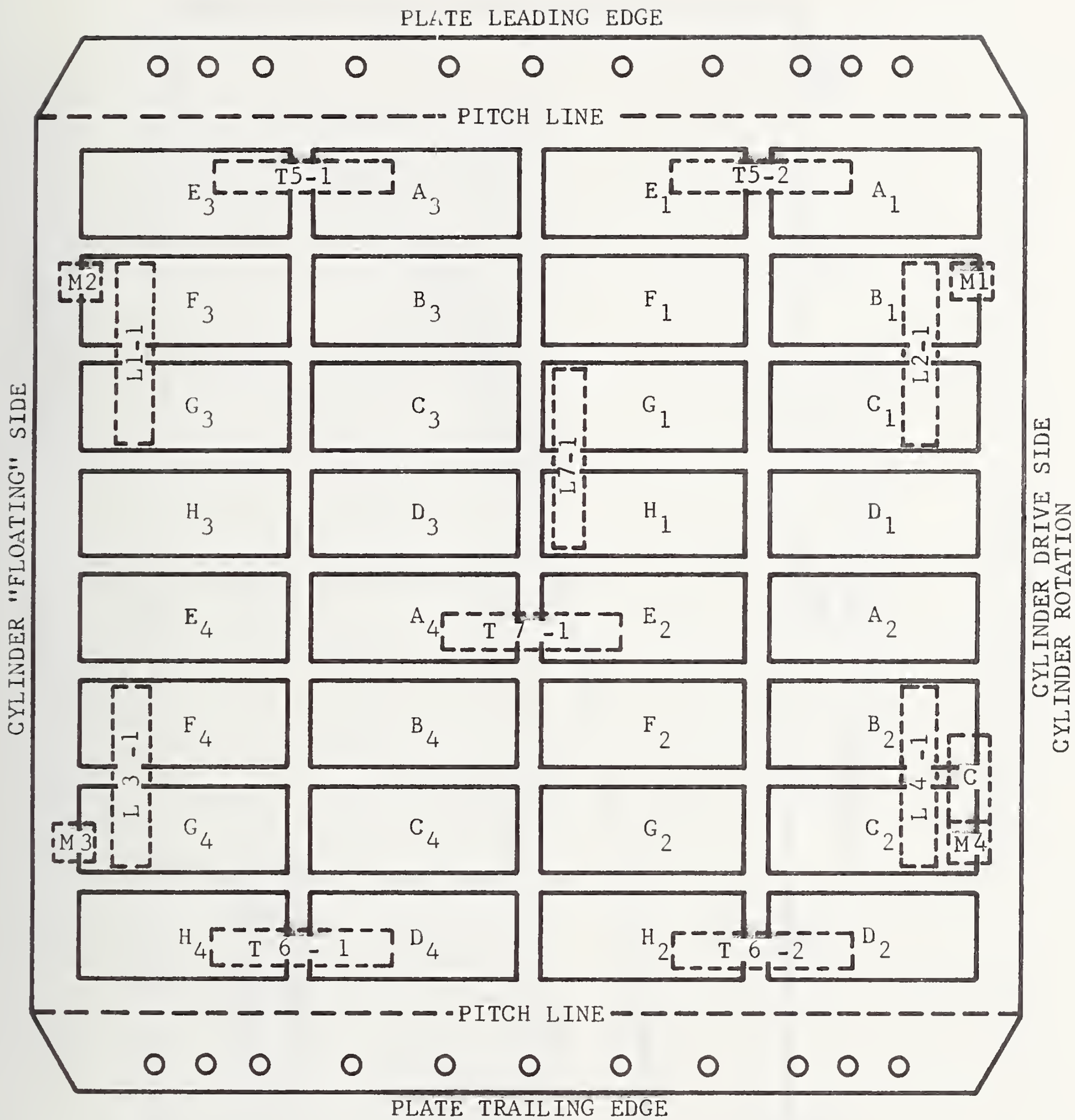


Figure 2. Cutting Map Showing Location of Tensile, Metallographic and Chemical Analysis Specimens Cut from Blank Plates, 1C and 2C. Not drawn to scale.

L - Longitudinal tensile specimen.
T - Transverse tensile specimen.
M - Metallographic specimen.
C - Chemical analysis specimen.

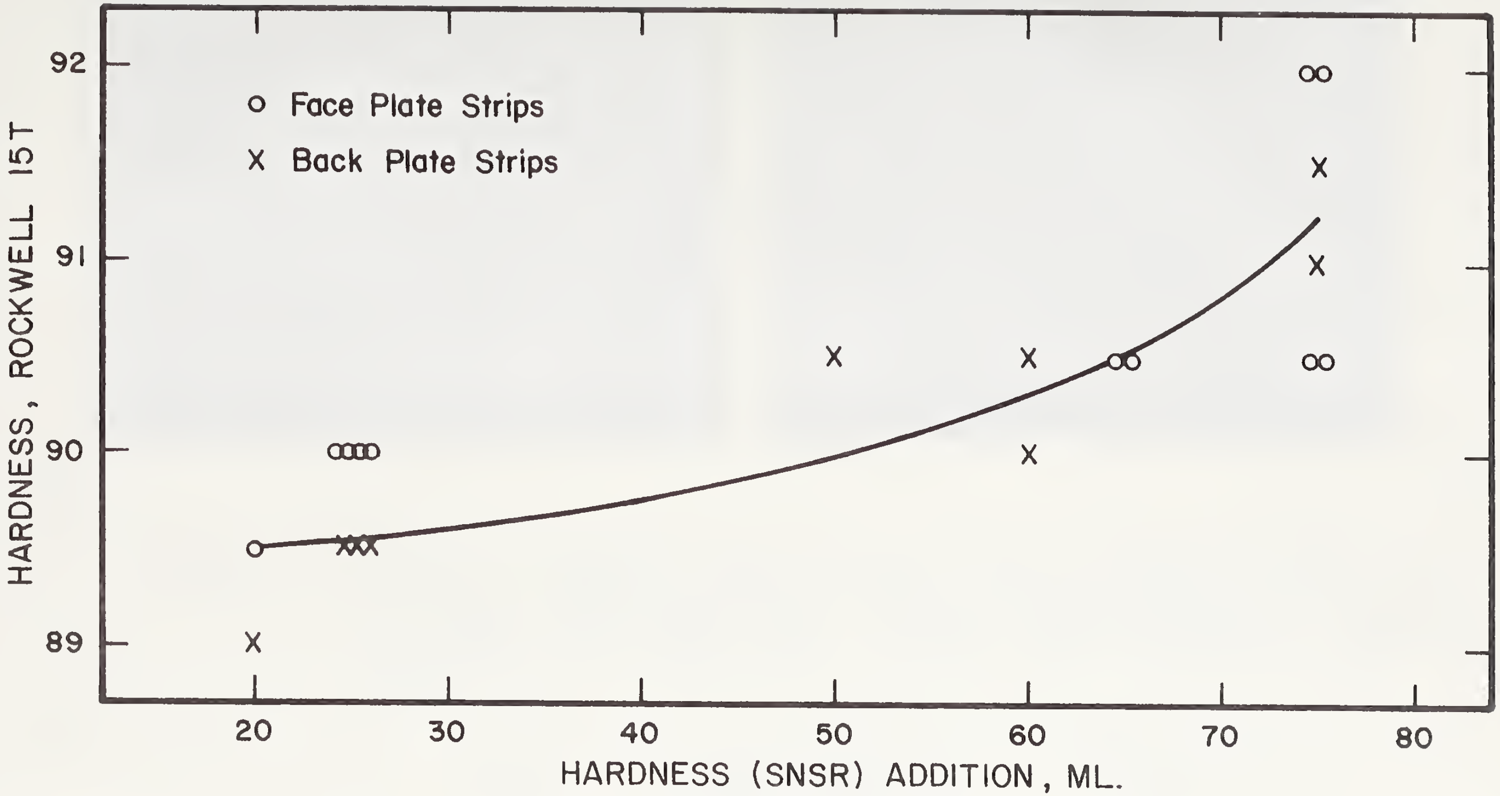
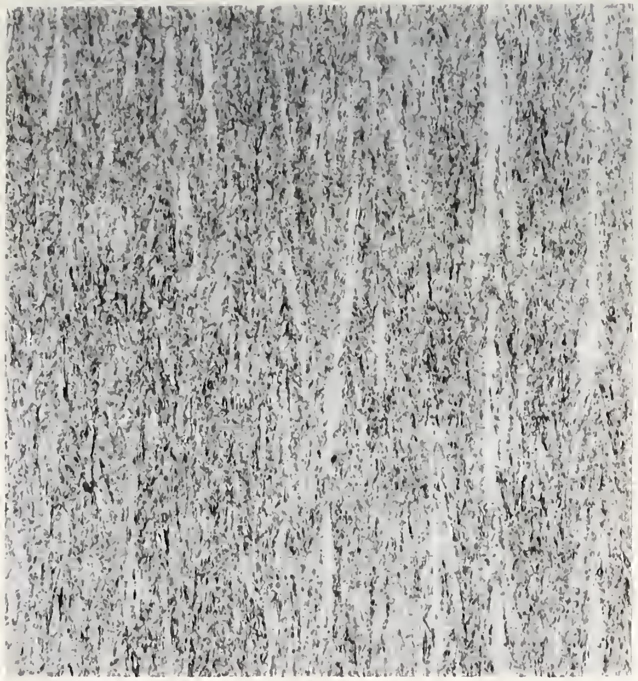
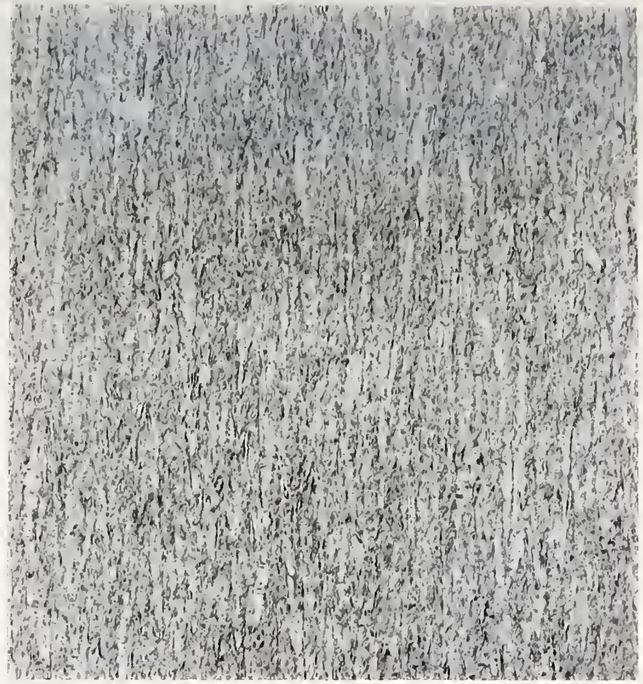


Figure 3. Effect of SNSR Addition in Electroforming on Hardness of Strips.



a



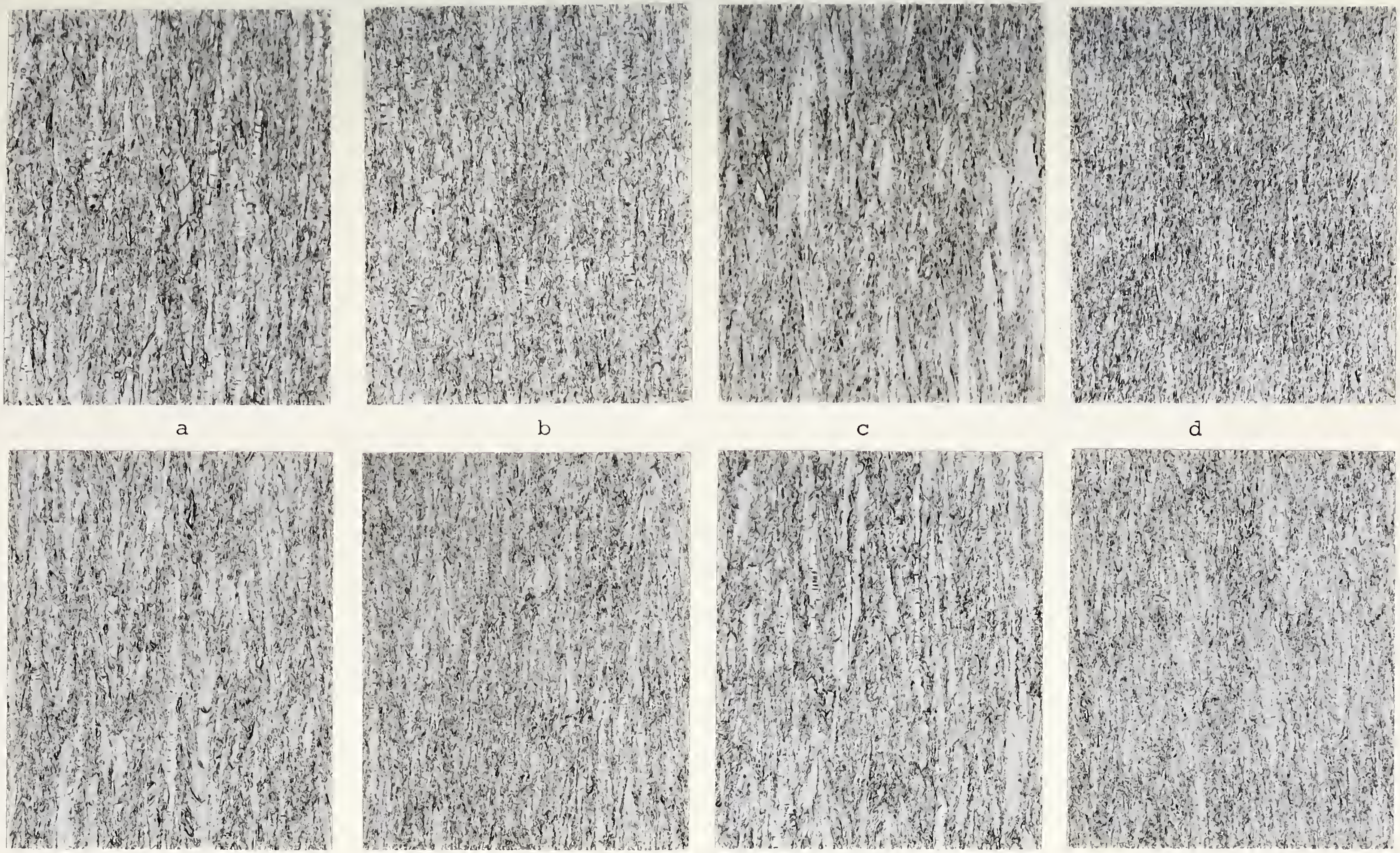
b

Figure 4. Photomicrographs Showing Structures in Blank Plates, 1c and 2c. The structures shown are representative of that in plate cross-sections. Etched with Carapella's reagent following a 3 acetic to 1 nitric acid chemical polish. X 250

	Plate No.	Specimen Location (See Figure 2)	SNSR Addition M1
a	1c	M1	25
b	2c	M3	50

Figure 5. Photomicrographs Showing Structures in Specimens Cut from Face and Back Plate Strips. The structures shown are representative of that in strip cross-sections. Etched with Carapella's reagent following a 3 acetic to 1 nitric acid chemical polish. X 250.

	Plate Strip No.	Plate Type	SNSR Addition, Ml.	Mileage
a	42239T	Face	25	825207
b	42245T	Face	75	834963
c	42233T	Face	20	129163
d	42248T	Face	75	257435
e	7639T	Back	25	732396
f	7646T	Back	75	468736
g	7637T	Back	20	270305
h	7645T	Back	75	205811


a
b
c
d
e
f
g
h

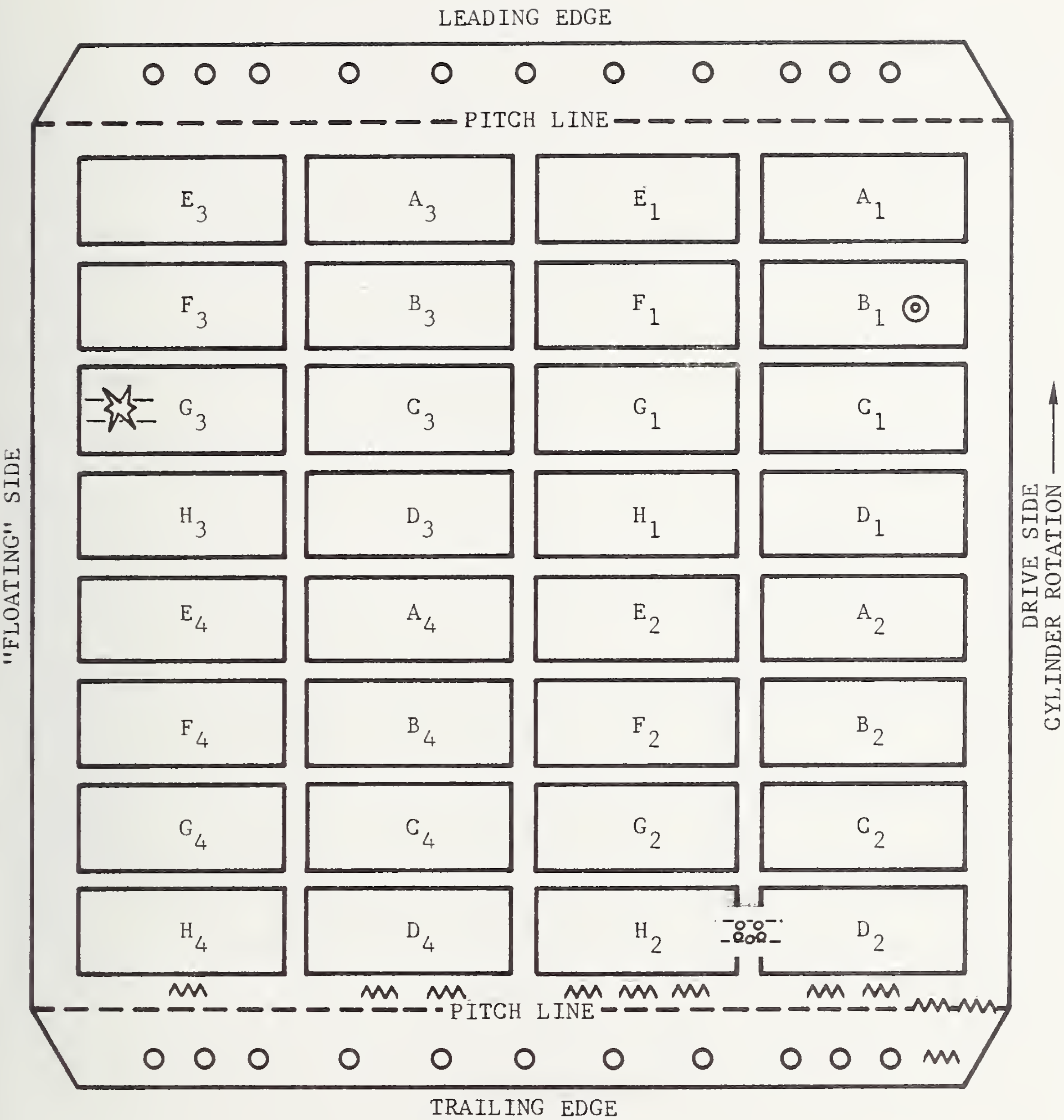


Figure 6. Sketch Showing Nature and Approximate Location of Face Plate Failures.

Symbols indicate each failure of a similar nature.

- Fatigue cracking.

- Dimple

- Rippling and blistering

- Ball-up (rippling)

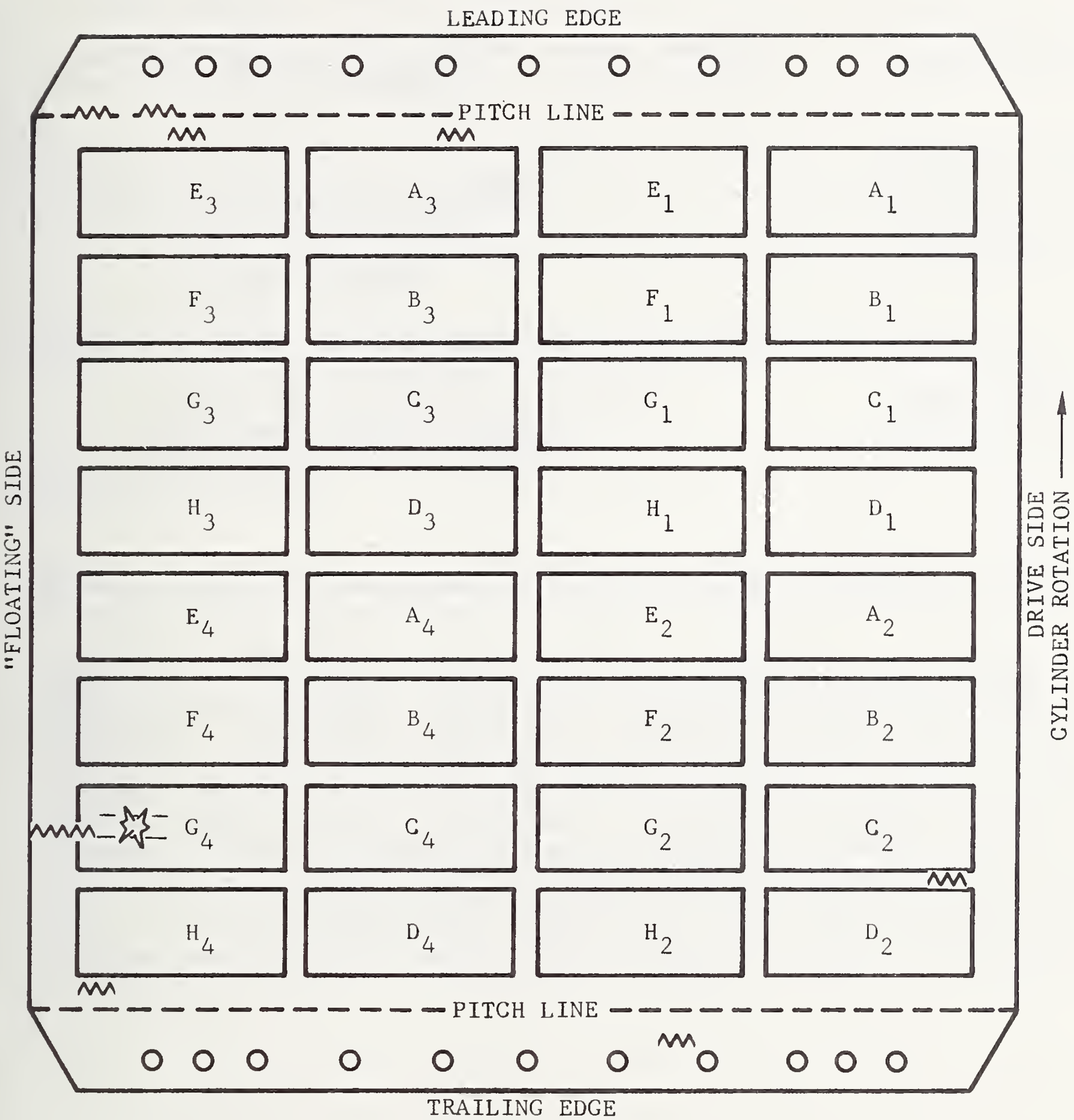


Figure 7. Sketch Showing Nature and Approximate Location of Back Plate Failures.

Symbols indicate each failure of a similar nature.

- Fatigue cracking.

- Ball-up and rippling. (One Shown; Approximate location of two additional failures of this nature were not reported.)

NBS-114A (REV. 7-73)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR 74-425	2. Gov't Accession No.	3. Recipient's Accession No.

4. TITLE AND SUBTITLE INVESTIGATION OF G-74 CURRENCY PLATE TENSILE PROPERTIES AND PERFORMANCE	5. Publication Date January 1974 6. Performing Organization Code
7. AUTHOR(S) I. J. Feinberg and T. R. Shives	8. Performing Organ. Report No. NBSIR 74-425
9. PERFORMING ORGANIZATION NAME AND ADDRESS NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234	10. Project/Task/Work Unit No. 3120541 11. Contract/Grant No.
12. Sponsoring Organization Name and Complete Address *(Street, City, State, ZIP)* Electrolytic Section Bureau of Engraving and Printing Department of the Treasury Washington, D. C. 20226	13. Type of Report & Period Covered Test Report 14. Sponsoring Agency Code

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.)*

This investigation revealed that a desirable uniformity in composition, thickness, hardness, microstructure and tensile properties is attained from plate to plate in electroforming. Tests programed to determine whether an increase in plate yield and tensile strengths would afford and improvement in plate service life were inconclusive due to the scatter in the service lives obtained in the limited number of tests conducted at various strength levels. Fatigue cracking, apparently due to excessive vibration and cyclic stressing, was found to be the chief cause of plate failure in the tests. It is unlikely that significant improvements in the service life of G-74 currency plates can be attained until conditions leading to excessive vibration and cyclic stressing in the G-74 presses are remedied.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Currency plate, electroformed nickel, fatigue, mechanical properties

18. AVAILABILITY ☐ Unlimited [X] For Official Distribution. Do Not Release to NTIS [ ] Order From Sup. of Doc., U.S. Government Printing Office Washington, D.C. 20402, SD Cat. No. C13 [ ] Order From National Technical Information Service (NTIS) Springfield, Virginia 22151	19. SECURITY CLASS (THIS REPORT) UNCLASSIFIED 20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	21. NO. OF PAGES 36 22. Price

USCOMM-DC 29042-P