OTTAWA November 20th, 1940.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 926.

An Examination of Six Broken Welded Sheet
Steel Tensile Test Specimens.

BUREAU OF MINES
DIVISION OF METALLIC MINERALS

ORE DRESSING AND
METALLURGICAL LABORATORIES

CANADA
DEPARTMENT
OF
MINES AND RESOURCES
MINES AND GEOLOGY BRANCH

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Origin of Material and Object of Investigation:

On November 6th, 1940, Flight Lieutenant R. C. Smith, of the R. C. A. F., Ottawa, Ontario, brought in six broken welded sheet tensile test specimens. According to report these specimens had all broken under the minimum required load. In view of this, an examination of the materials was requested.

Macro-Examination:

The following table gives the results of the visual examination:

SPECIMEN NO.	Sheet thickness, in.	Weld thickness, in.	Weld condition.	Location of Break.
1	0.052	0.090	Irregular.	At edge of weld.
2A	0.062	1.030	Fair.	About ½ in. from weld.
2B	0.049	0.086	Good.	" " " "
3	0.062	0.089	Fair.	" " " "
4	0.073	0.094	Irregular.	In weld.
5	0.032	0.078	Good.	About ½ in. from weld.

Chemical Analysis:

The following table gives the results of the chemical analyses. No silicon, sulphur or phosphorus determinations were made, as these elements are usually present in fairly constant amounts.

Specimen No.	Carbon, per cent	Manganese, per cent	Chromium, per cent	Molybdenum, per cent
1	0.38	0.56	1.09	0.22
2A	0.32	0.55	1.03	0.19
2B	0.34	0.55	1.01	0.22
3	0.30	0.50	1.17	0.26
4	0.29	0.55	1.02	0.22
5	0.28	0.55	1.01	0.21

Hardness Tests:

Allowing for some variation near the weld in the zone referred to as "unwelded", the test specimens may be considered as being divided into "unwelded" (base sheet), "intermediate" (about 0.2 inch on either side of the weld), and weld metal zones. Hardness tests were made in the "unwelded" zone several inches from the weld (position 1),

(Continued on next page)

(Hardness Tests, cont'd) -

in the "unwelded" metal adjacent to the "intermediate" zone (position 2), in the "intermediate" zone adjacent to the "unwelded" metal (position 3), in the middle of the "intermediate" zone (position 4), in the "intermediate" zone adjacent to the weld metal (position 5), and in the weld metal (position 6). The results obtained are given in the following table:

VICKERS HARDNESS NUMBERS.

Specimen No.	Position 1.	Position 2.	Position 3.	Position 4.	Position 5.	Position 6.
1	234	266	433	514	498	270
2A	202	289	306	348	342	266
2B	212	304	309	351	351	253
3	160	274	322	351	425	245
4	221	279	304	304	304	251
5	206	287	330	336	336	212

Microscopic Examination:

Two specimens, one about 2 inches from the weld and one including the weld zone, were cut from each test piece, mounted on edge in bakelite, given a metallographic polish, and examined under the microscope. All specimens examined were found to be sound. The samples were then etched in a 2 per cent solution of nitric acid in alcohol. In so far as the "intermediate" zones were concerned, the sample from Test Piece 1 etched most rapidly, while specimens from Test Pieces 2B and 3 etched more rapidly than the remainder of the samples.

The specimens were then re-examined under the

(Microscopic Examination, cont'd) -

microscope. The structure of the "unwelded" materials was practically uniform up to the edge of the intermediate zone. The structures of the different "unwelded" materials varied, however, the various types of structures encountered being shown in Figures 1 to 3, all photomicrographs at X1000 magnification. The white areas in Figures 1 and 2 are ferrite, the iron constituent; the dark areas are fine pearlite, the eutectoid of the iron constituent and iron carbide. Specimens 2B, 4 and 5 have the structure shown in Figure 1, Specimens 1 and 2A the structure shown in Figure 2. The structures are fairly similar, the only difference being that the former is finer-grained and free from a ferrite banding in a direction parallel to the sheet surface of the ferrite constituent. Specimen 1 contains somewhat more pearlite than the other samples. Figure 3 shows the structure of Specimen 3. The rounded white particles are iron carbide; the background constituent broken up by grain boundary, ferrite.

The "intermediate" zone of all specimens but that taken from Test Piece 1 had the structure shown in Figure 4, a photomicrograph at X1000 magnification obtained from the "intermediate" zone of Test Piece 2A. The light etching areas are ferrite, the dark etching areas are fine pearlite. The grain size is quite large, the only grain boundary shown beginning at the bottom of the right-hand corner. The structure of the "intermediate" zone in Specimen 1, shown at X1000 magnification in Figure 5, is similar to other "intermediate" zone structures save that it is more acicular. The rapidity with which this area etched also shows

(Microscopic Examination, cont'd) -

that the pearlite is considerably finer.

The structure shown in Figure 6, a photomicrograph at X1000 magnification obtained from the weld zone of Specimen 2A, is that of all the weld metal areas, the white areas being ferrite and the dark etching material being pearlite.

Discussion:

Macro-Examination -

The welds on Specimens 1 and 4 were somewhat irregular in thickness while the weld metal on Specimens 3 and 4 was not sufficiently thick. Only Specimen 4, however, actually broke in the weld, so, with this exception, weld metal defects cannot have been responsible for the poor physical properties of the specimens. There was only a very thin layer of weld metal on Specimen 4, however, and this condition was probably responsible for the low physical properties obtained from this specimen.

Chemical Analysis -

The relative chemical requirements for S.A.E. X4130 steel, the material usually specified for welded aircraft construction, are as follows:

Carbon, per cent	Manganese, per cent	Chromium, per cent	Molybdenum, per cent
0.25-0.35	0.40-0.60	0.80-1.10	0.15-0.25

With the exception of the carbon content of the steels in Specimens 3, 4 and 5, and the molybdenum content of the steel in Specimen 2A, all the elements analysed for

(Discussion, cont'd) -

approach the specified maximum, with the chromium and molybdenum contents of the Specimen 3 material and the carbon content of the steel in Specimen 1 being sufficiently high to place these steels outside the specification limits. Because of their higher alloy and carbon contents these steels would tend to air harden more than the average S.A.E. X4130 steel. This is especially true of the steel in Specimen 1 which because of its high carbon content qualifies as an S.A.E. 4140 steel, for of all the elements in steel carbon is probably the most effective hardener. Up to a point there is an advantage in an air hardening steel. However, if the steel hardens too much it becomes brittle and the weld is weakened.

Hardness Tests -

The uniform hardness of the weld metal and intermediate zones indicates fairly good welding technique. These hardnesses, with the exception of a small point in Specimen 3 and the entire intermediate zone in Specimen 1 which are excessively hard, may be considered satisfactory. These latter very hard zones would have good strength under steady loads but would probably break under any suddenly applied or out-of-line stress. The following table lists an estimate of the physical properties of the intermediate zone material based on their hardnesses and information given in Climax Molybdenum Company physical charts. The fall in impact properties when the hardness exceeds 400 is

(Continued on next page)

(Discussion, cont'd) -
(Hardness tests, cont'd) -

evident and would be even more marked in this case, as a welded structure is essentially a cast structure while these figures are for wrought heat-treated materials.

Steel.	Vickers hardness.	Ultimate strength, p.s.i.	Yield point, p.s.i.	Reduction in area, p.c.	Elongation in 2 in., p.c.	Izod impact, ft.lb.
4140 (Specimen 1)	514	275,000	250,000	30	7	7
X4130	415	215,000	180,000	45	11	16
X4130	350	175,000	150,000	55	17	50
X4130	300	160,000	130,000	60	19	78

With the exception of Specimen 3, the "unwelded" materials have fairly uniform hardnesses and would be expected to have tensile strengths in the neighbourhood of 100,000 p.s.i., with corresponding physical properties. The unwelded material in Specimen 3 is, however, in the softest condition that it is possible to get S.A.E. X4130 steel and would probably have a tensile strength of about 80,000 p.s.i.

Whittemore and Brueggeman (Technical Publication 348, pp. 323-359, 1930 U. S. National Advisory Committee for Aeronautics) give the results of Vickers hardness tests made on welded X4130 tubing. The "unwelded" material they tested had an average hardness of 240. They found that the "intermediate" zone and weld metal had average hardnesses of 275 and 175 respectively.

With the exception of the "unwelded" material, the steels examined all have, for a similar location with

(Discussion, cont'd) -
(Hardness tests, cont'd) -

respect to the weld, higher hardness than the material examined by Whittemore and Brueggeman. With the exception of the very high hardness of the "intermediate" zone of Specimen 1, which was the only one to fail near the weld, this is of no great importance and merely indicates the steels were either cooled more rapidly or are higher in air hardening elements. The softer "unwelded" material in the specimens examined would not be expected to be as strong as the "unwelded" material tested by Whittemore and Brueggeman. Probably this explains the low tensile strengths of test specimens that broke away from the weld. A harder and stronger sheet would have been produced if the steels had been cooled more rapidly in the normalizing treatment. The welder, of course, cannot be held responsible for this.

Microscopic Examination -

The soundness of the weld showed good welding technique. The relative amounts of pearlite and ferrite in the weld metal show that a low carbon welding rod was used. The "intermediate zone" structures are what would be expected in an S.A.E. X4130 steel that had been heated to a fairly high temperature and cooled rapidly in air. The acicular nature and rapid etching of the "intermediate" zone in Specimen 1 along with its hardness indicate that the fine pearlite in this material is approaching the brittle troostitic form, probably as a result of the higher carbon content of this steel. The uniformity and similarity of the "intermediate" and "unwelded" areas of the other test

(Discussion, cont'd) -
(Microscopic examination, cont'd) -

specimens indicate good welding practice.

The various "unwelded" materials vary more in structure than the metal affected by the welding operation. The banding of the ferrite in Specimens 1 and 2A probably indicates that they were cooled somewhat more slowly than unbanded specimens 2B, 4, and 5. The high pearlite content in Specimen 1 is in keeping with its higher carbon content. The most striking fact brought out by the microscopic examination is that Steel 3 is in the spheroidized state. Steel is generally only heat treated to this condition when great ductility is required and strength is of relative unimportance, the structure usually being produced by quenching from over the critical temperature and then holding for a period at just under the critical temperature (1380° F. for X4130 steel). In view of its structure it is not surprising that Specimen 3 broke at a low load.

The variety of structures found in each test specimen is a definite proof that they were not heat treated after welding.

<u>Summary and Conclusions:</u>

The welds on Specimens 1 and 4 were somewhat irregular in thickness, with the weld on Specimen 4 being definitely too thin. The compositions of the steels in Specimens 1 and 3 were found to be outside the limits specified for S.A.E. X4130 steel. With the exception of Steel 1, all "unwelded" materials were somewhat softer than expected, an indication that they had been cooled more

(Summary and Conclusions, cont'd) -

slowly than usual. The weld metal zones were of uniform hardness. All "intermediate" zones were fairly hard, that of Specimen 1, as a result of its higher carbon content, being dangerously so. Microscopic examination showed that the welds were sound, that a low carbon welding rod had been used, that the "intermediate" zone structures, with the exception of that in Specimen 1, were satisfactory. This latter material because of its higher carbon content approached the unsatisfactory troostitic condition. All "unwelded" material but that in Specimen 3 had structures typical for a normalized S.A.E. X4130 steel. Steel 3 was in the spheroidized form.

The poor physical properties obtained must be attributed to the metal in which failure occurred. Specimen 4 failed in the weld, and in this case the welder is responsible, as the weld metal is considered to be too thin. Specimen 1 failed in the intermediate zone and failure in this case is attributed to this material becoming embrittled because of the high carbon content of the sheet. All other specimens failed in the unwelded material. The low strength properties of Specimens 2A, 2B and 5 were probably due to the fact that the sheets used for these specimens were cooled somewhat more slowly in the final heat treatment than is the usual practice. The poor properties obtained from Specimen 3 can definitely

(Summary and Conclusions, cont'd) -

be attributed to the soft spheroidized condition of the base sheet. Only one of the failures, then, can be definitely blamed on poor welding practice.

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Figure 1.

X1000.
"Unwelded" material, Specimen 4.

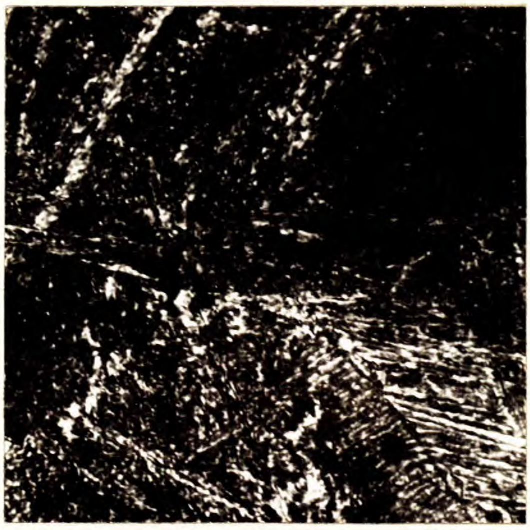
Figure 2.

X1000.
"Unwelded" material, Specimen 2A.

Figure 3.

X1000.
"Unwelded" material, Specimen 3.

Figure 4.



X1000.
"Intermediate" zone, Specimen 2A.

Figure 5.

X1000.
"Intermediate" zone, Specimen 1.

Figure 6.

X1000.
Weld metal, Specimen 2A.

(NOTE: All specimens etched in 2 per cent Nital.)

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