SSC-84

AN APPRAISAL OF THE PROPERTIES AND METHODS OF PRODUCTION OF LAMINATED OR COMPOSITE SHIP STEEL PLATE

Prepared by the

COMMITTEE ON SHIP STEEL

National Academy of Sciences - National Research Council

SHIP STRUCTURE COMMITTEE

SHIP STRUCTURE COMMITTEE

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ADDRESS CORRESPONDENCE TO:

SECRETARY
SHIP STRUCTURE COMMITTEE
U. S. COAST GUARD HEADQUARTERS
WASHINGTON 25, D. C.

January 12, 1956

Dear Sir:

Early in 1953 proposals having to do with the improvement of the notch toughness of ship steel by suitable variations in the texture of the plate were presented before the Committee on Ship Structural Design of the National Academy of Sciences-National Research Council. Following discussion, the Committee on Ship Structural Design recommended that studies be undertaken to evaluate the ability of such materials to inhibit brittle crack initiation and propagation. This recommendation was concurred in by the Ship Structure Committee.

Since the proposals involved mainly metallurgical problems, they were referred to the Committee on Ship Steel of the National Academy of Sciences-National Research Council. The available information on the subject was collected and summarized under the direction of this Committee, and a report prepared discussing technical and economic factors governing the use and production of these materials.

Herewith is a copy of this report entitled "An Appraisal of the Properties and Methods of Production of Laminated or Composite Ship Steel Plate". The conclusions and opinions stated herein regarding the feasibility of the suggestions presented before the Committee on Ship Structural Design have been unanimously approved by the Committee on Ship Steel. The report is being distributed to those individuals and agencies associated with and interested in the work of the Ship Structure Committee.

Sincerely yours,

K K Cowart

K. K. COWART
Rear Admiral, U. S. Coast Guard
Chairman, Ship Structure
Committee

Serial No. SSC-84

Special Report
to the
SHIP STRUCTURE COMMITTEE

on

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COMMITTEE ON SHIP STEEL

Division of Engineering and Industrial Research
National Academy of Sciences-National Research Council

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INTRODUCTION

At its second meeting, held in January of 1953, the Committee on Ship Structural Design of the National Academy of Sciences-National Research Council discussed at some length the proposition that by suitable adjustments to its texture ship plate might be endowed with properties making it more resistant to the initiation and/or propagation of brittle fractures(1). Three specific proposals were developed and were subsequently discussed before the Ship Structure Subcommittee(2) (see appendix B):

1. Inhibit crack initiation by the use of plates containing layers of weakness parallel to the plate surfaces.
2. Deter crack propagation by means of plates containing layers of notch tough material.
3. Arrest brittle cracks through the use of plates within which rods of notch tough material are incorporated at their edges parallel to the maximum tensile stress.

The Committee on Ship Structural Design recommended that laboratory study of materials such as those described above be undertaken to evaluate the extent of their ability to inhibit crack initiation or propagation, as the case might be. This recommendation was made in full recognition of the changes in design practice and fabrication procedure which might be necessary if such materials were used, and with the realization that for some of the materials suitable production procedures did not exist(1).

Since the problem was primarily metallurgical in nature, the Committee on Ship Structural Design requested the sister Committee on Ship Steel to undertake preliminary investigations(1). Accordingly, the Committee on Ship Steel discussed the matter at its next meeting in October of 1953 and, after extended consideration of these suggestions, concluded that an appreciable amount of research work had already been performed on materials such as those proposed. It therefore recommended that the presently available information be collected and analyzed prior to discussion relating to initiation of experimental work(3).

Appendix A to this report represents the "collection and analysis" recommended by the Committee on Ship Steel. Based on the technical data contained therein and on economic considerations, the committee has developed this report as its considered opinion on the use in the construction of ships of materials identical or similar to those described briefly above and in more detail in appendices A and B.

DISCUSSION

It is the purpose of this section to present the views of the Committee on Ship Steel on the technical and economic feasibility of incorporating materials of the type described above and in appendix B into the hull structure of ships, with the expectation that such materials might inhibit crack initiation and/or brittle crack propagation. The discussion will be divided into three parts, coinciding with the three general types of material under consideration.

Plates containing layers of weakness parallel to the plate surface. As pointed out in appendices A and B, the effectiveness of this material in inhibiting crack initiation was postulated to be a result of the inability of such materials to develop the triaxial stress component in the thickness direction, which is felt to be necessary for brittle crack initiation.

The data presented in appendix A show that laminations or inclusions in steel plate, while they may increase energy absorption in Charpy V-notch tests in the upper part of the transition range, have little or no effect on Charpy V-notch test results at energy levels in the 0 to 20 ft-lb range. Extensive studies at the National Bureau of Standards on steel from fractured ships have shown that for the type of steel under investigation (0.25C, 0.45Mn) brittle cracks have not initiated when the steel absorbed more than 10 ft-lb in the Charpy V-notch test at the temperature of ship failure. Therefore, it can be concluded that layers of weakness in the thickness direction would not be effective in inhibiting the initiation of brittle cracks in ships.

Plates containing layers (in the thickness direction) of notch tough material. This proposal is predicated on the well-established effectiveness of even very thin layers of ductile material in inhibiting brittle crack propagation and possibly in arresting the progress of an incipient crack. For purposes of discussion, this proposition can, on the basis of both technical and economic considerations, be reduced to the case of a mild steel plate, clad on either one or both sides with a layer of more notch tough material.

The data presented in appendix A illustrate the effectiveness of welded and commercial notch tough austenitic stainless steel cladding (on one side only) in decreasing transition temperature. Further, the data show the added effectiveness of the cladding as its thickness is increased.

The primary mitigating factor to the extensive use of austenitic clad steels in shipbuilding would be the high cost and limited production facilities for such materials. The current price of mild steels clad with 18-8 stainless steel (10% of total thickness) ranges from 6 to 8 times the cost of current semikilled ship plate. In addition, complicated and costly welding procedures would have to be adopted. Since both the necessary welding electrodes and the cladding material would require strategically critical elements, the continued availability of such composite steels in the event of mobilization could not be assured.

It should be pointed out that a potentially successful alternative to austenitic cladding might be the use of available notch tough ferritic materials as cladding. This would lower the cost of the clad and reduce the need for critical materials, but the cost increase resulting from the cladding process itself could not be avoided.

It is the opinion of the Committee on Ship Steel that, with currently available facilities, homogenous ferritic materials possessing sufficient notch toughness could be produced at much lower cost than that of clad materials.

A means of achieving notch tough surface layers in steel plate might be through decarburization of the surface. All rimming steels have decarburized surfaces to a limited extent. It might, therefore, be possible to exaggerate this decarburization through revision of rimmed steel ingot practice, but such a procedure would increase the segregation of carbon and sulfur in the center of the thickness of the plate and would tend to increase the ferrite grain size of the rim. The segregation of carbon would result in increased transition temperature of the core; the sulfur concentration would result in cracking during welding, and the increased ferrite grain size of the rim would tend to increase transition temperature. A further improvement in the general level of notch toughness of rimmed steels would result from increasing the manganese content of these steels beyond the levels available in current rimmed steels produced in this country. The increase in manganese would reduce the thickness of the low carbon rim, however, and would result in poor plate surface.

Even though a casting process (in which either the cladding or the base metal is cast around or within the other component) would appear to hold promise with regard to the production of appreciable quantities of clad ship plate, it is not likely that materials made by such a method could ever compete on a price basis with currently available homogenous notch tough steels. While very small ingots of composite materials have been prepared commercially, casting problems, low product yield, and discontinuous processing would place a severe strain on available facilities, particularly in a time of emergency.

Plates containing rods of notch tough material at their edges. There is no known means for effectively achieving this composite structure as it is described in appendix B. However, a logical extension of the idea is the use of notch tough beads in the seam (longitudinal) welds in ships (to act as crack arrestors) or, going one step further, and using a steel of superior notch toughness either in critical sections to allay incipient cracks or to act as a crack arrestor.

The effectiveness of weld beads and notch tough plating in arresting cracks is being studied under Ship Structure Committee Project SR-134 at the University of Illinois. Several comments on these methods seem pertinent, however.

The use of a notch tough weld deposit in the seams of ships will in all probability have a dual effect. These welds, besides having a good chance of being effective as crack arrestors, would undoubtedly reduce the incidence of crack initiation observed at poor welds in ships. This follows from the experience obtained with such weld metals--even though more difficult to apply, the resulting joint has a high level of integrity. In time of mobilization, however, such weld rods have the disadvantage of requiring extra skill on the part of the welder, which may not then be available to the necessary extent, and the austenitic electrodes (at least) contain critical materials.

SUMMARY

Based upon the technical and economic considerations discussed above and in appendix A, the conclusions and opinions of the Committee on Ship Steel with regard to the use of laminated or composite steels in ships can be summarized as follows:

1. The available data indicate that plates containing layers of weakness in the thickness direction are no more effective in inhibiting crack initiation than similar homogenous materials.
2. Mild steels clad with notch tough surface layers on one or both sides have lower transition temperatures than the unclad base material, but clad materials are expensive to produce and frequently require the use of strategically critical materials. Moreover, there are homogenous steels of sufficient

notch toughness available that can be produced on a tonnage basis at a much lower cost than clad steels.

3. Considerable promise in inhibiting crack initiation or propagation has been shown in preliminary tests of properly applied notch tough weld beads and strakes of notch tough plating. Further exploration of these possibilities is currently underway.

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REFERENCES

1. Minutes 3rd meeting Committee on Ship Structural Design, January 21 and 22, 1953, paragraphs 12 and 13-e.
2. Minutes 46th meeting Ship Structure Subcommittee, February 25, 1953, paragraphs 4, 5, 9 and 13 and Enclosure A.
3. Minutes 12th meeting Committee on Ship Steel, October 1, 1953, paragraph 7.

APPENDIX A

THE EFFECT OF VARIATIONS IN TEXTURE ON ENERGY ABSORPTION AND TRANSITION TEMPERATURE

by

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SUMMARY

It has been suggested (See Appendix B of this report) that notch tough carbon steel plate for ships could be made cheaply by using (a) plates containing layers of weakness, (b) plates containing lamellae of highly notch tough material and (c) plates with rods of tough material inserted near the edges. These suggestions are discussed herein and evaluated on the basis of existing information.

It has been concluded that plates containing planes of weakness would not be particularly beneficial in ship construction. However, plates containing notch tough lamellae or cladded plates and plates with tough rods inserted near their edges may be useful. The use of plates with rods of tough material (or some variation thereof) appears most promising.

INTRODUCTION

An extensive amount of research has been and is being conducted for the purpose of providing cheaper notch tough carbon steel plate for ship construction. Appendix B suggests that cheap notch tough material could be produced by endowing it with a suitable texture.

One means of accomplishing this is to make plates having planes of weakness parallel to the plate surfaces. An example of such material is wrought iron. In such plates the initiation of brittle fracture should be difficult. Although plates containing layers of weakness may inhibit the initiation of brittle cracks, there is doubt as to whether such material could stop a rapidly-running brittle fracture.

In addition, Appendix B postulates that the stress necessary for brittle crack propagation is a function of the work of fracturing. By making steel plates with layers of more notch tough material, the work of fracturing should be increased to prevent the propagation of rapidly-running brittle fractures.

It has also been proposed that rapidly-running brittle fractures may be stopped by incorporating notch tough rods within the steel plates near the edges and parallel to the direction of maximum tension.

Thus, three new methods for producing ship steel plate resistant to crack initiation and propagation have been proposed. These are

1. Plates containing layers of weakness parallel to the plate surfaces (to inhibit crack initiation).
2. Plates containing layers of notch tough material. (to inhibit brittle crack propagation).
3. Plates within which rods of notch tough material are incorporated at their edges parallel to the maximum tensile stress. (to stop brittle cracks).

It is the purpose of this study to evaluate existing data and to determine if the above suggestions can be substantiated by previous research.

DISCUSSION

1. Plates containing layers of weakness.

The term laminated plate has been used to denote several different things. It has been used to denote banding, "a segregated structure of nearly parallel bands aligned in the direction of working", in steel(1). Others have used it to indicate the presence of inclusions, either of slag or sulfides. In other cases it is not clear what was meant. The laminated plates which have been advocated and are here being discussed, are plates having planes of weakness parallel to the plate surface.

It has been postulated that before a crack can develop into a rapidly-running brittle fracture in carbon steel plate, triaxial stresses must be built up at the end of a crack. If this is not possible, due say to the presence of planes of weakness (laminations) parallel to the plate surface, rapidly-running brittle fractures cannot develop.

Earlier investigations(2,3) have indicated that under conditions of static loading the capacity of steel specimens to absorb energy is generally increased when laminations open up during fracture (fissuring).

It has been determined that the steel plates in which brittle ship fractures originated absorbed 10 ft-lbs or less in the Charpy V-notch test at the temperature at which the ship failed(4). Thus, based on this study, if fracture initiation is to be inhibited by introducing planes of weakness, these planes must manifest themselves by lowering the temperature at which steel absorbs say 10 ft-lbs in the Charpy V-notch test.

Charpy V-notch tests of laminated and unlaminated steel(5)* have shown that the laminated fractures absorbed more energy than the normal type of fracture. These data are shown in Fig. 1. Several comments seem pertinent in considering the evidence presented in this chart. The only specimens showing laminations on the fractured surfaces were those that absorbed more than 60 ft-lbs at rupture. That is, only tough specimens disclosed the presence of planes of weakness. While all specimens were presumed to have had identical microstructures, this point was not established by metallographic studies. Nevertheless it is at least possible to conclude that the ductile fractures made the laminations visible rather than to conclude that the presence of the laminations in certain specimens made them tough. Other investigators, particularly Soete,(7) prefer the latter interpretation. Soete states that laminated plates are more resistant to brittle fracture than sound plates but presents no data to support this opinion.

Fig. 1 shows that one of three specimens tested at 10°F gave a Charpy value of less than 20 ft-lbs, a value that might be used to define transition temperature. Only one of 15 specimens tested at

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*0.21% C, 0.47% Mn, 0.012% P, 0.033% S, semi-killed steel.

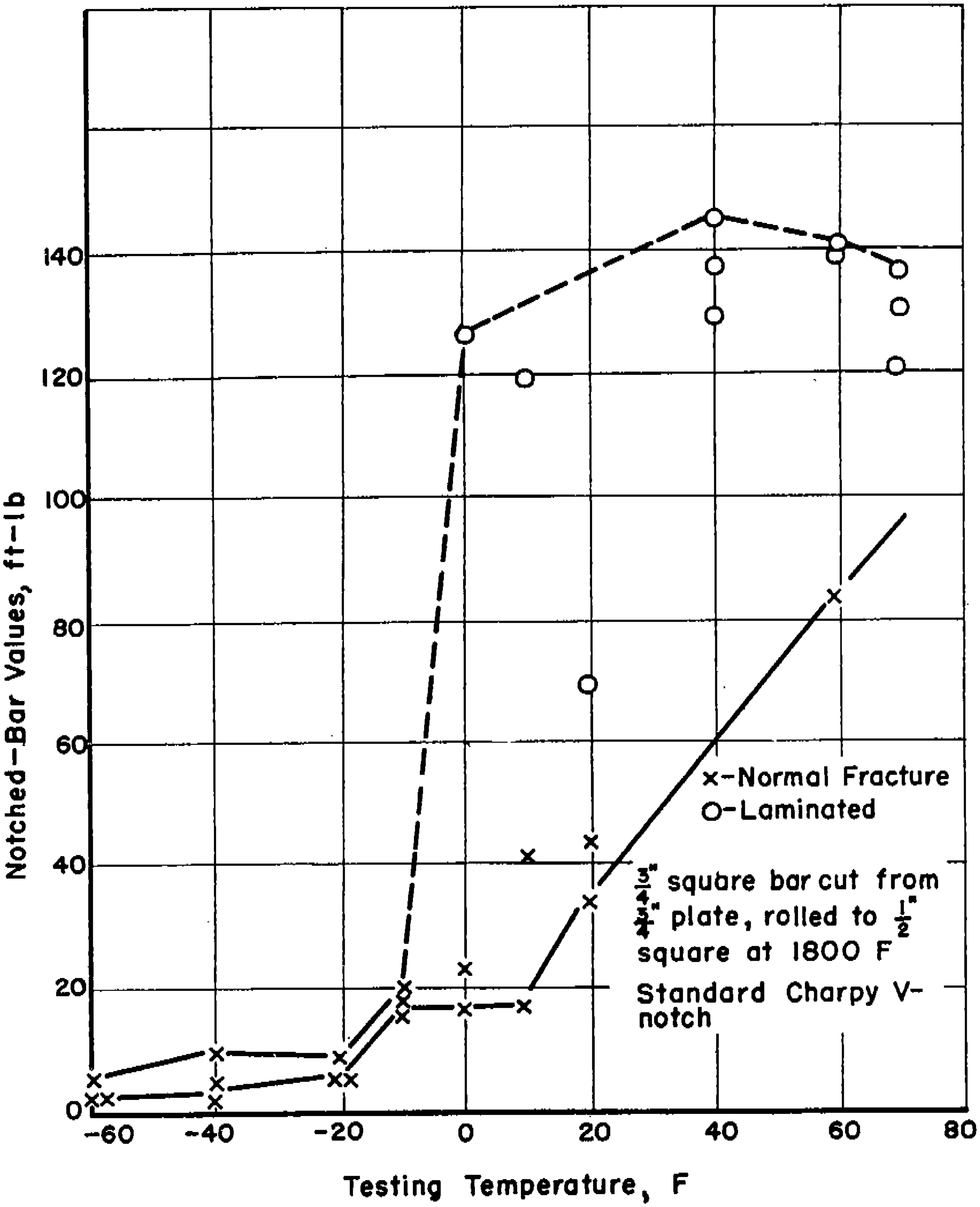

FIGURE I. EFFECT OF LAMINATED FRACTURE ON ENERGY ABSORPTION
(Reference 5)

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lower temperatures had a laminated fracture. This suggests that the development of the laminations increased the scatter in the transition shown but did not change the transition temperature or the energy values at the lowest temperatures. Otherwise it must be assumed that the samples capable of developing laminations were not uniformly distributed among the subgroups. This seems unlikely since samples having different microstructures could hardly have been so nonuniformly distributed as to account for laminations appearing in only one of 15 tests below 10°F and in 9 out of 12 tests at higher temperatures.

Table 1 presents some data(6) obtained on four plates produced from one commercial ingot. Steel rolled from the bottom cut of the ingot contained an inordinate quantity of unusually large silicate inclusions. The plate from the top cut was relatively free of inclusions; those from the second and third cuts contained intermediate amounts of nonmetallics. Most of the specimens from the bottom cut were laminated. Tests at 75°F showed that the inclusions raised the V-notch Charpy values of specimens notched parallel to the plate surface. The inclusions and laminations had little if any effect on the Charpy value of bars notched perpendicular to the plate surface. None of the specimens exhibited brittle fractures because they were tested above the transition temperature of this steel. These data disagree with some information published on the subject. That is, even though the laminations opened up enough to

TABLE 1. INFLUENCE OF LAMINATIONS ON V-NOTCH CHARPY VALUES OF STEEL SPECIMENS TESTED AT 75 F$^{(A)}$ (Reference 6)

Specimen Orientation	Notch Orientation	Charpy Values, ft-lb for Plates From Ingot Position Indicated			
		Top Cut	Cut No. 2	Cut No. 3	Bottom Cut
Parallel to rolling direction	Parallel to plate surface	46/61	57/72	56/94*	102*/108*
	Perpendicular to plate surface	31/39	41/52	66/70	52*/57*
Perpendicular to rolling direction	Parallel to plate surface	25/31	27/38	35/109*	72*/127*
	Perpendicular to plate surface	24/35	34/36	31*/36	30*/37*

* Fractures showed presence of laminations.

(A) The steel contained 0.15 per cent C, 0.77 per cent Mn, 0.93 per cent Si, 0.09 per cent Zr and was tested in the hot rolled condition. All plates came from the same ingot. Samples from the top cut had a 10-ft-lb transition temperature of -30 F. Values given in the table are the extremes for tests on four specimens.

show on the fractured surfaces, they did not increase the Charpy values of samples notched perpendicular to the plate surface. Most other published information shows a direct correlation between higher energy values and the presence of visible laminations on fractured surfaces.

Limited experimental work has been conducted on plates especially produced to provide planes of weakness parallel to the plate surfaces. Two such plates have been studied.

One plate (B876) was made by casting steel in nine layers in a mold 24 inches long, 6 inches wide, and 8 inches high. A delay of approximately 30 seconds occurred between pouring each layer. This permitted the cast surface to form an oxide scale which was expected to form laminations in the final product.

The liquid steel used for this ingot, B876, contained 0.25% C, 0.41% Mn, 0.04% Si, 0.014% P, 0.033% S and 0.004% N. Because it was a semikilled steel, some of the carbon reacted with oxygen to form the blowholes shown in Figure 2. This is a photograph of one side of a slice cut from one end of the ingot. Figure 3 shows the end of the ingot when it was removed from the mold. It is obvious from the photograph that this ingot was poured in nine layers. This ingot was rolled to 3/4-inch plate using a finishing temperature of 1850 F.

Figure 4 compares the appearance of etched sections of slabs from the layered ingot and from a regular laboratory ingot (B803).

FIGURE 2. CROSS SECTION OF INGOT B867, WHICH WAS POURED IN NINE HORIZONTAL LAYERS, INDICATING GAS WAS EVOLVED DURING FREEZING

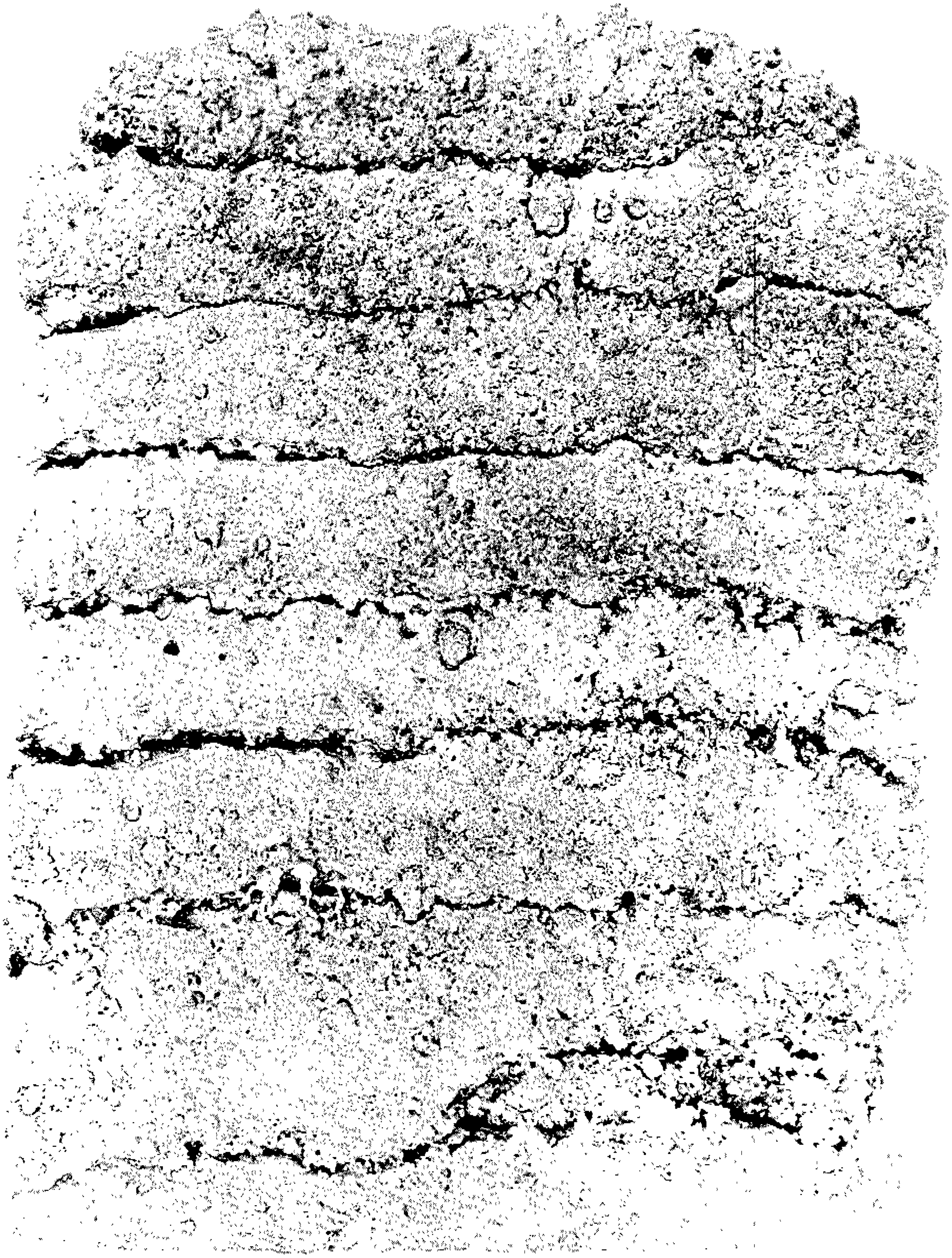


FIGURE 3. ONE END OF INGOT B867 WHICH WAS POURED IN NINE HORIZONTAL LAYERS

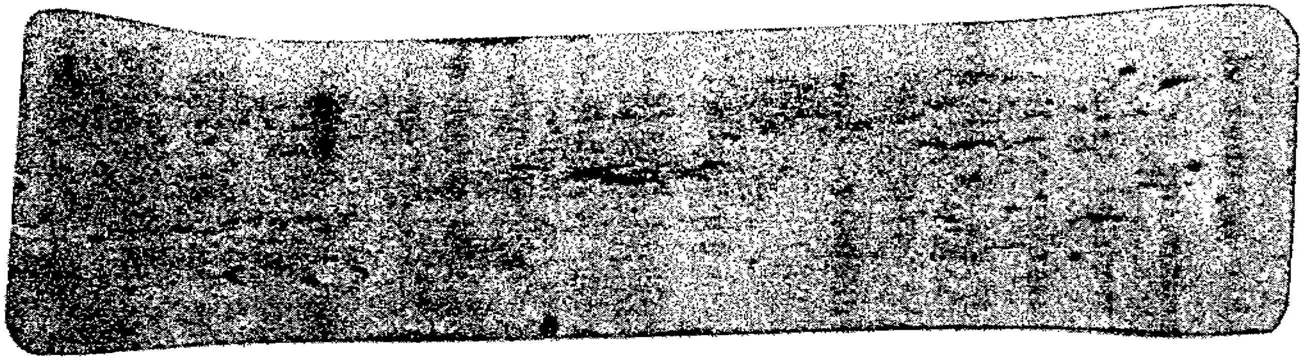


Plate B803 From Ingot Processed by Regular Method

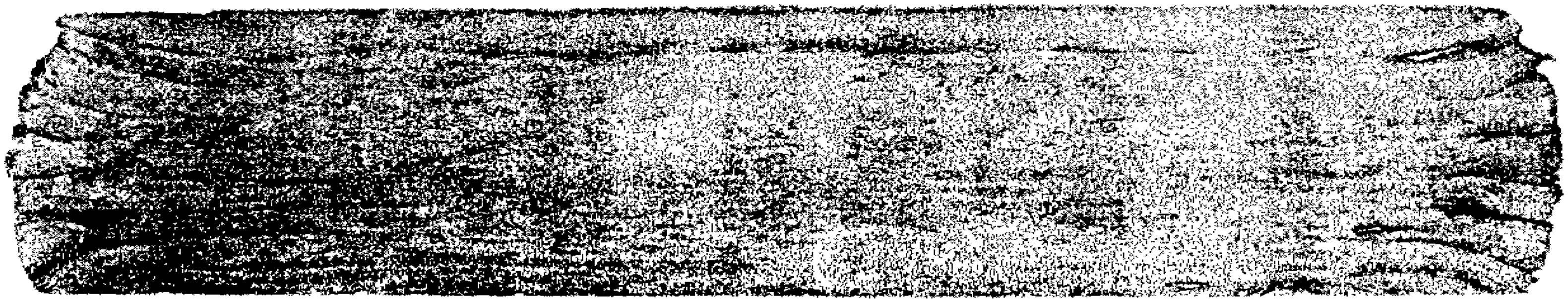


Plate B876 From Layered Ingot

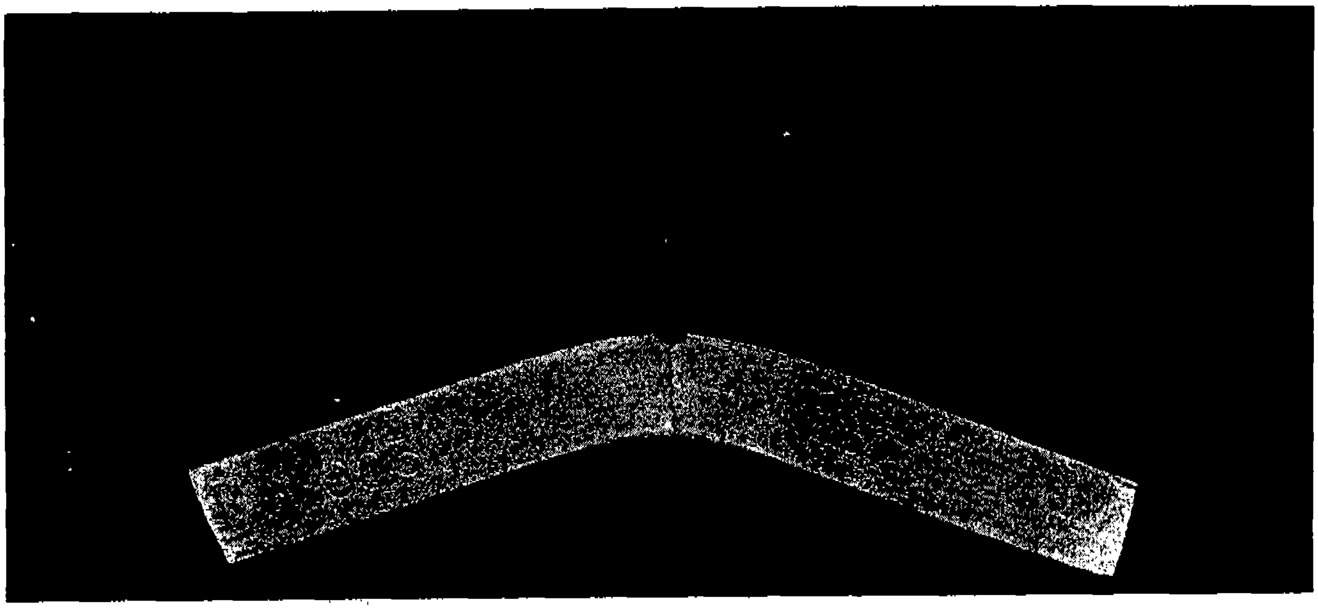
FIGURE 4. MACROSECTIONS FROM 1-1/2-INCH SLABS OF TWO EXPERIMENTAL INGOTS

Inhomogeneities resulting from the special pouring practice are visible in the bottom photograph. These inhomogeneities persisted to form laminations when the slab was reduced to 3/4-inch plate.

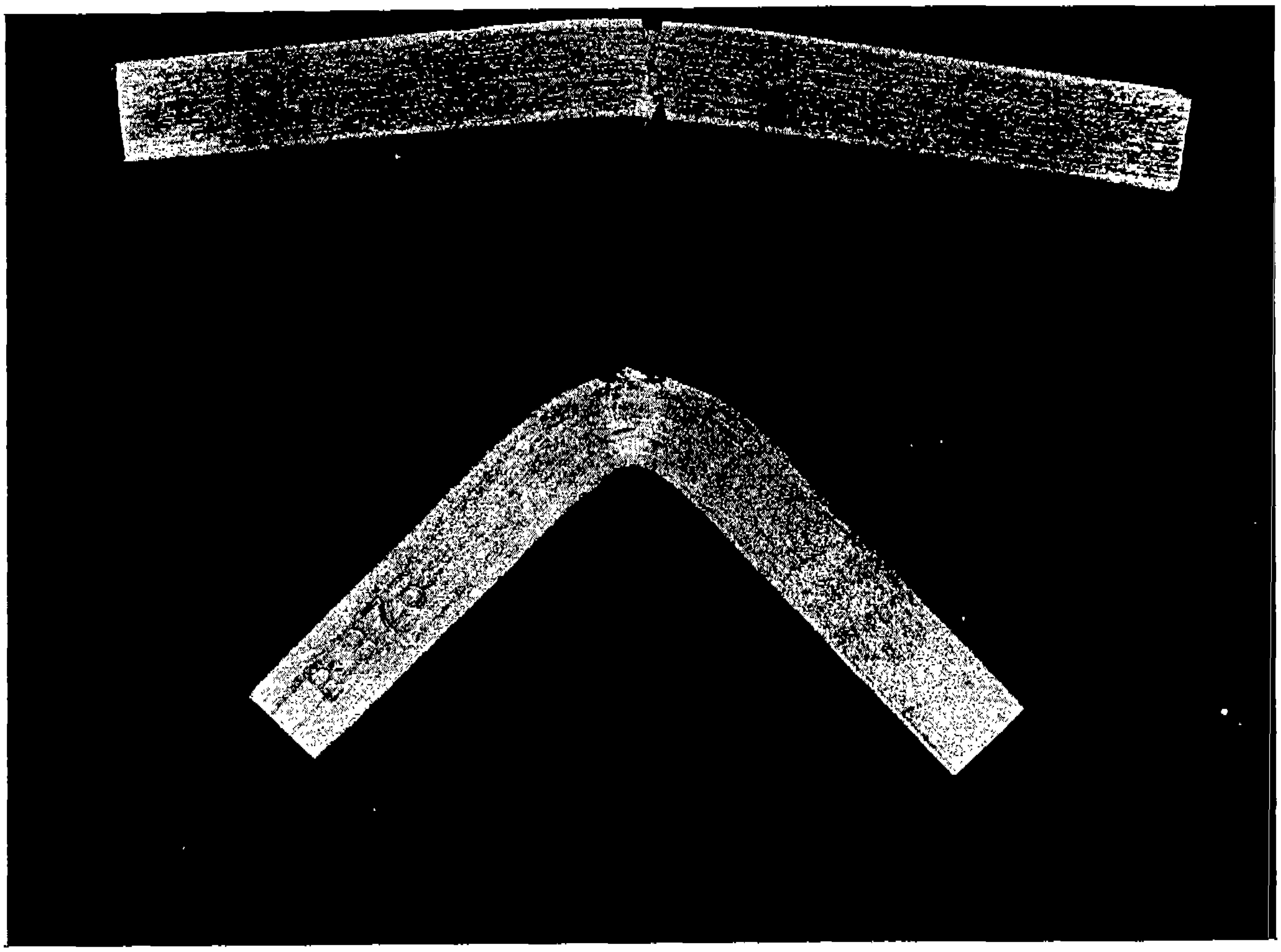
Figure 5 shows nick-break specimens from the two plates after bending at room temperature. These specimens were notched with a saw cut parallel to the plate surface and perpendicular to the rolling direction. The hot-rolled sample from the regular ingot, B803, broke after bending about 40°. The fractured surface exhibited a brittle texture. The laminated plate, B876, did not break even though it was bent about 90°. Bending caused this plate to split along a lamination about 1/4 inch above the compressive side of the specimen.

The second experimental plate was made from an edge-welded assembly of nine 1/6-inch plates subsequently rolled to 3/4-inch plate. To prevent perfect welding during hot rolling, the surfaces of the 1/6-inch plates were oxidized by heating for ten minutes at 1200 F after grit blasting but before assembling the sandwich. The 1/6-inch plates were obtained by hot rolling some commercial ship plate. The steel (LW-1) contained 0.23% C, 0.52% Mn, 0.013% P, 0.037% S and 0.09% Si.

Figure 6 is a micrograph showing inclusions in and near the welded joint between two sheets used to make up the laminated plate "LW-1". Most of the visible inclusions are oxides, the larger ones presumably mark the original surfaces of the sheets forming the pack.



Heat B803 - Plate From Regular Ingot



Heat B876 - Laminated Plate From Layered Ingot

FIGURE 5. NICK-BREAK SPECIMENS FROM SOUND AND FROM LAMINATED PLATES BENT AT ROOM TEMPERATURE

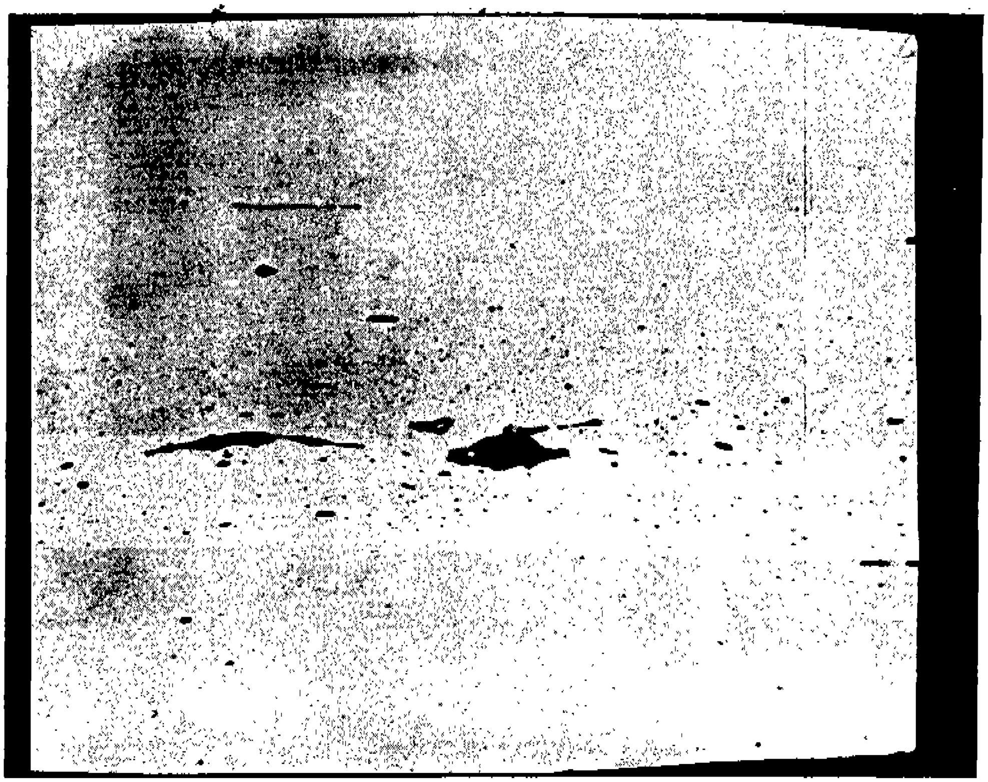


FIGURE 6. INCLUSIONS IN LAMINATED PLATE LW-1 MADE BY PACK ROLLING LIGHTLY-OXIDIZED SHEETS

Most of the inclusions are oxides.

Some of this oxide film dissolved and diffused in the steel during rolling and precipitated later to form the small, spherical inclusions. The laminated plate "B876" contained inclusions similar in size, shape, and number to the large ones visible in the micrograph. However, the laminated plate made from the ingot poured in layers, B876, did not exhibit the small oxide inclusions.

The original data obtained using Charpy keyhole and tear tests on laminated and un-laminated plates made in the laboratory are given in Appendix C. The results are summarized in Table 2 and Figure 7 for comparison with values for conventional plates of similar composition free of laminations.

Figure 7 shows that the laminated plates behaved like conventional plates of similar composition in Charpy tests. The differences in Charpy values, between sound and laminated plates, were within the normal scatter band in tests at 30°F or lower. The laminated plate, B876, absorbed more energy than the comparison steel, B803, in tests at 80°F. This apparent improvement was not supported by the data obtained on plates 8W-1 and LW-1 at room temperature.

The average transition temperatures of the four plates are listed in Table 2. The Charpy transition temperatures of sound and of laminated plates did not differ significantly in these tests. Differences as large as those shown for the 12 or 20-ft-lb levels could occur by chance. They are well within the limit of reproducibility of transition temperatures based on 25 specimens tested over

TABLE 2. NOTCHED-BAR DATA OBTAINED ON SAMPLES(1) FROM STEEL PLATES MADE IN THE LABORATORY

Steel Plate	B803(2)	B876(3)	8W-1(2)	LW-1(3)
Laminated	No	Yes	No	Yes
Charpy Value at 80 F	29	38	35	35
Charpy Transition Temperature, F				
12-ft-lb level	4	14	-10	-16
20-ft-lb level	21	21	7	5
Navy Tear-Test Transition Temperature(4), F	82	80	80	40

(1) Standard keyhole Charpy bars notched perpendicular to the plate surfaces and Standard Navy Tear Test Specimens were used for the test. Compositions of steels are given in the text.

(2) These steels were made by normal processing and exhibited no laminations.

(3) These plates were laminated. B876 came from an ingot poured in layers; LW-1 was a plate made by welding sheets of 8W-1 together by hot rolling.

(4) The highest temperature where one or more of four specimens broke with less than 50 per cent of the fractured area exhibiting a dull or fibrous texture.

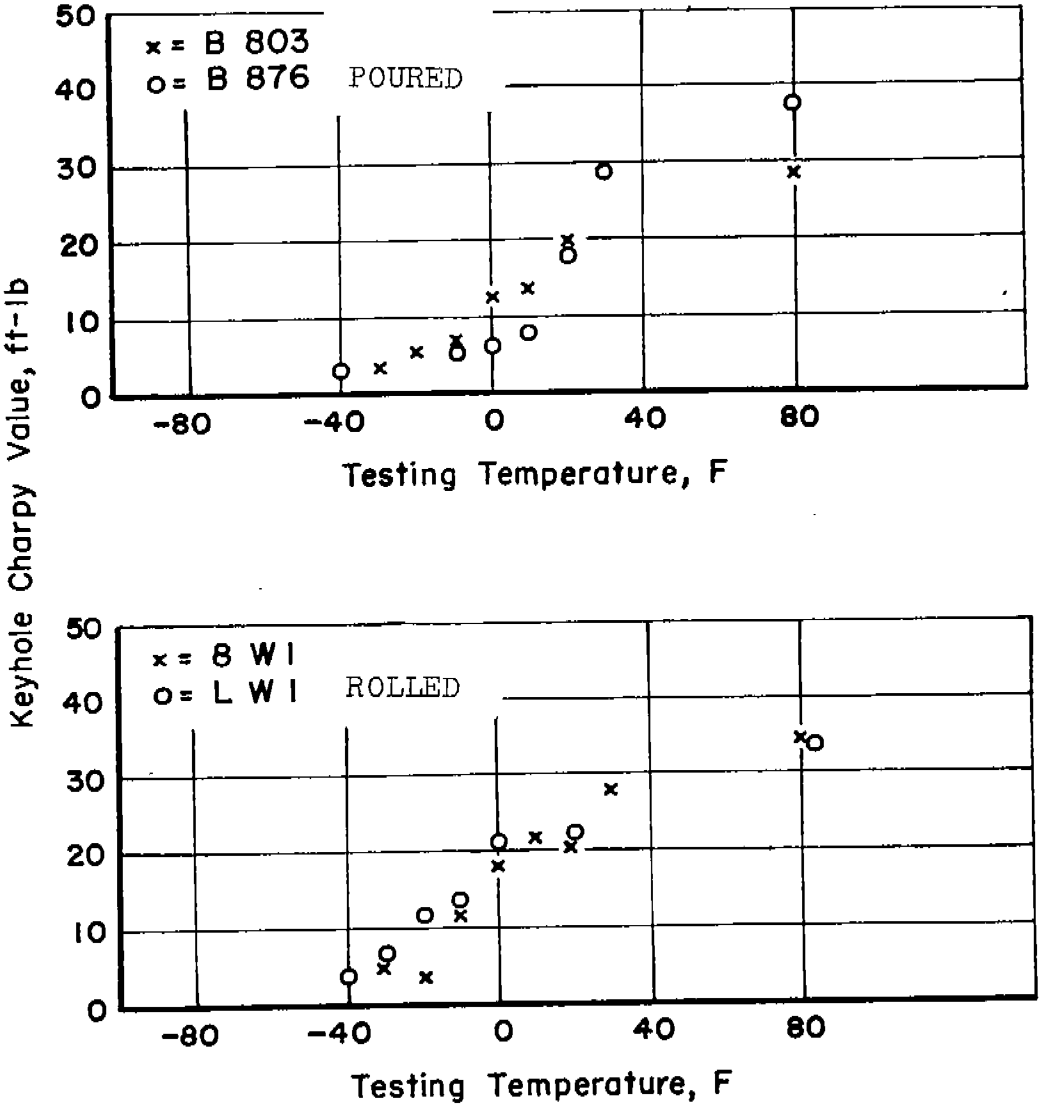


FIGURE 7. EFFECT OF LAMINATED TEXTURE ON ENERGY ABSORPTION IN CHARPY TESTS

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a range in temperatures. The differences in transition temperatures, shown in Table 2, between the two kinds of steel result from the differences in carbon, manganese, and silicon contents.

In these tests, the laminations were visible on the fractured surfaces of all specimens which evidenced appreciable ductility or gave high energy values. No evidence of laminated textures was discernible in areas exhibiting cleavage texture. This was especially noticeable in samples having shear and cleavage fractures. In such cases, the laminations were visible only in the areas of shear fracture and absent in regions with a cleavage fracture.

It is of interest to note that while wrought iron has been given as an example of a tough laminated material there is not much evidence to support this view. Charpy V-notch impact values of Byers process wrought iron indicate a 15 ft-lb transition temperature of approximately 120°F, Fig. 8(8). Based on the drop weight test wrought iron showed resistance to fracture initiation equal to the poorest of ship plates tested to date(8). Double-refined wrought iron has shown a 15 ft-lb transition temperature of nearly 40°F using unnotched Charpy bars, Fig. 9(9). From these results it appears that the presence of laminations and slag inclusions have not resulted in a particularly tough material. Most wrought iron contains approximately 0.12 per cent phosphorus and less than 0.10 per cent manganese. Therefore it would be expected to have a high transition temperature despite its low carbon content. Apparently, the

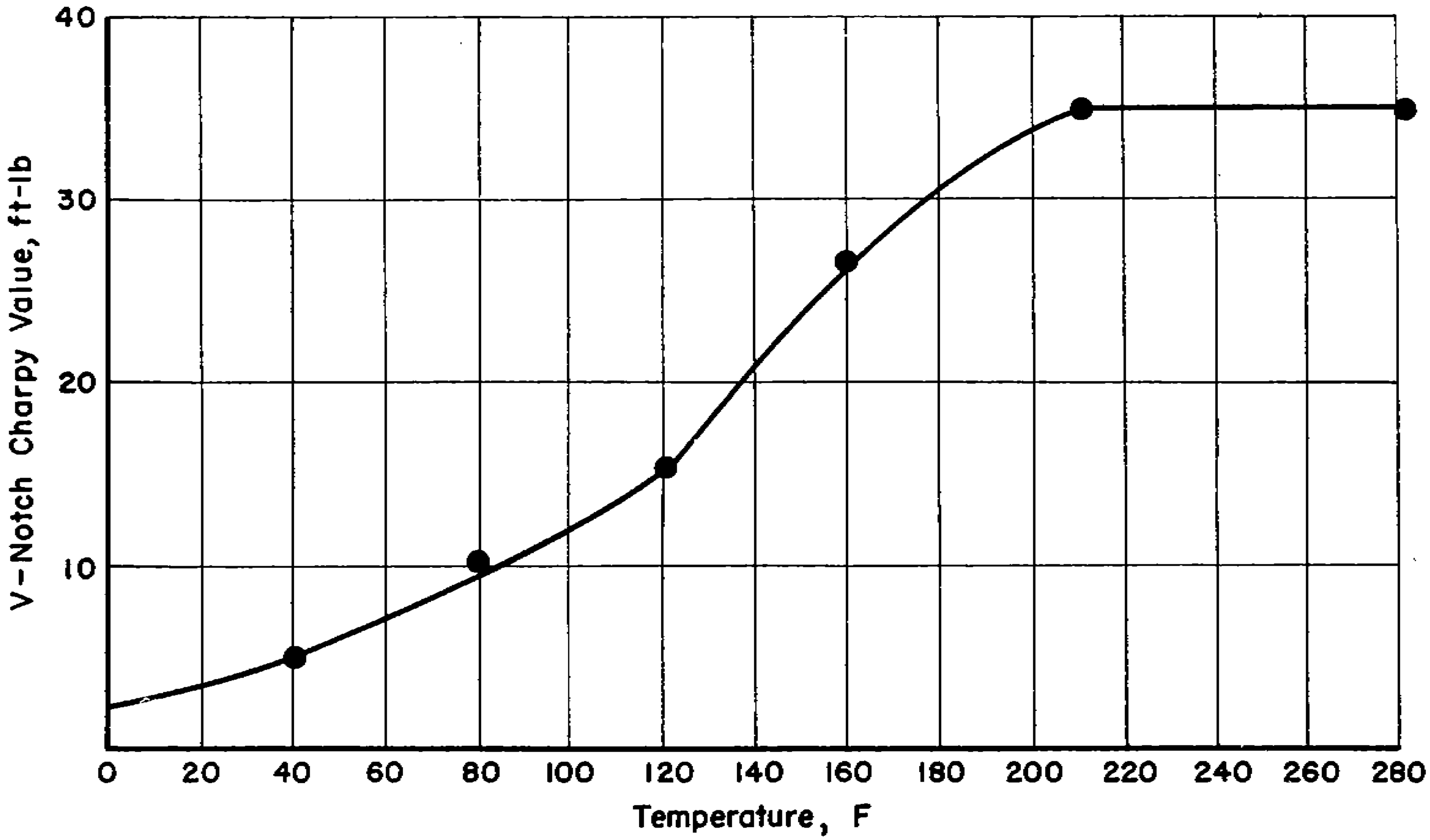

FIGURE 8. CHARPY V IMPACT VALUES OF BYER'S PROCESS WROUGHT IRON
(Reference 8)

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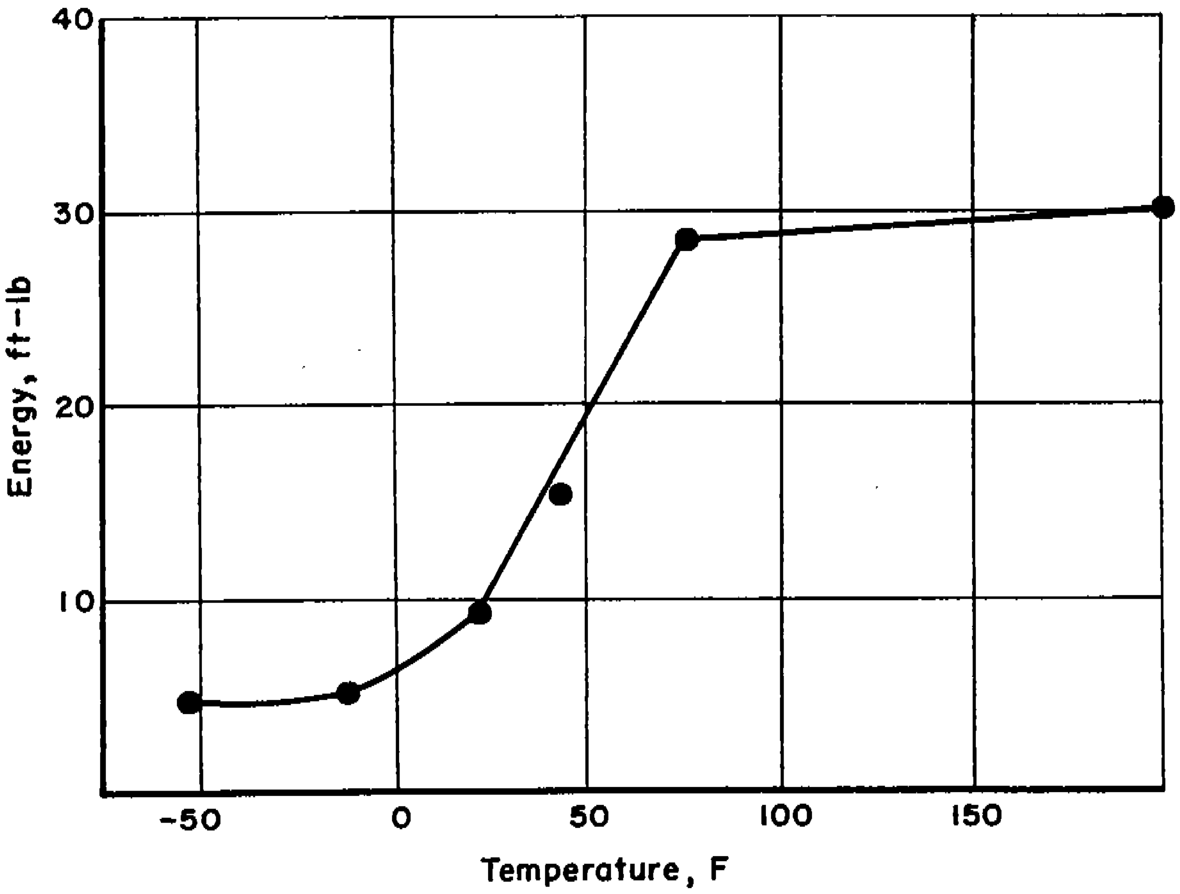

FIGURE 9. CHARPY UNNOTCHED IMPACT VALUES OF WROUGHT IRON
(Reference 9)

A-10898

presence of slag stringers is not helpful enough to overcome the effects of the low manganese and high phosphorus contents.

Although the evidence is fairly conclusive that layers of weakness usually result in higher energy values in notched static tests as well as impact tests, the effect of banding is not clear. It has been reported(10) that a finely banded microstructure will give a lower transition temperature than a coarse structure. These data are illustrated by Fig. 10. More data on the same steels made available later by C. F. Tipper(11) indicated that banding was not the only difference between the two plates. She reported that the superior steel contained a "large number of exceptionally large inclusions" and had been finished at a lower temperature in hot rolling. Her analyses also indicated that small differences in C, Mn, Si, and Al all favored the steel classed by Matton-Sjoberg as finely banded. Thus, the differences in notched-bar properties shown in Figure 10 are not entirely attributable to banding.

In other tests(12) of banded steels, only one steel showed increased resistance to brittle fracture. This steel was described as having severe, wide bands of alloy segregation.

The effect of alloy banding on the Charpy V-notch transition temperature of high tensile steels used for hull construction has also been studied(13). Fig. 11 shows data obtained on plates rolled from two slabs from the same ingot. In one case the 6-inch slab was heated for ten hours at 2350°F to reduce segregation before

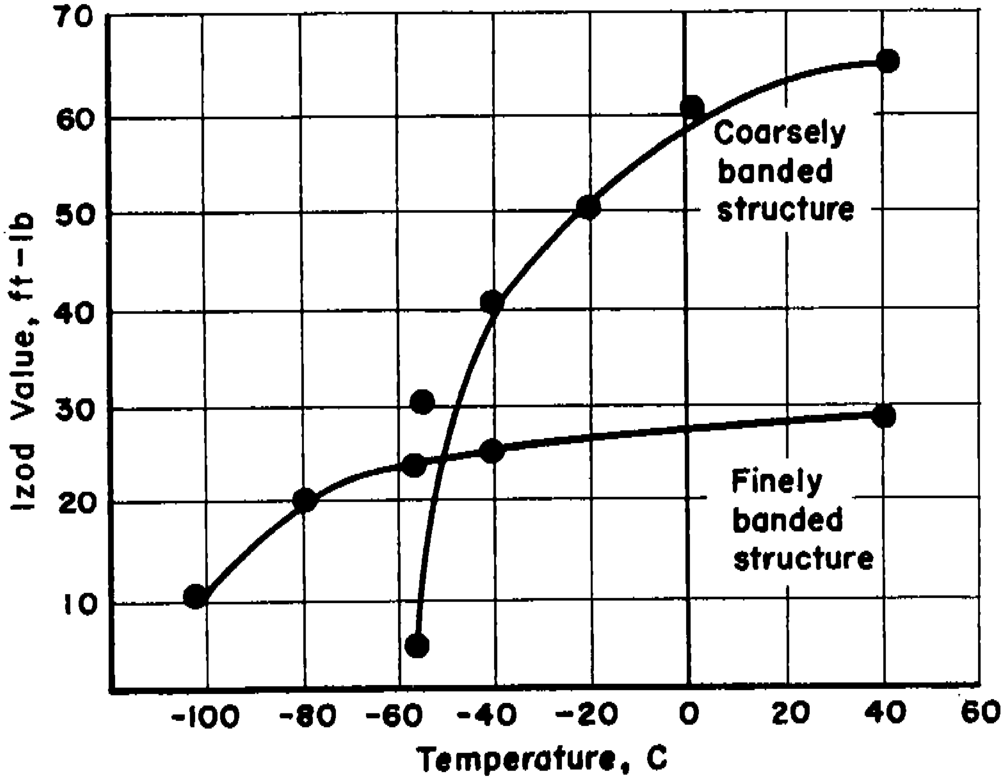

FIGURE 10. EFFECT OF BANDING ON ENERGY ABSORPTION
After Matton-Sjöberg
(Reference 10)

A-10895

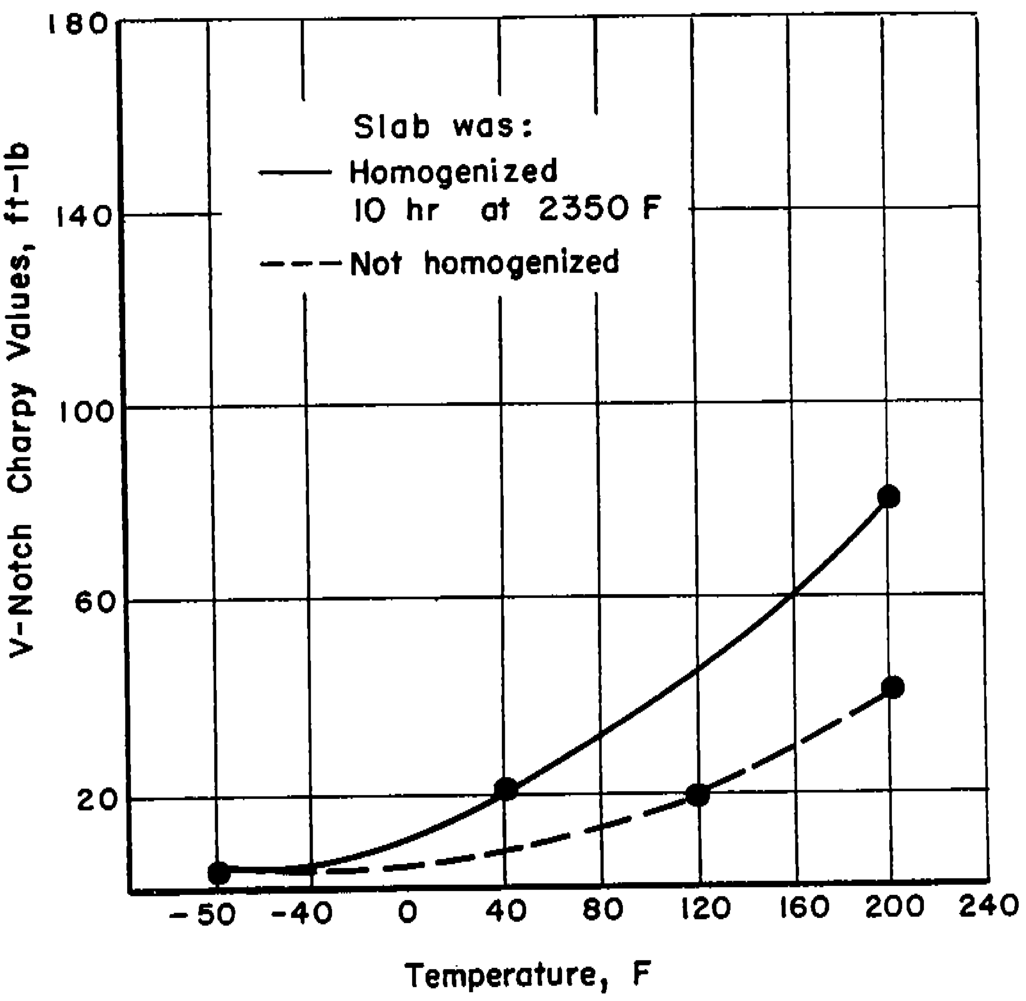

FIGURE 11. EFFECT OF HOMOGENIZATION ON ENERGY ABSORPTION
(Reference 13)

This aluminum-killed steel containing 0.19% C, 1.46% Mn, 0.25% Si, and 0.37% Mo was tested in the as-rolled condition.

A-10896

rolling to one-inch plate. The other slab was not homogenized but was given the same rolling treatment. Homogenizing the slab lowered the 10 ft-lb Charpy V-notch transition temperature of this steel about 60°F. For another steel this change amounted to 30°F.

Thus it seems safe to conclude that a banded microstructure is less resistant to brittle fracture than uniform unbanded structures. While the reasons for the lower notch toughness of the banded structures are not clear, it is inferred that banding does not produce layers of sufficient weakness to reduce triaxiality and thereby inhibit brittle crack formation.

2. <u>Plates containing layers of notch tough material</u>.

No tests are known of steels containing alternate layers of notch tough materials. A limited study has, however, been performed at the Naval Research Laboratory(14) on the effect of cladding. A series of four tests have been performed and these are summarized below:

I. Navy Tear Tests - Six standard Navy Tear Test specimens were made from one piece of 3/4-in. ABS Class B steel. Longitudinal weld beads, about 3-in. long, of 18 Cr-8Ni steel were deposited in way of the fracture, in accordance with the following schedule:

    a. Specimen A: One bead was deposited in about the center of the specimen on each side; the specimen was then hot-rolled until the weld beads were even with the surface.

b. Specimen B: The entire surface from about 1/2-in. behind the notch root was covered with weld metal on both sides; the specimen was then hot-rolled to 3/4-in. thickness.

c. Specimen C: The entire surface, from about 1/2-in. behind the notch root, of one side only, was covered with weld metal; the specimen was hot-rolled to 3/4-in. thickness.

d. Specimen D: Two beads were deposited, in about the center of the specimen on one side only; the specimen was hot-rolled to 3/4-in. thickness.

e. Specimen E: A single bead was deposited, in about the center of the specimen on one side only; the specimen was not rolled.

f. Specimen F: Single beads were deposited, in about the center of each side of the specimen; the specimen was not rolled.

All of the specimens were tested at 28°F, which is below the Navy Tear Test transition temperature of the plate. Results were as follows:

Specimen	Maximum Load	% Fibrous
A	31,700	2
B	33,100	2
C	31,800	2
D	31,600	2
E	33,400	0
F	37,500	0

It is considered that these tests(14) did not indicate any benefit of the surface layers. On the other hand, they may not have proved conclusively that the surface layers could not be beneficial. This conclusion is explained by noting that the elastic energy was sufficient to fracture both the base steel and the tough surface layers. Under other conditions in which a lesser amount of elastic energy was available for crack propagation, the ability of the surface layer to retard or arrest the brittle crack could have been manifested.

II. Charpy V-Notch Impact Tests of Killed Steel(14)

Two Charpy specimen blanks of a 0.30%C, 1.00%Mn, Si-Al killed steel were cut 1/16-in. undersize in width. Weld metal of 25% Ni-20% Cr was deposited on each side. These two blanks, along with two control blanks of the same steel with no weld metal, were normalized at 1750°F. The coated blanks were then fabricated to standard V-Notch Charpy specimens, which left about 1/32-in. of weld metal on each side of the specimen. All four specimens were tested in impact with two levels of initial energy of the hammer. The test temperature was -100°F; previous tests had shown that the steel had a 15 ft-lb transition temperature of -30°F. Results were as follows:

Specimen	Temperature	Hammer Energy	Energy Absorption
Coated	100°F	240 ft-lbs	10 ft-lbs
Not-coated	100°F	240 ft-lbs	2 ft-lbs
Coated	100°F	100 ft-lbs	10 ft-lbs
Not-coated	100°F	100 ft-lbs	4 ft-lbs

Examination after fracture showed that the weld metal was of a coarse columnar structure. It is considered that if the overlay were wrought, the energy absorption would have been greater.

III. Charpy V-Notch Impact Test of Commercial Clad Steel, with Cladding on One Side Only(14).

Specimens were machined from a piece of 3/4-in. commercial clad steel. The base metal was A285 grade C; the cladding was type 304 stainless steel. Specimens were machined such that one side had various thicknesses of cladding, from 0 to 9/64-in. Standard Charpy V-Notch impact tests were conducted at -100°F. Initial hammer energy was 240 ft-lbs. Results were as follows:

Coating Thickness	Energy Absorption
0	1 ft-lbs
1/32	4 ft-lbs
1/16	9 ft-lbs
3/32	11.5 ft-lbs
9/64	19.5 ft-lbs

IV. Slow Bend Tests of Charpy V-Notch Specimens(14).

Six Charpy V-Notch specimens were fabricated from the material and in the manner described in paragraph III above. The coating thickness was 0, .040-in. and .080-in. They were tested by slow bending at -67°F and -175°F.

The specimens with no cladding snapped completely in two, at both temperatures, after slight yielding.

All of clad specimens cracked at about the same load and deflection as the unclad specimens, but the crack ran only about 3/4 of the way through the specimen on the unclad side. The clad side of the specimen did not crack at all. After the crack stopped in the clad specimens the load was about 1/3 of the maximum load, indicating the ability of the cladding to retard and arrest the brittle crack in the mild steel.

This limited study indicates that cladding may be beneficial in lowering transition temperature; in addition it is noted that improvements in notch bar performance are obtained at low energy values indicating that cladding may be effective in inhibiting brittle crack initiation.

3. Plates within which rods of notch tough material are incorporated at their edges parallel to the maximum tensile stress.

No direct investigations in this field are known. However, several projects related to the proposal have been undertaken on a limited scale.

Studies involving the Explosion Bulge Test as conducted at the Naval Research Laboratory(15) have shown that notch tough weld metal laid in a circle enclosing the origin of fracture can stop brittle cracks. Other work by Tipper(16) and Leide(17) has shown that tougher material welded to more notch sensitive steel can stop the propagation of a brittle crack which was initiated in the notch sensitive steel. The effectiveness of such crack stoppers would probably depend on their width, the distance from the crack origin, and the energy available for propagating a running crack.

CONCLUSIONS

The information obtained from the literature and from experiments discussed in this report are considered to justify the following conclusions. Since the data are scanty on all points they should be verified or disproved by additional experiments if designers consider such steels applicable to ship construction.

1. Cladding of mild steel with a tougher material will produce a composite which will resist brittle fracture to lower temperatures. This is a special case of the suggestion about steels containing lamellae of high toughness.

2. The incorporation of rods or areas of tougher material in structure made of ship plate will reduce the likelihood of brittle fractures propagating great distances. The rods might be rolled into the plate or might consist of notch tough weld metal.

3. Plates containing planes of weakness between layers of ship plate parallel to the surface are not likely to be beneficial in resisting the initiation of brittle fracture. The reasons for this opinion include:

A. Homogeneous and laminated ship plates have the same "ductility" transition temperature even though the latter may have lower "fracture" transitions.

B. Brittle layers in wrought iron do not overcome the inherent brittleness of the metallic phase.

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APPENDIX B

SUGGESTIONS FOR THE DEVELOPMENT OF TEXTURALLY TOUGH LOW CARBON STEELS

Presented at the 46th meeting
of the
Ship Structure Subcommittee
by representatives of the Committee on Ship Structural Design
of the
National Academy of Sciences-National Research Council

Until a few years ago it was hoped that the notch brittleness of low carbon steel would be due to impurities, and that it could be remedied by purification. These hopes came to nought when iron of almost spectroscopic purity could be produced and it did not prove much tougher than some commercial low-carbon steels. After this, the only remaining way of increasing the toughness by changing the composition was to add substantial quantities of beneficial alloying elements, and the cost of this is prohibitive in the case of ship steel or structural steel.

At present, therefore, the only possibility for producing cheap steel of high toughness seems to be to endow it with a suitable texture. That this can be very effective is shown by the example of wrought iron. This material is full of slag lamellae which burst open before the triaxial tension can reach the value necessary for starting brittle fracture; once a slag lamella has burst open, the triaxiality of tension is annihilated at the free surfaces of its walls, and it is strongly reduced in the surroundings. The effect of this can be observed in many broken Charpy specimens; if there was a surface of weakness (in rolled steel, usually a welded-up gas bubble) which burst open under the triaxial tension developed in the specimen, the fracture around it is fibrous even if it is surrounded by a larger area of brittle fracture. If there are many such fibrous patches, the plastic work p required for producing unit area of the surface of fracture is strongly increased, and according to the crack propagation condition $\sigma \approx \sqrt{\frac{Ep}{c}}$

the stress σ needed for brittle crack propagation in the presence of a crack of given depth c may rise above the maximum that can be produced by plastic constraint. In this case, brittle fracture cannot start. This is strikingly verified by the extremely high toughness of wrought iron and by the fact that "dirty" steel which contains many rolled-out slag particles or bubbles is usually much tougher than clean steel of the same composition.

During the last 6 or 7 years Professor E. Orowan has made a study of the possibilities of producing highly tough low-carbon steel by methods that would not increase the price substantially; one at least of these may in fact reduce somewhat the price of the steel. In what follows, a brief description will be given of the three main methods found in the course of this study. The first aims at obtaining a material in which the initiation of the brittle crack is difficult, as in wrought iron; in material obtained with the second method, the rapid propagation of the crack is made difficult and, therefore, typical brittle fracture is in general eliminated; in material of the third type, finally, the crack is stopped before it can become dangerous. The principles upon which these three methods are based are not new; the first is utilized in wrought iron, the second in safety glass of the sandwich type, and the third in wire-reinforced glass.

1. Steel containing layers of weakness

As mentioned, the toughness of wrought iron is due to patches of weakness represented by slag lamellae. In order to produce a material equaling or exceeding wrought iron in toughness, it is apparently not necessary to have the same number and distribution of weak lamellae; it seems better to restrict them to a number of planes parallel to the steel plate, i.e., to build up the plate of a number of layers the cohesion between which is slightly lower than the brittle strength of the steel. This can be achieved by joining the layers after a small amount of slag, oxide, or other material has been distributed on their surface. A suggestion by Professor Orowan would make this possible without increasing the price of the steel, by building up the ingot of a number of successively poured layers in a long horizontal mold, each layer being separated from the next by patches of oxide, slag, or other material.

It might appear that the toughness would be achieved in this case by a sacrifice in the "Z-strength" (the strength for tension perpendicular to the plate). This, surprisingly, need not be the case. If the Z-strength remains above the yield stress Y, the resistance of the material to tension normal to the plate is not affected; if, at the same time, the Z-strength of the lamellar inclusions is less than, say, 1.5Y or 2Y, they will burst and blow out the triaxiality of tension in their surroundings before it can reach a very high value.

2. Steel containing lamellae of high toughness

The method of introducing layers of weakness can reduce the maximum triaxiality of tension and thus prevent the start of brittle fracture at notches or cracks in many or most cases that may occur in practice. It is difficult to recognize, however, whether a repidly running brittle crack will be stopped when it runs into such laminated material; according to recent results (see the report, "Theory of Notch-Brittleness", to the Committee on Ship Structural Design by Professor Orowan), triaxiality probably plays a minor part once a brittle crack has gathered speed.

A method by which the possibility of crack propagation can be suppressed is pointed out by the crack propagation condition

$$\sigma \approx \sqrt{\frac{Ep}{c}}$$

This shows that the stress required for crack propagation can be raised to levels too high to occur in a plastic material by an increase of the work of separation p. A simple expedient for this could be to sandwich a thin, very tough layer of steel (or, of course, some other metal) in the plate. A very thin sheet could raise p intensely without adding much to the cost of the material (even if the sheet contains substantial quantities of alloying elements), or reducing noticeably the yield stress of the plate (if the inset sheet is very soft in order to be immune against brittle fracture). Such a thin layer could be sandwiched between two steel plates by rolling or by placing a plate or the required material into the ingot mold before pouring. Naturally, it is a condition that no brittle transition layers should develop around the sandwich boundaries by diffusion.

3. Steel reinforced by inset rods or strips of a highly tough material

If, at a suitable phase of rolling, one or more rods or strips of a highly tough steel are placed on to the plate and hot rolled into it, they form obstacles impenetrable to a brittle crack. Whether or not such "crack arrestors" are effective depends on their spacing; if a crack can run across several courses of plates in a tank or a ship, the weakening of the structure is so considerable that large plastic deformations with the possibility of new brittle cracks can occur. However, if every plate has, say, two crack arrestors rolled in, preferably near the welded edges that run parallel to the maximum tension, the chances for a brittle crack to penetrate into and across the plate may become very small. Since the inset rods should run parallel to the tension, their presence does not weaken the plate much even if their yield stress is relatively low.

Conclusions

The first piece of work that ought to be carried out as a basis for the development of texturally tough steels should be an investigation of the properties of wrought iron; in particular, the ability or otherwise of this material to resist the propagation of brittle cracks running into it from another material joined to it by welding. At the same time, specimens built up according to the preceding paragraphs 1., 2., and 3. (not necessarily by methods suitable for large-scale manufacture) could be investigated. If a promising solution emerges, problems of manufacture and welding will have to be solved.

Prepared by E. Orowan

APPENDIX C

TABLE C-1: KEYHOLE CHARPY IMPACT DATA ON EQUIPMENT STEELS

Heat No.	Testing Temperature, F	Charpy Value, ft-lb				
		1	2	3	4	Average
B803	80	29	29	-	-	29.0
	20	26	12	21	21	20.0
	10	16	6	19	15	14.0
	0	11	7	16	17	12.8
	-10	10	6	6	5	6.8
	-20	5	8	6	7	6.5
	-30	3	4	-	-	3.5
B876	80	38	38	-	-	38.0
	30	23	31	31	31	29.0
	20	20	26	7	23	19.0
	10	14	5	6	7	8.0
	0	7	4	6	7	6.0
	-10	4	5	9	5	5.8
	-40	3	3	-	-	3.0
BW1	80	35	34	-	-	34.5
	30	27	26	28	30	27.8
	20	22	27	21	13	20.8
	10	19	24	25	20	22.0
	0	18	19	17	18	18.0
	-10	18	6	3	20	11.8
	-20	4	4	3	6	4.3
	-30	4	5	4	8	5.3
LW1	80	34	35	-	-	34.5
	20	22	23	-	-	22.5
	0	22	21	21	22	21.5
	-10	25	6	6	18	13.8
	-20	18	8	5	16	11.8
	-30	3	4	15	6	7.0
	-40	5	3	5	3	4.0

TABLE C-2: TEAR TEST DATA ON EXPERIMENTAL STEELS

Heat Number	Specimen Number	Testing Tempera-ture, F	Maximum Load, lb	Energy to Start Fracture, ft-lb	Energy to Propagate Fracture, ft-lb	% Shear in Fracture
B803	Q1	80	37,150	790	175	15
	Q2	80	36,350	715	75	10
	R1	80	37,400	815	100	12
	A1	80	37,050	725	58	10
	A2	90	37,500	815	183	20
	P1	90	36,750	757	590	82
	P2	90	36,450	707	616	82
	R2	90	36,750	675	650	80
	B1	100	35,700	658	642	87
	B2	100	37,450	784	633	85
	C1	100	37,250	715	590	90
	C2	100	37,100	684	193	25
	D1	110	36,600	715	575	97
	D2	110	36,800	740	575	85
	K1	110	35,950	684	725	95
	K2	110	36,250	665	850	95
B976	G2	50	36,900	1025	50	3
	H1	50	35,950	1050	92	4
	H2	50	36,150	1020	108	3
	K2	50	35,950	1080	150	8
	F2	60	36,800	1090	83	2
	G1	60	36,050	1077	33	7
	A1	60	34,950	960	650	58
	A2	60	35,050	925	75	3
	E2	70	36,400	1010	584	48
	F1	70	36,250	1100	525	45
	B1	70	34,100	833	808	73
	B2	70	34,550	935	308	23
	E1	80	37,450	1342	650	70
	C1	80	34,550	935	167	13
	P1	80	35,350	833	550	50
	P2	80	35,300	1033	150	12

TABLE C-2: (CONTINUED)

Heat Number	Specimen Number	Testing Temperature, F	Maximum Load, lb	Energy to Start Fracture, ft-lb	Energy to Propagate Fracture, ft-lb	% Shear in Fracture
B876 (Cont.)	C2	90	33,850	1000	734	80
	D1	90	31,800	715	784	73
	D2	90	32,250	800	766	70
	K1	90	34,300	860	961	80
8W1	P1	50	41,650	961	334	30
	P2	50	41,150	950	117	3
	Q1	50	41,200	961	142	5
	Q2	50	41,900	961	508	60
	K1	60	37,350	790	125	5
	K2	60	38,050	833	167	16
	L1	60	37,700	842	492	55
	L2	60	37,950	750	75	5
	N1	70	40,700	875	700	90
	N2	70	39,850	790	750	100
	A1	70	38,700	891	450	53
	A2	70	38,650	775	83	18
	B1	80	37,500	808	508	68
	B2	80	37,500	700	665	89
	C1	80	37,150	790	665	88
	C2	80	38,100	750	100	30
	M1	90	39,750	824	725	100
	M2	90	40,350	891	665	95
	D1	90	36,200	734	675	83
	D2	90	37,500	725	200	33
	H1	100	36,400	757	700	98
	H2	100	37,150	725	633	83
	J1	100	35,200	707	650	90
	J2	100	36,000	642	684	95
LW1	F2	20	38,150	766	50	1
	J2	30	38,100	815	590	97

TABLE C-2: (CONTINUED)

Heat Number	Specimen Number	Testing Temperature, F	Maximum Load, lb	Energy to Start Fracture, ft-lb	Energy to Propagate Fracture, ft-lb	% Shear in Fracture
LW1 (Cont.)	B1	40	37,800	790	625	87
	B2	40	38,300	842	108	1
	H2	40	36,750	684	625	92
	J1	40	38,400	800	584	97
	G1	50	37,800	790	584	95
	G2	50	37,350	750	616	93
	H1	50	36,950	790	609	99
	A2	50	37,700	740	625	95

APPENDIX D

DISCUSSION BY E. OROWAN OF

"An Appraisal of the Properties and Methods of Production of Laminated or Composite Ship Steel Plate"

It is known that steels containing slag particles compressed to thin lamina by rolling, or incompletely welded-up gas inclusions, are usually tougher in the notch impact test than "clean" steels. The reason for this is clear. Cleavage fracture occurs only if the tensile stress reaches the value of the cleavage strength ("brittle strength") B. The yield stress Y of low carbon steels in uniaxial tension at moderate straining rates and not too low temperatures is lower than B: this is the reason why in the usual static tensile test no cleavage fracture occurs. If the rate of straining is extremely high, such as it is at the tip of a fast running crack, Y can rise to the value of B in the lower part of the transition range; in this case, cleavage fracture occurs without any visible plastic deformation. At somewhat higher temperatures (in the middle or upper parts of the transition range), high rates of straining alone cannot elevate Y to the level of the cleavage strength B; the effect of the velocity must be complemented by more or less plastic constraint which raises the tensile stress from Y to qY, where q is the "constraint factor." The highest value of q that can be produced by a sharp crack or notch is between 2 and 3. The necessity of complementing the effect of velocity in raising Y by plastic constraint manifests itself in the development of a "shear lip." Another case where plastic constraint is essential for the occurrence of brittle fracture is that of a statically loaded plate containing a stationary crack or notch. Here the velocity effect is absent; and the only way in which the tensile stress can be raised to the level of B, in general, is by the development of plastic constraint.

Plastic constraint means the superposition of a hydrostatic tension T to the uniaxial tensile yield stress Y; the relationship between T and the constraint factor q, of course, is $Y + T = qY$. At a given temperature and rate of straining, a hydrostatic tension T may be needed in order to raise the tensile stress to the value B; the necessary hydrostatic tension, of course, is zero if the temperature is low enough and the strain rate high enough. In a "clean" steel, nothing stands in the way of T reaching the highest value compatible with the notch geometry present. In a steel containing slag lamina or incompletely welded gas bubbles, however, these have a characteristic tensile strength S; if the tensile stress exceeds S, the slag or gas lamina burst. In other words, the slag or gas inclusions represent safety valves which prevent the hydrostatic pressure from rising above S. If S is lower than the hydrostatic tension T required for cleavage fracture under the given circumstances, no brittle fracture can occur. In this way, the presence of slag or gas lamina may increase the toughness of the steel.

In order that the lamina may be effective, two conditions must be satisfied. First, the bursting strength S of the lamina must be lower than the hydrostatic tension T with which the yield stress Y must be complemented; if S exceeds a value between Y and 2Y which is the maximum of T obtainable by notch constraint, the lamination is completely ineffective. Secondly, the thickness of the steel layers separated by slag or gas inclusions must be sufficiently small; otherwise, each layer behaves like a non-laminated plate which can develop high enough hydrostatic tensions T by plastic constraint if a crack or notch is present. How thin they must be is easily recognized. If, under given conditions, brittle fracture in a plate would be accompanied by the formation of shear lips of width W, a plate may develop cleavage fracture between two shear lips if its thickness is greater than 2W; otherwise cleavage is not possible. For instance, if the lamination is expected to have a beneficial effect at temperatures and strain rates at which the width of the shear lips is 0.01 in., the spacing of the lamina must not substantially exceed 0.02 in.

On the basis of these considerations, the present writer has suggested a method for the cheap commercial production of texturally tough low carbon steels (see Appendix B). The method consists in the production of laminated ingots by pouring them horizontally in layers, and separating each layer from the following one by a thin film of some suitable material (e.g., powdered slag) capable of giving a strength S of the laminar bond that is low enough to be effective in the sense explained above. The material obtained by rolling out the laminated ingot differs from ordinary wrought iron substantially in that both the spacing of the lamination and the strength S of the slag lamina can be controlled so as to represent an optimum for the toughness of the steel; in the case of wrought iron, both S and the spacing are more or less imposed by the nature of the production process, irrespectively of the result obtained. For laboratory experiments, of course, laminated material may be made more easily by forging or rolling together a stack of steel plates separated by patches of a suitable material such as a refractory powder or slag. By trying different separating materials and thicknesses of lamination (in the final product), those combinations would have to be found which satisfy the above conditions for increasing the toughness of the product.

In the preceding report (see Appendix A), experiments with laminated plates carried out by Mr. Mangio and Mr. Boulger in the Battelle Memorial Institute are reported. The result was substantially negative: lamination had little if any effect on the toughness of the plate. In order to avoid the impression that these experiments have demonstrated the ineffectiveness of the lamination principle, I should like to point out, therefore, that the laminate was made without taking into account the two basic conditions for the effectiveness of the lamination mentioned above. Had they led to any positive result, this would have been accidental, and their actual negative outcome proves nothing about the effectiveness or otherwise of the lamination principle. The thickness of the steel lamina joined together was so large (1/12 in.) that this circumstance alone might have excluded any significant effect upon the toughness of the product. Moreover, no slag or other low-strength separating material was used; the layers were separated only by their oxide skins which must have been more or less completely reduced to iron during the rolling of the stack. No attempt was made to measure the S-strength and to make sure that it was below Y or 2Y; in fact, this vital condition does not seem to have been considered.

The effectiveness of the lamination principle is hardly subject to any doubt: anybody who has made a few dozen Charpy tests has probably come across specimens containing planes of weakness parallel to the plane of rolling (due to incompletely welded-up gas bubbles). Such specimens, which split up in the test like wood, show unusually high impact values. The experiments described in the report, therefore, show only that the conditions suitable for reproducing this beneficial effect have not been found.

In the Battelle report, impact tests on wrought iron are described, and it is found that this material is not substantially tougher than ordinary ship steel. As it is pointed out in the report, this comparison is not very helpful in assessing the effect of the slag inclusions. Modern ship steel has 0.7 to 0.9 per cent manganese which accounts for its remarkably low transition range; wrought iron, on the other hand, is not allowed to contain more than a trace of manganese in order to qualify as wrought iron according to an antiquated specification based on the accidentally low manganese content of ancient wrought iron. A ship- or structural steel with the composition of the matrix of wrought iron would be extremely brittle.

There is some danger that the Battelle experiments may prejudice the investigation and development of texturally tough steels if not counteracted by an explanatory discussion; to provide this, has been the purpose of the present note. It would be most desirable to carry out methodical experiments on the effect of lamination guided by the principles described above.

APPENDIX E

COMMENTS BY P. E. KYLE ON PROFESSOR E. OROWAN'S DISCUSSION OF

"An Appraisal of the Properties and Methods of Production of Laminated or Composite Ship Steel Plate"

Some comments on Professor Orowan's discussion seem in order from the person who was Chairman of the Committee on Ship Steel at the time the project referred to was undertaken.

It appears that the objectives of the work undertaken at Battelle have been misinterpreted by the discussor. This work does not represent the Committee's planned investigation to evaluate the merits of his original suggestions. As stated in the letter transmitting the report draft, and in the report itself, Battelle was requested by the Committee on Ship Steel to review and interpret the available literature. No experimental work was planned under the sponsorship of the Committee pending a review of the results of this literature survey. The experimental ingots were manufactured and tested at Battelle at the suggestion of the investigators. At no time was the Committee of the opinion that these test results and other data reported from the literature could serve as a basis for a final critical judgment of the validity of the discussor's theory. However, even though the reported results are not complete, they are based on studies of a sufficiently broad scope to serve as a good indication of the probable behavior of such materials.

Because of the lack of evidence supporting the advantage of this type of material and in view of the economic factors involved, which were given careful consideration, the Committee on Ship Steel did not feel justified in recommending that the Ship Structure Committee sponsor further work.

SHIP STRUCTURE COMMITTEE

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MILITARY SEA TRANSPORTATION SERVICE, DEPT. OF NAVY
UNITED STATES COAST GUARD, TREASURY DEPT.
MARITIME ADMINISTRATION, DEPT. OF COMMERCE
AMERICAN BUREAU OF SHIPPING

ADDRESS CORRESPONDENCE TO:

SECRETARY
SHIP STRUCTURE COMMITTEE
U. S. COAST GUARD HEADQUARTERS
WASHINGTON 25, D. C.

January 12, 1956

Dear Sir:

Early in 1953 proposals having to do with the improvement of the notch toughness of ship steel by suitable variations in the texture of the plate were presented before the Committee on Ship Structural Design of the National Academy of Sciences-National Research Council. Following discussion, the Committee on Ship Structural Design recommended that studies be undertaken to evaluate the ability of such materials to inhibit brittle crack initiation and propagation. This recommendation was concurred in by the Ship Structure Committee.

Since the proposals involved mainly metallurgical problems, they were referred to the Committee on Ship Steel of the National Academy of Sciences-National Research Council. The available information on the subject was collected and summarized under the direction of this Committee, and a report prepared discussing technical and economic factors governing the use and production of these materials.

Herewith is a copy of this report entitled "An Appraisal of the Properties and Methods of Production of Laminated or Composite Ship Steel Plate". The conclusions and opinions stated herein regarding the feasibility of the suggestions presented before the Committee on Ship Structural Design have been unanimously approved by the Committee on Ship Steel. The report is being distributed to those individuals and agencies associated with and interested in the work of the Ship Structure Committee.

Sincerely yours,

K K Cowart

K. K. COWART
Rear Admiral, U. S. Coast Guard
Chairman, Ship Structure Committee