NBSIR 80-2043

Examination of Expanded Metal Grating Material Used for Fencing along the United States-Mexico Border

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U.S. DEPARTMENT OF COMMERCE, Philip M. Klutznick, ***Secretary***

Luther H. Hodges, Jr., ***Deputy Secretary***
Jordan J. Baruch, ***Assistant Secretary for Productivity, Technology, and Innovation***

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Director***

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SUMMARY

At the request of the Immigration and Naturalization Service, U. S. Department of Justice, the NBS Fracture and Deformation Division performed an examination of samples of galvanized steel expanded metal grating used for fencing along the United States-Mexico border. The samples were from four locations - San Ysidro, California; El Paso, Texas; San Luis, Arizona; and Nogales, Arizona.

The properties of the material were compared to the specifications in Military Standard MIL-M-17194C. Samples from El Paso, San Luis, and Nogales failed to meet the weight per square foot requirement of the standard. All samples met dimensional and thickness of the galvanized coating requirements. The primary rolling direction of the material from El Paso, San Luis, and Nogales was not in accordance with specifications, and the material from El Paso exhibited directionality of the microstructure.

The material from all four sites was mild steel in accordance with specifications. The material from El Paso was extremely clean, whereas the material from the other sites had some sulfide and oxide inclusions.

There was considerable variation in hardness for any given sample, but there were no significant differences in hardness among the materials from the four sites.

In a simple mechanical test that attempts to simulate field failure, the fencing material from El Paso appeared to offer greater resistance to penetration (failure) than the materials from the other sites.

Examination of Expanded Metal Grating Material
Used for Fencing along the United States-Mexico Border

1. INTRODUCTION

1.1 Reference

Immigration and Naturalization Service, Department of Justice, 425 I Street, NW, Washington, DC 20536. This examination was conducted at the request of Mr. W. A. Morris, Chief, Facilities and Engineering, Immigration and Naturalization Service, under order number COW-0-13710 dated February 12, 1980. The letter of authorization, dated February 19, 1980, was signed by Mr. James A. Kennedy, Associate Commissioner, Management.

1.2 Background Information

The information in this section was furnished by Mr. W. A. Morris of the Immigration and Naturalization Service. New fencing is being installed along the border between the United States and Mexico. The fence is ten feet high and consists of four feet of expanded galvanized steel grating at the bottom overlapped and topped with seven feet of galvanized chain link material. The expanded metal part of the fence is installed such that the long dimension of the openings is vertical with respect to the ground. After installation of some of the fence segments, intrusion through the expanded metal part was being experienced in some areas, particularly at Nogales, Arizona.

1.3 Parts Submitted

Samples of the expanded metal grating being used for the fencing at four different sites along the border were submitted to the NBS Fracture and Deformation Division for examination. The material was specified to be fabricated in accordance with Military Standard MIL-M-17194C and was reported to be type 1, class 2, grade A galvanized expanded steel. Samples from San Ysidro, California; El Paso, Texas; San Luis, Arizona, and Nogales, Arizona, shown as received at NBS in figures 1, 2, 3, and 4a, respectively, were submitted on February 7, 1980. An additional sample from Nogales, shown as received at NBS in figure 4b, was submitted on March 11, 1980.

2. PURPOSE OF THE EXAMINATION

The Immigration and Naturalization Service, through Mr. W. A. Morris, requested that the NBS Fracture and Deformation Division examine the submitted samples of expanded metal fencing for the following purposes:

1. Photographic documentation of the submitted material.

2. Determination of weight per square foot for samples from each site in accordance with Standard MIL-M-17194C.

3. Dimensional measurements of samples from each site in accordance with Standard MIL-M-17194C as follows:

   a. Nominal width of mesh opening.

   b. Width center to center of bridge.

   c. Length center to center of bridge.

   d. Width of strand.

4. Determination of the zinc coating thickness on samples from each site by the bend method and/or the microscopic test method in accordance with Standard MIL-M-17194C.

5. Chemical analysis of material from each site.

6. Metallographic examination of material from each site.

7. Hardness measurements of samples from each site.

8. Any test or examination not mentioned above but deemed advisable as the examination proceeds and agreed to by both NBS and the Immigration and Naturalization Service.

It was requested that the properties of the material from the four sites be compared in the report stating the results of the examination.

3. RESULTS OF THE EXAMINATION

Material from all four sites was used in each aspect of the examination. In the case of the material from Nogales, the large sample shown in figure 4a and designated Nogales A in this report was used for each aspect of the examination except for the simulated field intrusion test. The sample shown in figure 4b, designated Nogales B, was received after most of the examination had been completed and was used in a limited number of the tasks specified in section 2.

3.1 Photographic Documentation

Documentary photographs of the expanded steel fencing material as received at NBS appear in figures 1 through 4b. Photographic documentation of other aspects of the examination appear later in the report.

3.2 Determination of Weight per Square Foot

The pieces of submitted material from San Ysidro, El Paso and San Luis as shown in figures 1, 2, and 3, respectively, and the large piece of material from Nogales (figure 4a) and the second large piece of material from Nogales (shown in figure 4b) were used in the as-received-at-NBS condition for the weight per square foot determinations. The two samples from Nogales were treated separately since it was not known whether they were from the same sheet. The area from each piece was determined by measuring the dimensions with a scale and the weight was determined to at least the nearest 1/3 ounce. The results of the weight per square foot determinations are as follows:

Site	Area of Sample (ft^2)	Weight of Sample (lbs)	Pounds per ft^2
San Ysidro	1.00	3.08	3.08
El Paso	1.13	3.38	2.99
San Luis	1.11	3.14	2.83
Nogales A	0.75	2.19	2.92
Nogales B	4.49	13.46	3.00

The applicable standard, MIL-M-17194C, specifies a weight per square foot value of 3 pounds ± 5 percent based on the weight of any sheet or bundle of uncoated expanded material. The samples for which the weight determinations were made were much smaller than a sheet and the samples were coated. In order to determine the approximate percentage of the weight attributable to the galvanized coating, one of the small pieces of the expanded metal from Nogales A (shown in figure 4a) was weighed as received, the coating was stripped off by both mechanical and chemical means, and the piece was reweighed. The piece weighed about 5 1/2% less with the coating removed than it did with the coating in place.

Based on the thickness values for the galvanized coating of the material from the various locations as determined by the microscopic test method (see Section 3.4.2) and the percentage of the total weight attributable to the coating for the small Nogales sample, and assuming that the average coating thickness is representative for a given submitted sample, the weight per square foot values given above for the material from San Ysidro, El Paso, San Luis, Nogales A, and Nogales B would be reduced by approximately 4%, 8%, 4%, 5 1/2%, and 6 1/2%, respectively. The weight per square foot values adjusted for the galvanized coating are as follows:

Site	Pounds per Square Foot
San Ysidro	2.96
El Paso	2.75
San Luis	2.72
Nogales A	2.77
Nogales B	2.80

Based on these values, only the sample from San Ysidro clearly meets the weight per square foot requirement of Standard MIL-M-17194C. The sample from San Luis does not meet the weight per square foot requirements even with the weight of the coating included.

The value for sample Nogales B fails to meet the required minimum thickness by less than two percent. The error of measurement may be greater than two percent; therefore, it cannot be said with certainty that this sample actually does not meet the weight per square foot requirement of Standard MIL-M-17194C.

The values for the material from El Paso and Nogales A fail to meet the minimum requirement by about 3 1/2% and 3%, respectively. It seems unlikely that the errors in measurement would be great enough to permit the samples from El Paso and Nogales A to meet the standard.

3.3 Dimensional Measurements

Four different dimensions were checked against Standard MIL-4_17194C for material from each of the four sites. Ten randomly chosen locations were used for each dimension for each sample.

3.3.1 Nominal Width of Opening

Standard MIL-M-17194C specifies the nominal width of the opening to be 15/16 inch. The results of the width of opening measurements in inches to the nearest 0.01 inch are as follows:

	San Ysidro	El Paso	San Luis	Nogales A
Average	1.00	1.05	1.05	1.04
Range	0.99-1.00	1.05-1.06	1.04-1.07	1.04-1.05

All measurements are greater than 15/16 inch, but no measurement deviates significantly from the nominal value.

3.3.2 Width of Bridge

Standard MIL-M-17194C specifies the width of the bridge, center to center, to be 1.33 inches ± 10%. The results of the width of bridge measurements in inches to the nearest 0.01 inch are as follows:

	San Ysidro	El Paso	San Luis	Nogales A
Average	1.20	1.25	1.26	1.24
Range	1 .19-1.22	1.23-1.26	1.25-1.27	1.23-1.25

All average values fall within the specified limits. Except for four measurements for the material from San Ysidro, all of the individual measurements also fall within the specified limits. The four measurements that do fall outside the limits miss by only 0.01 inch. With measurements being made to the nearest 0.01 inch, this is not considered significant.

3.3.3 Length of Bridge

Standard MIL-M-17194C specifies the length of the bridge, center to center, to be 5.33 inches ± 10%. The results of the length of bridge measurements in inches to the nearest 0.01 inch are as follows:

	San Ysidro	El Paso	San Luis	Nogales A
Average	5.35	5.33	5.34	5.34
Range	5.32-5.39	5.32-5.37	5.31-5.36	5.31-5.36

All the average values as well as all of the individual values fall within the limits of the specification.

3.3.4 Width of Strand

Standard MIL-M-17194C specifies the width of the strand to be within 0.259-0.269 inch. The results of the width of strand measurements in inches to the nearest 0.001 inch are as follows:

	San Ysidro	El Paso	San Luis	Nogales A
Average	0.275	0.285	0.273	0.273
Range	0.273-0.279	0.283-0.288	0.269-0.275	0.271-0.277

These measurements were made on the coated material, whereas the standard specifies values for uncoated material. In order to determine the approximate width of the strand without the coating, twice the coating thickness (based on the coating thickness measurements in section 3.4.2) was subtracted from the width of strand measurements resulting in the following adjusted width of strand measurements:

San Ysidro	El Paso	San Luis	Nogales A
0.268	0.271	0.266	0.263

The adjusted values from San Ysidro, San Luis and Nogales A all fall within the limits of the specification. The adjusted average value from El Paso fails to meet the specification by .002 inch. Therefore, the width of strand value of the material from El Paso is marginal.

3.4 Determination of the Galvanized Coating Thickness

The thickness of the galvanized coating was determined by two methods in accordance with Standard MIL-M-17194C, the bend test method and the microscopic test method.

3.4.1 Bend Test Method

The thickness of the galvanized coating was measured by the bend test method on two specimens each from material from San Ysidro, El Paso, San Luis, Nogales A, and Nogales B. Five measurements were made on each of the two coating chips from each specimen. The results of these measurements to the nearest 0.0005 inch are as follows:

	San Ysidro	El Paso	San Luis	Nogales A	Nogales B
Average	0.0030	0.0067	0.0028	0.0030	0.0037
Range	0.0025-0.0030	0.0060-0.0080	0.0025-0.0030	0.0025-0.0035	0.0030-0.0045

The minimum coating thickness for grade A material is specified to be 0.0025 inch. All of the measurements meet specifications.

3.4.2 Microscopic Test Method

As a further check on the thickness of the galvanized coatings, the coating thickness was measured on metallographically prepared cross sections through two strands of material from different locations from the material from San Ysidro, El Paso, San Luis, Nogales A, and Nogales B. A measuring microscope was used for the measurements. The coating thickness was determined on each of the four sides of each sample. Measurements were made to the neares 0.0005 inch. The minimum and maximum values are given below for each of the four sides of each cross section. In addition, the average thickness value for each sample is given.

	San Ysidro		El Paso		San Luis		Nogales A		Nogales B	
Strand 1	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Side 1	.0035	.0045	.0060	.0100	.0020	.0030	.0020	.0080	.0025	.0060
Side 2	.0030	.0035	.0070	.0090	.0020	.0030	.0040	.0070	.0030	.0060
Side 3	.0040	.0060	.0045	.0060	.0020	.0050	.0030	.0060	.0025	.0120
Side 4	.0030	.0050	.0070	.0110	.0035	.0055	.0035	.0060	.0045	.0075
Average	0.0040		0.0075		0.0035		0.0050		0.0055	
Strand 2	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Side 1	.0025	.0045	.0065	.0080	.0020	.0035	.0035	.0060	.0030	.0100
Side 2	.0030	.0045	.0055	.0060	.0030	.0040	.0035	.0060	.0030	.0065
Side 3	.0020	.0030	.0065	.0080	.0015	.0040	.0030	.0075	.0050	.0070
Side 4	.0025	.0035	.0045	.0065	.0030	.0050	.0020	.0045	.0040	.0070
Average	0.0032		0.0064		0.0032		0.0045		0.0057	
Average, Both Strands	0.0036		0.0070		0.0034		0.0048		0.0056	

Although several of the minimum values for the material from San Luis, two of the minimum values for the Nogales A material and one of the minimum values for the San Ysidro material were below the specified minimum, the average values for all of the material were well above the specified minimum. Therefore, based on these measurements, the coating thickness for material from all four sites meets specifications.

3.5 Chemical Analysis

Samples of material from each of the four sites (not including Nogales B) were submitted to a commercial laboratory for chemical analysis of the basis steel material. The results of these analyses given as weight percent are as follows:

	San Ysidro	El Paso	San Luis	Nogales A
Carbon	0.08	0.06	0.05	0.08
Manganese	0.45	0.24	0.41	0.40
Phosphorus	<0.005	0.010	0.013	<0.005
Sulfur	0.008	0.012	0.011	0.010
Silicon	<0.01	0.08	0.01	<0.01
Nickel	<0.01	<0.01	<0.01	<0.01
Chromium	0.01	0.01	0.02	<0.01
Molybdenum	<0.01	<0.01	<0.01	<0.01
Copper	0.03	0.01	<0.01	0.03

The chemical composition of the material from all four sites indicates that all four samples of the fencing material analyzed were fabricated from mild steel in accordance with Standard MIL-M-17194C[1]. There are no specific chemical composition requirements in the standard. There are some minimal differences in the composition among the samples from San Ysidro, San Luis, and Nogales A, but the material from all three could be classified as either AISI 1006 or 1008 low carbon steels. The sample from El Paso differs from the others in that it is much lower in manganese content and somewhat higher in silicon content. The material from this sample could be classified as an AISI 1005 low carbon steel.

3.6 Metallographic Examination

For material from all four sites, two types of sections were examined metallographically: 1) sections through the strands parallel to the plane of the fencing and 2) sections through the strands perpendicular to both the plane of the fencing and the long diagonal of the openings. Representative fields parallel to the plane of the fencing from San Ysidro, El Paso, San Luis and Nogales A are shown in figures 5, 6, 7, and 8, respectively. In these figures, the material is shown in the as-polished condition and the direction of the long diagonal of the openings in the fencing is horizontal. These fields are away from the sheared edges of the strands. They are shown to indicate inclusion content and as an aid in determining the rolling direction of the material.

The inclusion content varies considerably among the materials from the four sites. There appear to be both sulfide and oxide type inclusions in the material from San Ysidro, San Luis and Nogales A. The material from San Ysidro (figure 5) is quite clean with few inclusions. The placement and configuration of the inclusions present indicate that the rolling direction of the material is in the direction of the long diagonal of the openings which is in accordance with Standard MIL-M-17194C. The material from El Paso (figure 6) is extremely clean with very few inclusions. In fact, there are so few inclusions that the rolling direction cannot be determined from an examination of the as-polished material. The material from San Luis (figure 7) has approximately the same inclusion concentration as the material from San Ysidro, but some of the inclusions are much larger. The configuration of the inclusions indicates that the primary rolling direction is in the direction perpendicular to the long diagonal of the openings which does not conform to specifications.

The material from Nogales A (figure 8) has a number of rather large inclusions, but the concentration appears to be no greater than that of the material from either San Ysidro or San Luis. As in the material from San Luis, the rolling direction appears to be perpendicular to the long diagonal of the openings which does not conform to specifications.

A section in the plane of the fencing was taken through one of the small pieces of material from Nogales A. An as-polished field from this section is shown in figure 9. The size of the inclusions in this field is somewhat less than that in figure 8, but it is still evident that the rolling direction is perpendicular to the long diagonal of the openings in the fencing.

As-polished fields from sections perpendicular to both the plane of the fencing and the long diagonal of the openings for material from San Luis and Nogales A are shown in figures 10 and 11, respectively. There is some evidence in figure 10 that the primary rolling direction of the material from San Luis is perpendicular to the long diagonal of the openings which is consistent with the findings shown in figure 7. Figure 11 strongly reinforces the conclusion that the rolling direction of the material from Nogales A is perpendicular to the long diagonal of the openings.

Representative etched fields parallel to the plane of the fencing from material from each of the four sites are shown in figures 12 through 16. The horizontal direction in the photographs is parallel to the long diagonal of the openings in the expanded material. The fields shown are away from the sheared edges of the strands.

There are some differences in the microstructure of the material from the various sites, and in the case of Nogales A (figures 15 and 16), there may be some differences in the microstructure of different pieces of material from the same site. In all cases, the microstructure consists primarily of ferrite with a small amount of pearlite[2]. There appears to be no directionality of the microstructure in the material from San Ysidro (figure 12), San Luis (figure 14), and Nogales A (figures 15 and 16). There is some evidence of directionality, particularly of the pearlite, in the material from El Paso (figure 13). The pearlite appears to be somewhat stretched out in the direction perpendicular to the long diagonal of the openings.

Representative etched fields from sections perpendicular both to the plane of the fencing and to the long diagonal of the openings are shown in figures 17, 18, 19, and 20 for material from San Ysidro, El Paso, San Luis, and Nogales A, respectively. The direction perpendicular to the long diagonal of the openings is horizontal in these figures. The grains in the microstructure are essentially equiaxed for the material from San Ysidro, San Luis, and Nogales, but there is a definite microstructure directionality exhibited by the material from El Paso (figure 17). There was some evidence of that directionality in figure 13. That directionality indicates that the rolling direction is perpendicular to the long diagonal of the openings which is not in accordance with specifications.

3.7 Hardness Measurements

Initially, Rockwell B (HRB) hardness measurements were made on the basis steel in sections perpendicular both to the plane of the fencing and to the long diagonal of the openings. These measurements were made about mid-thickness in the bridge areas and strand areas for material from all four sites. The average HRB results of these measurements are as follows:

	San Ysidro	El Paso	San Luis	Nogales A
Bridge	65	60	57	63
Strand	69	81	77	82

There is considerable variation among the hardness values presented above. During fabrication, the material is strain hardened by both the shearing operation and the expanding operation, and the degree of strain hardening varies, being greatest where the strain has been greatest. Because of this, the hardness of the finished product can be expected to vary considerably. Therefore, it is not surprising that there is a good deal of variation in the hardness results and that the hardness values for the strand material are consistently higher than those for the bridge material.

Rockwell 30T (HR30T) hardness measurements were made on strand sections parallel to the plane of the fencing material. Measurements were made near the center of the sections and near a sheared edge (but not in the galvanized coating). When converted to their approximate HRB equivalent hardness values, the average results of the measurements are as follows:

	San Ysidro	El Paso	San Luis	Nogales A
Center	68	63	80	81
Edge	81	84	86	86

In every case, the hardness near the edge is greater than that near the center demonstrating the effect of strain hardening due to the shearing action.

The preceding discussion indicates that regardless of the initial hardness of the sheet material before fabrication, it will harden during fabrication, and any further working after fabrication will tend to harden it further until the hardness reaches a maximum. As the hardness increases, the tensile strength also increases, but ductility decreases, and this decrease may be very significant.

3.8 Simulated Field Intrusion Test

After most of the examination had been completed, it was agreed by both Mr. Morris of the Immigration and Naturalization Service and NBS that a sample from each site would be tested to determine how difficult it would be to break through the material. A simple test was devised to simulate as nearly as possible the type of failure observed in service for the expanded metal fence, and to rank, at least qualitatively, the fencing samples from the various sites according to their breaking (mechanical) strength. This simulated field test consisted of inserting a crowbar into an opening in the expanded metal and bending the material manually until at least one strand fractured completely.

The crowbar was placed in one of the openings of a sample such that it was across the small diagonal of the opening, i.e., the crowbar was in a plane perpendicular both to the plane of the fencing and the long diagonal of the opening. Force was applied manually to the handle of the crowbar until the strand on one side of the opening was displaced approximately one strand width relative to the strand on the other side of the opening. The position of the crowbar was then reversed but kept in the same plane perpendicular to the plane of the fencing and to the long diagonal of the opening. Force was applied to the handle of the crowbar until the relative positions of the strands on either side of the opening had been reversed, i.e., the strand that had been displaced by one full strand width initially was now displaced one full strand width in the opposite direction. The above sequence was considered to be one cycle.

One test was performed on material from each site. For Nogales, the material designated sample B was used.

The results of these tests show that the sample from El Paso required 2 1/2 cycles to fail, whereas the samples from San Ysidro, San Luis, and Nogales failed after only 1 to 1 1/2 cycles. The interpretation of these results is highly subjective. However, the results do suggest that qualitatively, the material from El Paso is probably stronger and stiffer than the material from the other sites.

4. DISCUSSION

This examination was initiated because some installed fencing segments were experiencing intrusion more easily than others. This was especially true of the segment near Nogales, Arizona. A simulated field intrusion test showed that the fencing material from El Paso appeared to be more resistant to failure by intrusion than the material from San Ysidro, San Luis, and Nogales. These tests were highly qualitative and the interpretation of the results is highly subjective. More extensive and qualitative testing is required to verify these results. However, if the material from El Paso is actually significantly better in resisting failure, this improvement may be expected to result from the following differences between the material from El Paso and the material from the other sites: (1) an extremely low inclusion content, and (2) lower manganese and higher silicon content. Most of the sulfide inclusions in steel consist of manganese sulfide, and the low manganese content of the material from El Paso might help to account for the low inclusion content. The low inclusion content could contribute to improved mechanical properties, whereas the directionality exhibited by the material from El Paso, if it has any effect at all, could have a negative effect on the properties in the direction transverse to the grain orientation.

Samples from San Luis, El Paso and Nogales A fail to meet the weight per square foot requirement of Standard MIL-M-17194C, and the sample from Nogales B is marginal. These deviations from specifications are not expected to significantly affect the mechanical/structural performance of the material. The sample from San Ysidro did meet the weight per square foot requirement. It should be noted that the weight per square foot determinations were made on samples much smaller than a full sheet.

Samples from all sites meet the dimensional and galvanized coating thickness requirements of Standard MIL-M-17194C with possible exception of the marginal width of strand value for the material from El Paso.

The metallographic specimens from Nogales A exhibited the largest inclusions of all the samples examined which could have an adverse effect on mechanical properties. The metallographic examination also revealed that the primary rolling direction of the material from El Paso, San Luis and Nogales A was perpendicular to the long diagonal of the openings in the fencing which is not in accordance with Standard MIL-M-17194C. If there is any effect of directionality on mechanical properties, these properties would be expected to be greater in the rolling direction than transverse to it[3,4].

Although the chemical composition of the material from all four sites satisfies the applicable standard, the lower manganese and higher silicon content of the material from El Paso indicates that the steel making process, most likely the deoxidation procedure or casting practice, used to produce this steel was significantly different from the steel making process used to produce the materials from the other sites.

5. CONCLUSIONS

1. The sample from San Ysidro satisfies the weight per square foot requirement of Standard MIL-M-17194C.

2. The samples from San Luis, El Paso and Nogales A fail to meet the weight per square foot requirement of Standard MIL-M-17194C.

3. The weight per square foot result for the material from Nogales B indicates that the material is marginal.

4. Based on the determinations in this examination, the samples from all four sites satisfy the requirements of Standard MIL-M-17194C for nominal width of opening, width center to center of bridge, length center to center of bridge, and width of strand dimensions with the possible exception of the marginal width of strand value for the material from El Paso.

5. Materials from all four sites satisfy the requirements of MIL-M-17194C for chemical composition, although the composition of the material from El Paso is different (lower in manganese and higher in silicon) from the composition of the materials from the other sites, all of which are similar. All the material would be classified as mild steel.

6. The material from El Paso is extremely clean with almost no inclusions, whereas the materials from San Ysidro, San Luis and Nogales A all have both sulfide and oxide inclusions.

7. The microstructure of the material from all four sites consists primarily of ferrite with small amounts of pearlite.

8. The material from El Paso exhibits directionality in the microstructure in the direction perpendicular to the long diagonal of the openings in the fencing, whereas the material from the other sites exhibits no directionality and consists of essentially equiaxed grains.

9. The primary rolling direction of the material from El Paso, San Luis and Nogales A is perpendicular to the long diagonal of the openings in the fencing which is not in accordance with Standard MIL-M-17194C.

10. The rolling direction of the material from San Ysidro is parallel to the long diagonal of the openings of the fencing which is in accordance with Standard MIL-M-17194C.

11. There are no significant differences in hardness among the materials from the four sites.

12. There is a large variation in hardness (from the upper HRB 50's or low 60's up to the high HRB 80's) within any given sample. This variation reflects the differing amounts of strain hardening induced into different regions of the finished product by the shearing and expanding operations.

13. Based on the results of a simulated field intrusion test, the material from El Paso appears to withstand failure by intrusion better than the material from the other sites.

6. ACKNOWLEDGEMENT

The assistance of Leonard C. Smith in this examination is gratefully acknowledged.

7. REFERENCES

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3. Principles of Physical Metallurgy, Morton C. Smith, Harper & Brothers, 1956.

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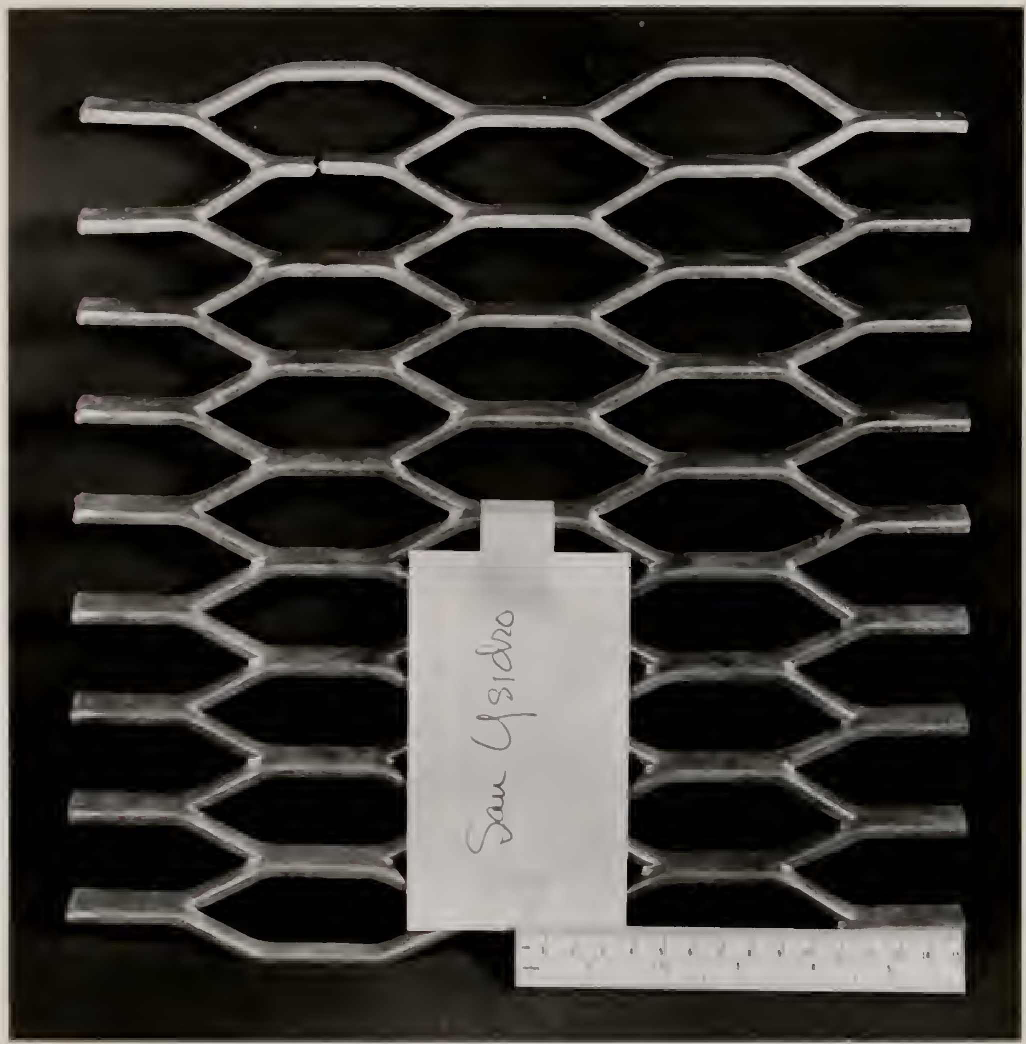

Figure 1. Galvanized expanded steel fencing sample from San Ysidro, California as received at NBS.
X 1/3

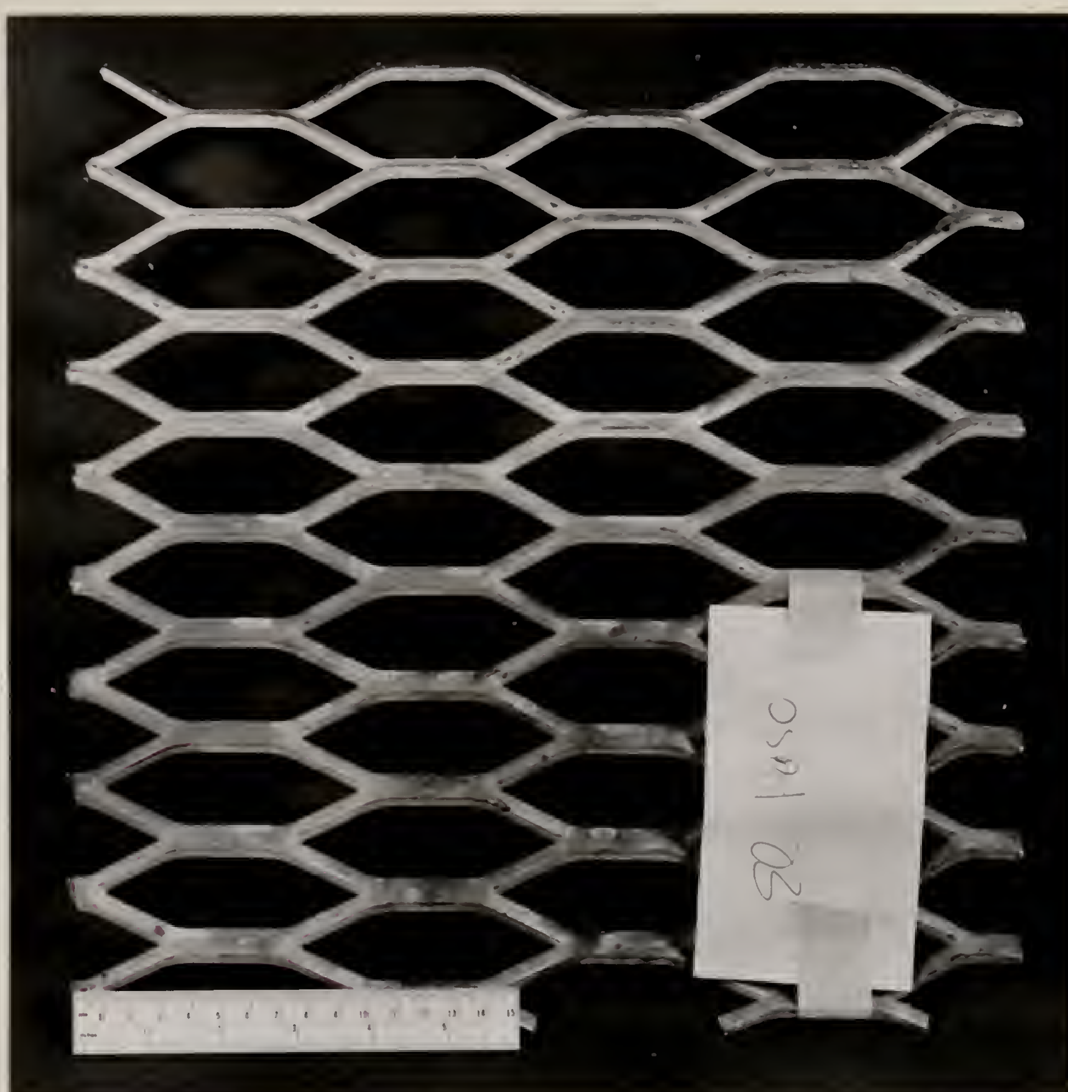

Figure 2. Galvanized expanded steel fencing sample from El Paso, Texas as received at NBS. X 1/3

Figure 3. Galvanized expanded steel fencing sample from San Luis, Arizona as received at NBS. X 1/3

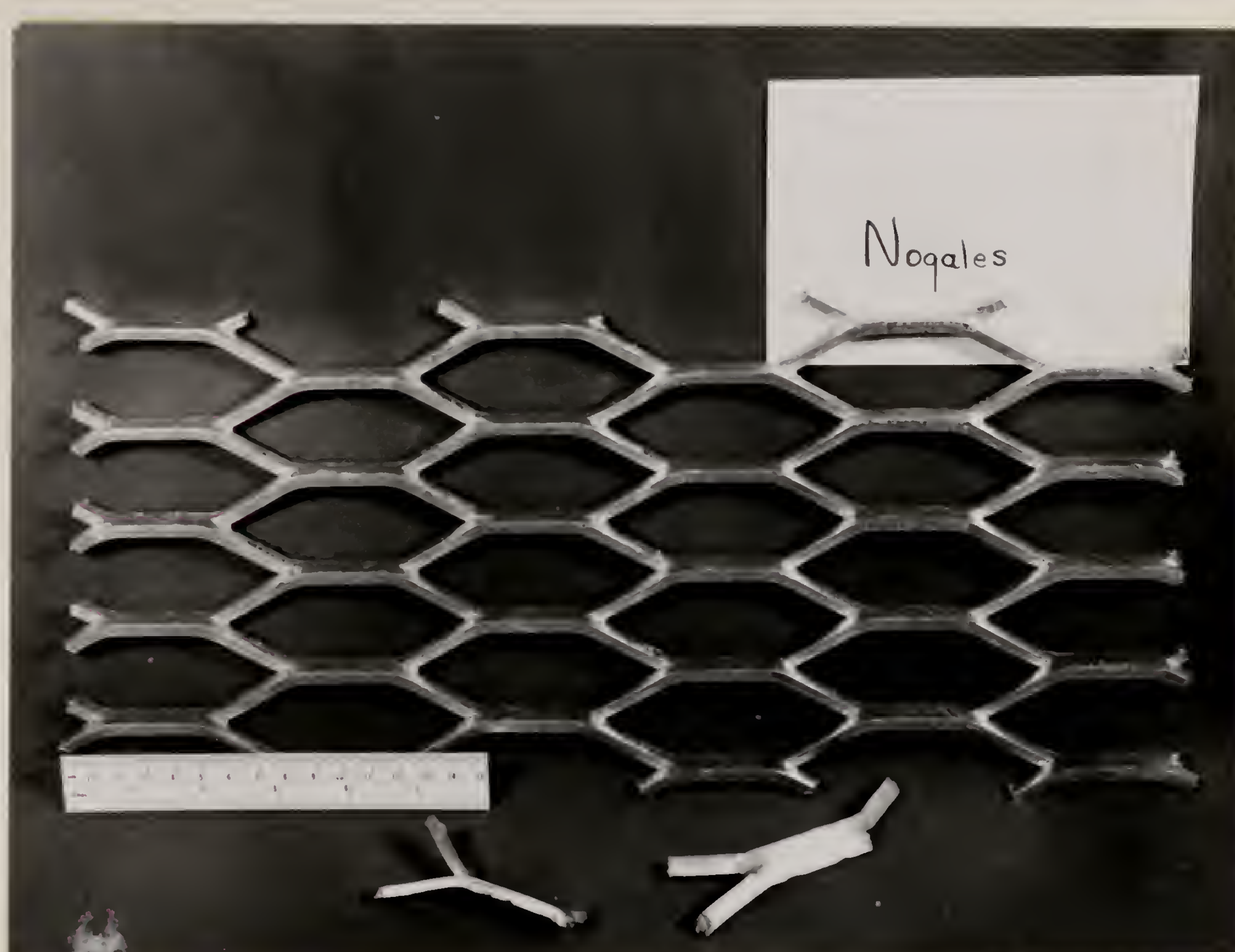

Figure 4a. Galvanized expanded steel fencing samples from Nogales, Arizona as received at NBS. The two small pieces had been fractured from the fencing before the material was submitted for examination.
X 1/3

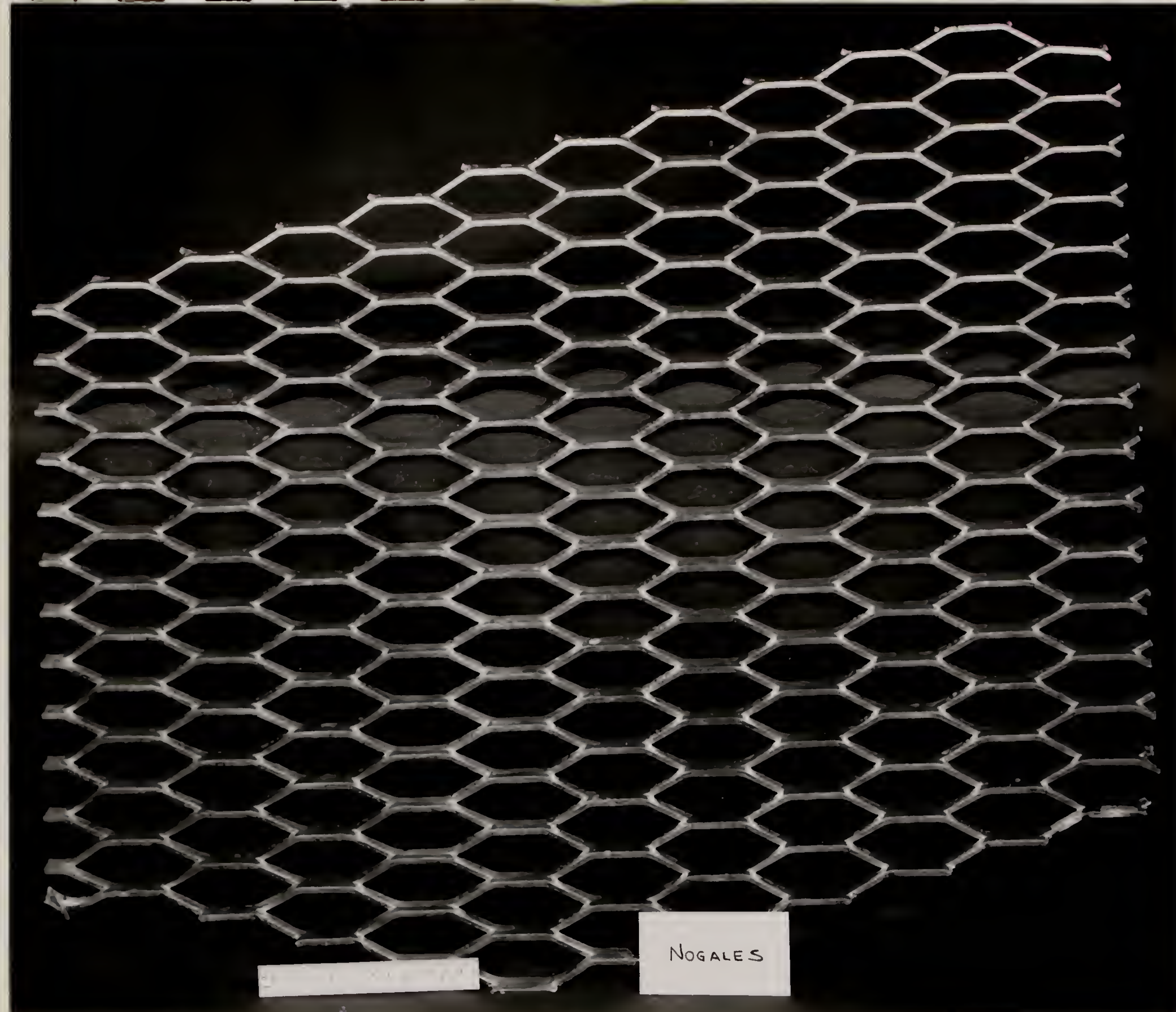

Figure 4b. Galvanized expanded steel fencing sample from Nogales, Arizona as received at NBS on March 11, 1980. X 1/4

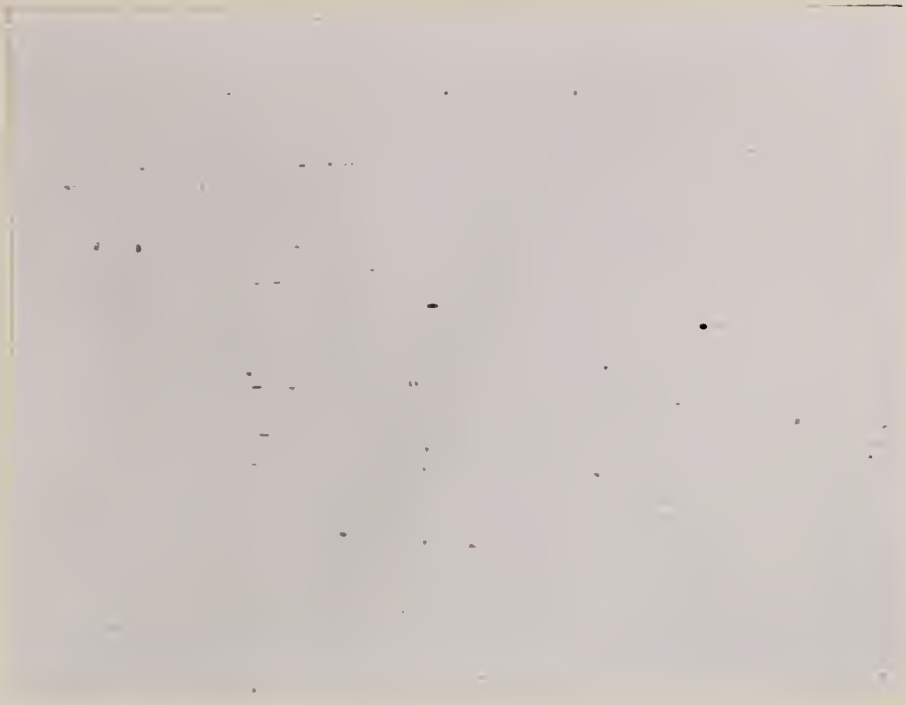

Figure 5. Unetched section parallel to the plane of the expanded steel fencing material from San Ysidro. The direction of the long diagonal of the openings in the material is horizontal. There are some sulfide and oxide inclusions. The direction of rolling is parallel to the long diagonal of the openings.
As polished X 100

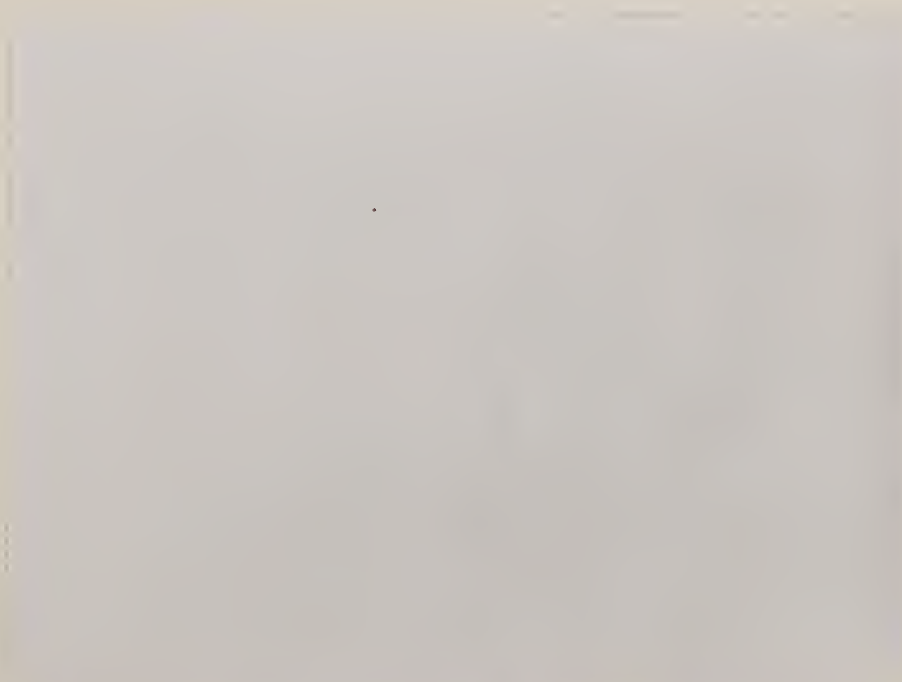

Figure 6. Unetched section parallel to the plane of the expanded steel fencing material from El Paso. The direction of the long diagonal of the openings in the material is horizontal. There are extremely few inclusions. The direction of rolling is unclear.
As polished X 100

Figure 7. Unetched section parallel to the plane of the expanded steel fencing material from San Luis. The direction of the openings in the material is horizontal. There are both sulfide and oxide inclusions present. The rolling direction is perpendicular to the direction of the long diagonal of openings.
As polished X 100

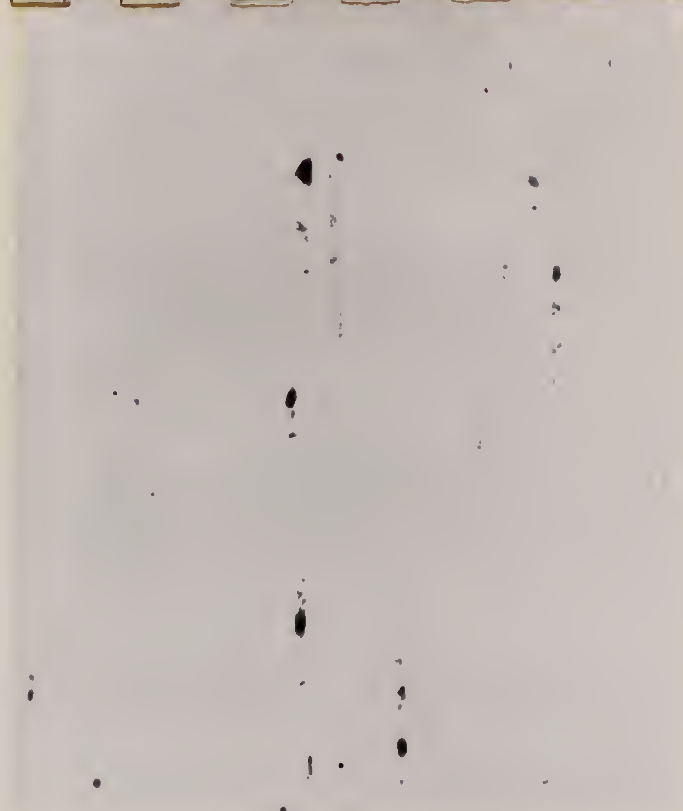

Figure 8. Unetched section parallel to the plane of the expanded steel fencing material from Nogales A. The direction of the long diagonal of the openings in the material is horizontal. There are both sulfide and oxide inclusions present. The rolling direction is perpendicular to the direction of the long diagonal of the openings.
As polished X 100

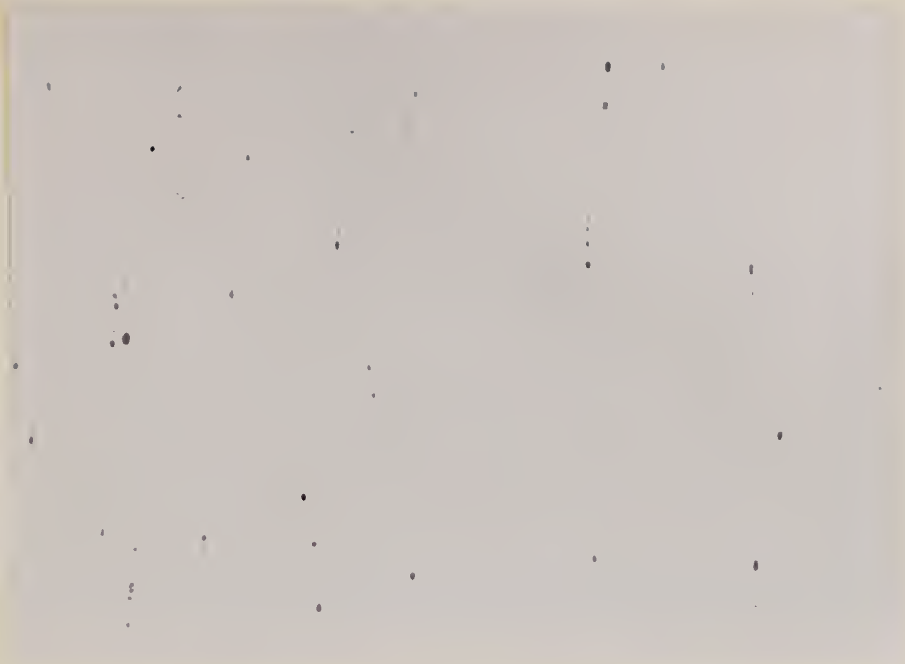

Figure 9. Unetched section parallel to the plane of the expanded steel fencing from one of the small pieces of material from Nogales A. The direction of the long diagonal of the openings in the material is horizontal. It is evident that the rolling direction is perpendicular to the direction of the long diagonal of the openings.
As polished X 100

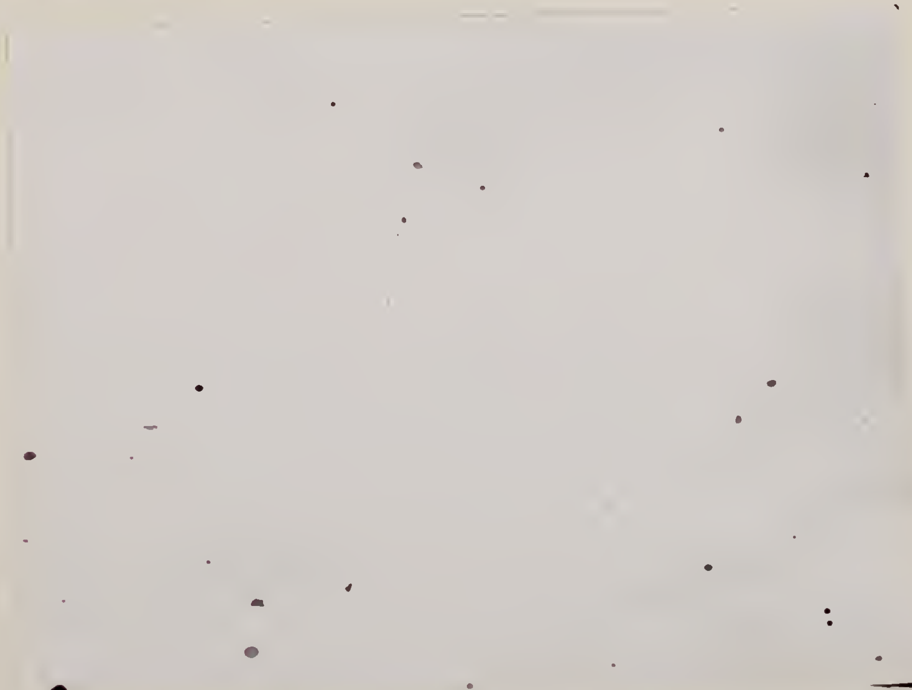

Figure 10. Unetched section through material from San Luis. This section is perpendicular to both the plane of the fencing and the long diagonal of the openings in the material. The direction of the short diagonal of the openings is horizontal. There is some evidence that the rolling direction is perpendicular to the long diagonal of the openings.
As polished X 100

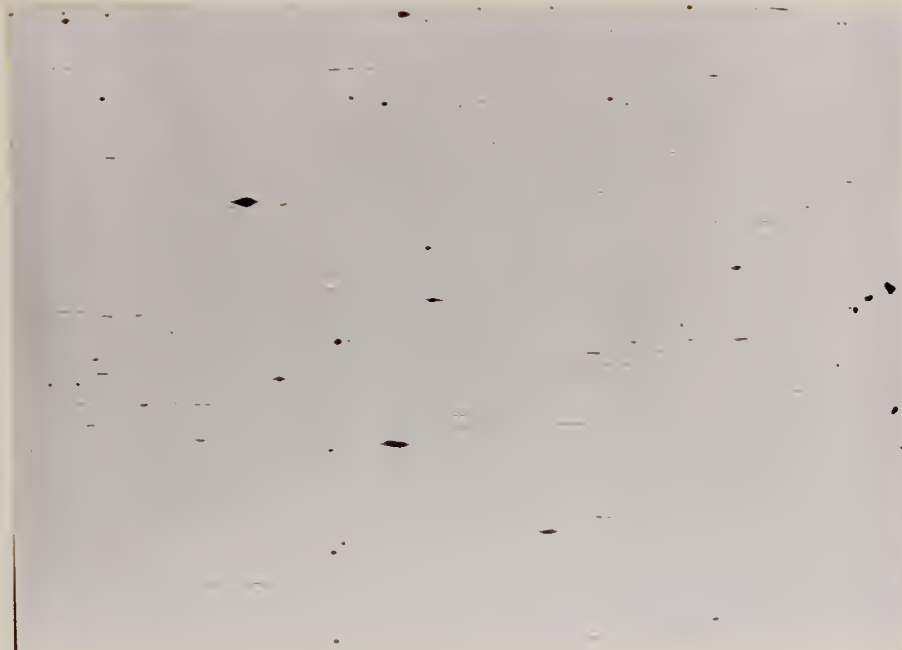

Figure 11. Unetched section through material from Nogales A. This section is perpendicular to both the plane of the fencing and the long diagonal of the openings in the material. The direction of the short diagonal of the openings in the material is horizontal. The rolling direction is perpendicular to the long diagonal of the openings.
As polished X 100

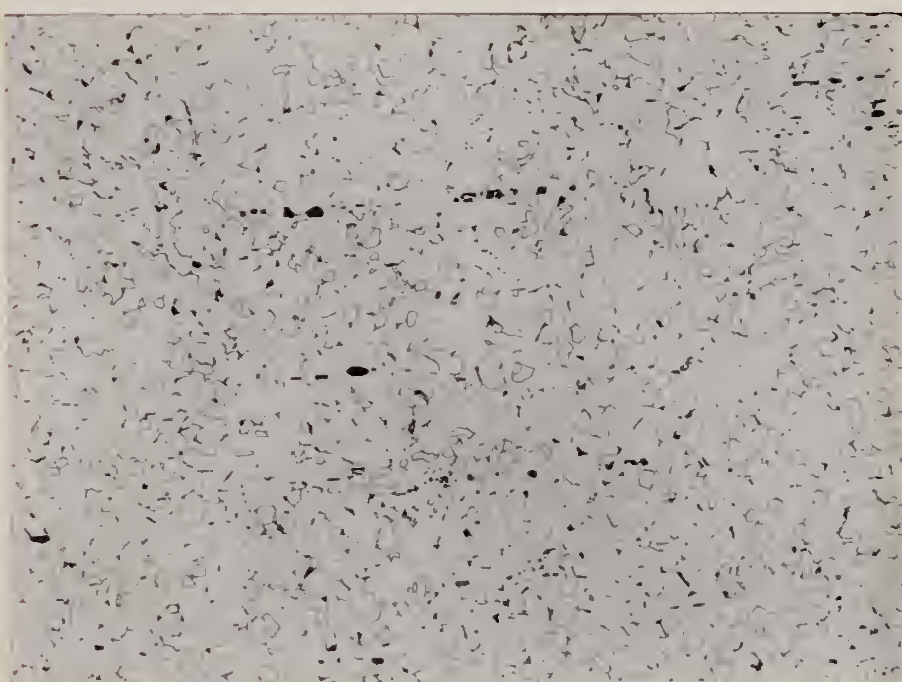

Figure 12. Etched section parallel to the plane of the expanded steel fencing material from San Ysidro. The direction of the long diagonal of the openings is horizontal. The microstructure consists essentially of equiaxed grains of ferrite and a very small amount of pearlite.
Etchant: 1% nital X 100

Figure 13. Etched section parallel to the plane of the expanded steel fencing material from El Paso. The direction of the long diagonal of the openings in the material is horizontal. The microstructure consists essentially of equiaxed grains of ferrite and some pearlite (dark patches). There appears to be some directionality in the pearlite patches which is perpendicular to the long diagonal of the openings. This indicates that the rolling direction was probably perpendicular to the long diagonal of the openings.
Etchant: 1% nital X 100

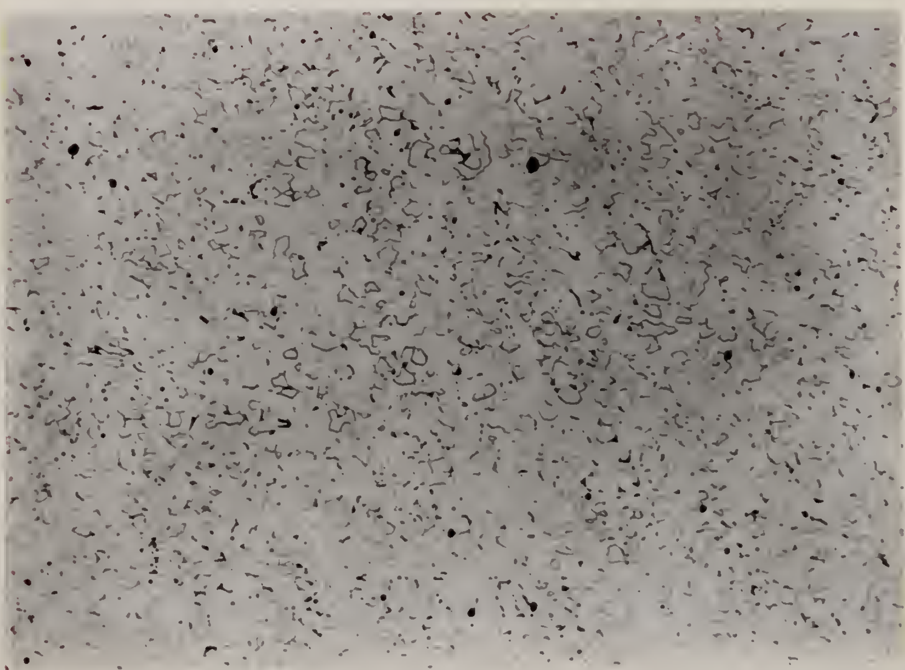

Figure 14. Etched section parallel to the plane of the expanded steel fencing material from San Luis. The direction of the long diagonal of the openings in the material is horizontal. The microstructure consists essentially of equiaxed grains of ferrite and a very small amount of pearlite.
Etchant: 1% nital X 100

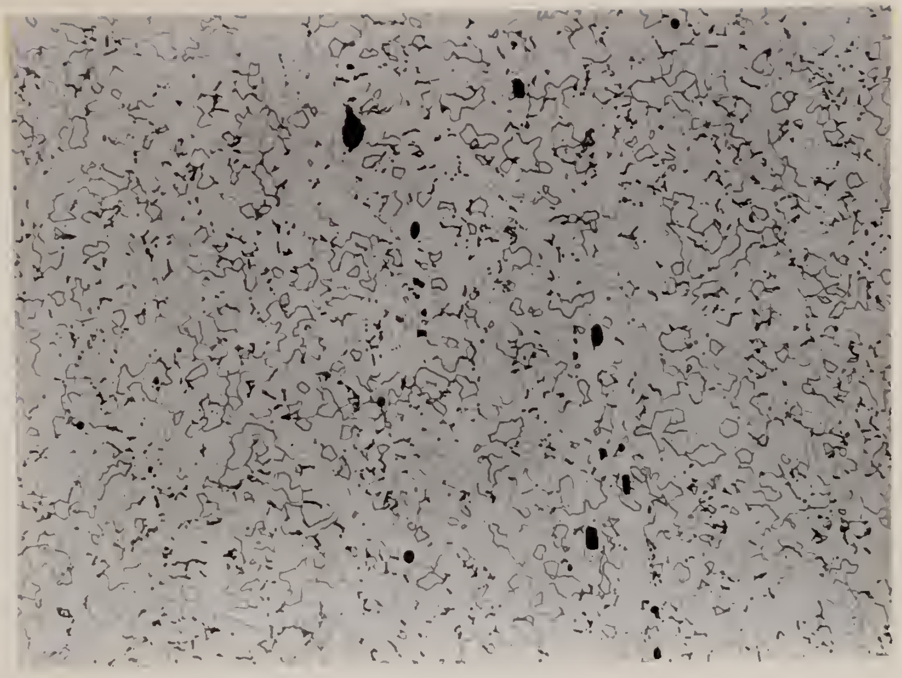

Figure 15. Etched section parallel to the plane of the expanded steel fencing material from Nogales A. The direction of the long diagonal of the openings in the material is horizontal. The microstructure consists essentially of equiaxed grains of ferrite and a small amount of pearlite.
Etchant: 1% nital X 100

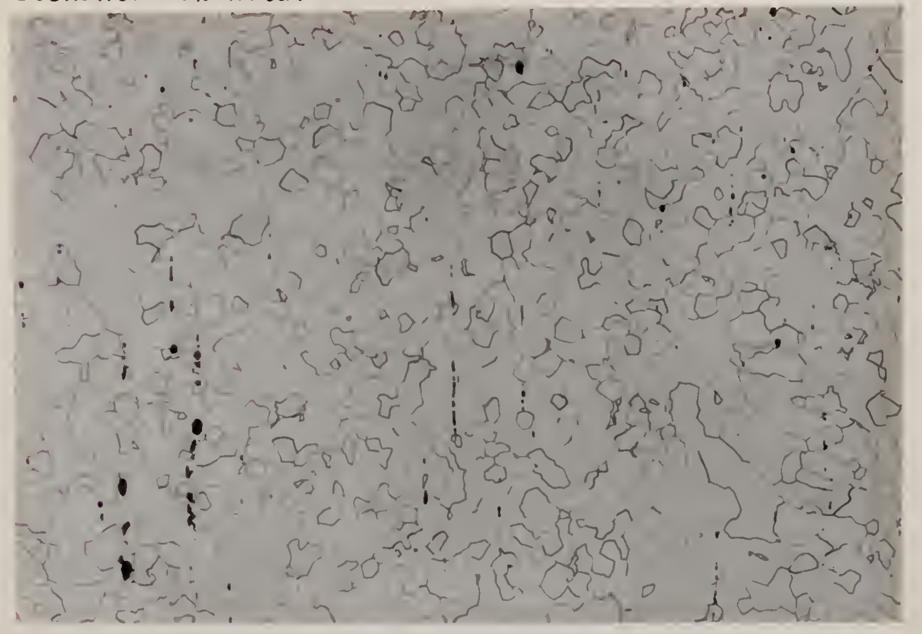

Figure 16. Etched section parallel to the plane of the expanded steel fencing from one of the small pieces of material from Nogales. The direction of the long diagonal of the openings in the material is horizontal. The microstructure consists of ferrite with essentially no pearlite. The grain size is somewhat greater than that of the field shown in figure 15.
Etchant: 1% nital X 100

Figure 17. Etched section through material from San Ysidro. This section is perpendicular to both the plane of the fencing and the long diagonal of the openings in the material. The direction of the <u>short</u> diagonal of the openings is <u>horizontal</u>. As in the section shown in figure 12, the microstructure consists essentially of equiaxed grains of ferrite with some pearlite.
Etchant: 1% nital X 100

Figure 18. Etched section through material from El Paso. This section is perpendicular both to the plane of the fencing and the long diagonal of the openings in the material. The direction of the <u>short</u> diagonal of the openings in the material is horizontal. The microstructure consists of ferrite and pearlite, and there is definite directionality that indicates that the rolling direction is perpendicular to the direction of the long diagonal of the openings.
Etchant: 1% nital X 100

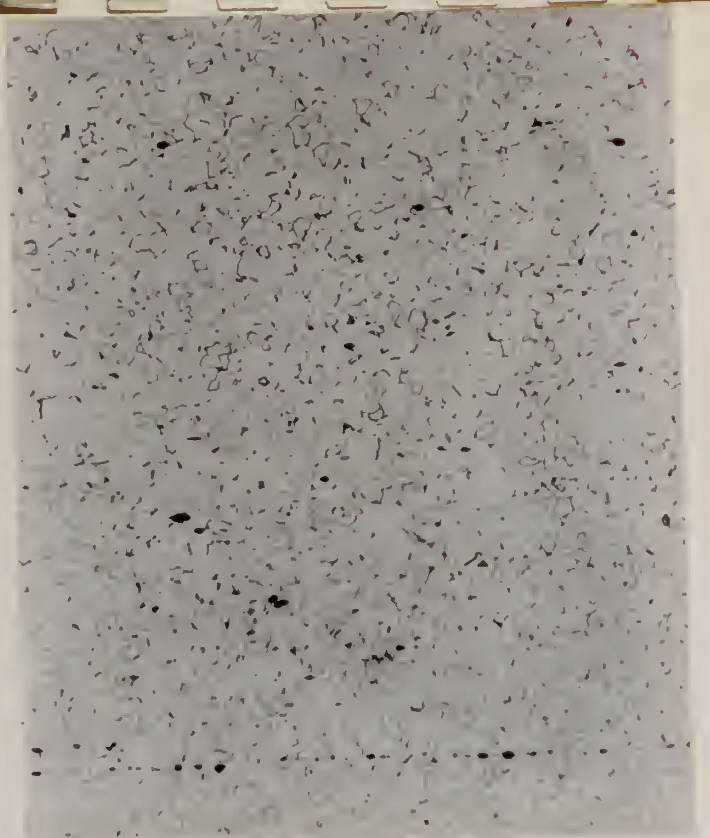

Figure 19. Etched section through material from San Luis. This section is perpendicular both to the plane of the fencing and the long diagonal of the openings in the material. The direction of the short diagonal of the openings in the material is horizontal. As in the section shown in figure 14, the microstructure consists essentially of equiaxed grains of ferrite and some pearlite.
Etchant: 1% nital X 100

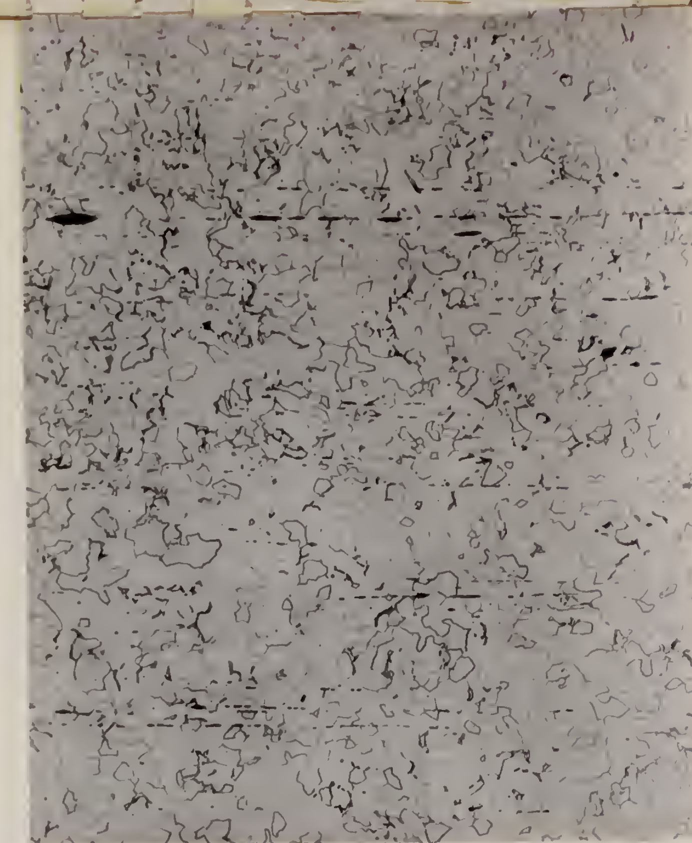

Figure 20. Etched section through material from Nogales A. This section is perpendicular both to the plane of the fencing and the long diagonal of the openings in the material. The direction of the short diagonal of the openings is horizontal. The microstructure consists of ferrite with a very small amount of pearlite.
Etchant: 1% nital X 100

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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.)*

Samples of galvanized expanded steel fencing from four sites along the United States-Mexico border were characterized. The sites were San Ysidro, California, El Paso, Texas, San Luis, Arizona and Nogales, Arizona. Properties were compared to the specifications in Military Standard MIL-M-17194C. Samples from El Paso, San Luis and Nogales failed to meet the weight per square foot requirement, and the rolling direction of these samples was not in accordance with specifications. All samples met dimensional and coating thickness requirements, and all were fabricated from mild steel as called for in the specification. The material from El Paso had extremely few inclusions compared to the materials from the other sites. In a simple mechanical test that attempts to simulate field failure, the fencing material from El Paso appeared to offer greater resistance to intrusion than the materials from the other sites.

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)*

Expanded steel; fencing; galvanized expanded steel; microstructure directionality; mild steel

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