

TESTS OF WELDED STEEL AIRPLANE JOINTS

by

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A. B., Sterling College, 1928

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A THESIS

submitted in partial fulfillment of the

requirements for the degree of

MASTER OF SCIENCE

KANSAS STATE COLLEGE  
OF AGRICULTURE AND APPLIED SCIENCE

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TABLE OF CONTENTS

INTRODUCTION . . . . .	4
PURPOSE . . . . .	5
GENERAL METHODS . . . . .	6
METHODS OF JOINING AIRCRAFT STRUCTURES . . . . .	7
Mechanical Methods . . . . .	7
<u>Bolting</u> . . . . .	7
<u>Riveting</u> . . . . .	7
<u>Seaming</u> . . . . .	8
<u>Pinning and swaging</u> . . . . .	8
Thermal Methods . . . . .	8
<u>Soldering</u> . . . . .	8
<u>Brazing</u> . . . . .	9
<u>Welding</u> . . . . .	10
WELDING TECHNIQUE . . . . .	12
WELDING ROD . . . . .	15
TYPES OF WELDED JOINTS . . . . .	16
PROPERTIES OF WELDS . . . . .	23
Chemical Properties . . . . .	23
PHYSICAL PROPERTIES . . . . .	25
Explanation of Table I, Figures 2, 3, and 4 . . . . .	25
Explanation of Table II . . . . .	36

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Explanation of Figure 6 . . . . .	45
Explanation of Figure 7 . . . . .	49
Explanation of Figure 8 . . . . .	53
MICROSTRUCTURE . . . . .	55
SUMMARY AND CONCLUSIONS . . . . .	76
ACKNOWLEDGMENT . . . . .	81
CITATION OF LITERATURE . . . . .	82

## INTRODUCTION

The fuselage of the early airplanes was a wooden structure. Since 1920, this type of structure has practically gone out of existence, although some planes still have their wing structures made of wood. With the early forms of aircraft, it was necessary to use a wooden structure in order to have the necessary lightness. However, the use of wood in airplane structure has many objectional features. A wooden structure lacks safety both from the standpoint of fire hazard and collapse in forced landing. Wood is affected by moisture and heat. The life of a wooden structure is comparatively short.

The use of a tubular steel structure with welded joints has eliminated these difficulties to a considerable extent.

The field of autogenous oxy-acetylene welding is comparatively new, hence its use in the manufacture of airplanes dates back only a very few years. Literature upon the subject of welded steel airplane joints is very limited at the present time. However, our colleges are realizing the importance of this ever increasing field and investigations are being promoted. Many industrial concerns

are conducting research in this field, but they are making their investigations for the sole purpose of having their firm produce a product superior to that of their competitors and, hence, they are not, in general, publishing their results.

#### PURPOSE

There has been very little information published upon the tests of oxy-acetylene welds in light steel tubing used in airplane construction. There are many lines of study in the field of airplane welding, some of the more important being as follows: tensile tests; heat-treatments; x-ray study; stethoscope study; testing of filler rods; study of microstructure; shear tests; bend tests; hardness tests; and welding by other processes than oxy-acetylene.

This study was carried on entirely in connection with: (1) the comparative strength of different types of welded joints, (2) the comparative strength of welds made by different welders, (3) the comparative strength of welds in carbon tubing (S. A. E. No. 1020) and chrome-molybdenum tubing (S. A. E. No. 4130), (4) the comparative strength of different heat-treatments, (5) the character of the failure, and (6) the study of microstructures.

## GENERAL METHODS

Specimens nine inches in length of carbon tubing (S. A. E. 1020) and chrome-molybdenum tubing (S. A. E. 4130) were made in (1) butt joints, (2) short miter joints, (3) long miter joints, and (4) fish-mouth joints.

The carbon tubing (S. A. E. 1020) was one inch in diameter with a wall thickness of one thirty-second of an inch. The chrome-molybdenum tubing (S. A. E. 4130) was seven-eighths of an inch in diameter with a wall thickness of one-sixteenth of an inch. In a few cases chrome-molybdenum tubing (S. A. E. 4130) of a slightly smaller diameter and somewhat less wall thickness was used on account of this being a stock size. Round tubes were used for all specimens.

After welding and heat-treating (where heat-treating was desired) the ultimate tensile strength was determined by the use of a Riehle tensile testing machine.

Microscopic and macroscopic examinations were made and the results are evidenced by microphotographs and macrophotographs.

## METHODS OF JOINING AIRCRAFT STRUCTURES

There are two general methods of joining metal airplane structures, namely, mechanical and thermal, depending upon whether or not fusion is used in the process. A brief description of these methods follows.

### Mechanical Methods

Bolting. Bolts are used extensively for joints between wood and metal for adjustable connections, hinged joints, and joints between various major assemblies. Bolts are generally used in shear. They are used through-out the motor assembly and for attaching the motor to the fuselage.

Riveting. Rivets are used to join dissimilar metals and heat-treated aluminum alloys and sometimes as an auxiliary means in connection with welded joints. Rivets are used in combining welded steel socket fittings and duralumin tubes. They are not good tension members, as the head is generally weak and liable to break off under the prying action of a tension load.

Seaming. Seaming is used very little for steel structures, but extensively for brass, copper, and coated steel in the manufacture of gasoline tanks, radiators, and similar parts. Since seams are generally used for fluid or gas containers, solder is used to fill the joint.

Pinning and swaging. Pinning and swaging are sometimes used in joining airplane structures but these are not considered important.

#### Thermal Methods

The thermal methods have practically superseded the mechanical methods for joining certain parts manufactured of steel, copper, brass and aluminum alloys.

Soldering. Soldering may be divided into two divisions, soft and hard soldering.

Soft soldering with a lead-tin alloy is usually used for copper, brass, and coated steel in conjunction with mechanical seams. It is sometimes used for filling joints to promote rigidity and prevent corrosion. It is doubtful whether this is of much value in the airplane, and its use should be confined to very minor parts. Soft solder yields gradually under a steadily applied load and is never used as the sole means of attachment of a structural member.



Hard soldering with a silver base alloy is used principally for copper fuel and oil lines. It contains approximately 50% silver and flows under the torch at 1430° F. A hard solder joint is superior to a soft solder joint under vibration, and for some copper or copper base alloys it is satisfactory.

Brazing. The term brazing is defined as a method of joining metal parts by means of a copper-zinc mixture which is applied by melting with an air-gas flame, oxy-acetylene flame, or by dipping into the molten mixture. Torch brazing has never been entirely satisfactory on aircraft fittings, as it is difficult for a mechanic to avoid scaling or oxidizing the joint, in which case good penetration is not obtained.

A low-melting point (1650° F.) brazing mixture containing 80% copper and 20% zinc must be used in case the parts are to be heat-treated after brazing. This mixture oxidizes easily and does not flow under the torch as well as the low copper mixture.

The strength of the brazed joint depends upon the surface area of the joint and the clearance between the parts to be joined. The strength will not be affected to an appreciable extent by the composition of the commercial brazing mixtures. Cleanliness and proper preheating are of utmost importance in securing a strong brazed joint.

The restricted depth of penetration of the brazing mixture into the joint and the stripping of the adhering brass after brazing have led to almost complete abandonment of this process except for very minor parts and repair purposes. Welding must never be used after a joint has been brazed or in repairing a brazed joint. Brazing, however, may be used after all welding is completed.

Welding. Welding is defined by the American Welding Society as the "localized intimate union of metal parts in the plastic or plastic and molten states with the application of mechanical pressure or blows, and in the molten and vapor states without the application of mechanical pressure or blows". This applies to all forms of welding whether the metal is heated in a forge fire, by electricity, or by a gas torch.

Electric welding for joining airplane structures may be divided into two classes metallic arc and flash welding.

Metallic Arc. This may be either alternating or direct current. Arc welding in airplane construction has not proven fully satisfactory. The outstanding reason for this lies in the fact that the bulk of the present electric generators now on the market are made for use on heavier material such as is found in railroad and general repair shops, hence they are not entirely suitable for welding

thin tubular structures. Arc welds are more subject to slag inclusions, blow holes and gas pockets than are oxy-acetylene welds. These defects prove very detrimental in the obtaining of high tensile strengths in welded steel tubing.

Flash welding is another kind of electric welding used in airplane construction utilizing an alternating current. It is only practical to use where a large number of duplicate pieces are to be manufactured, since each size of tubing requires a complete new set up. This method has not been used in the assembly of the fuselage of the airplane as yet, but, will be highly desirable once sufficient quantity production is attained to warrant the great expense involved in its use. A very sound weld is produced by this method as complete fusion is almost certain. The molten metal which might have been slightly oxidized is usually forced out in the flash and does not form a part of the weld. Gas inclusions and blow holes are practically unknown in this type of welding.

Gas welding in airplane construction is practically confined to the oxygen-acetylene process as it is very adaptable to the welding of thin metal. Oxy-hydrogen is sometimes used for welding aluminum alloys.

The oxy-acetylene flame has a maximum temperature of about 6000° F. This is ample heat to assure the proper melting and complete fusion of both the base metal and the welding rod.

The investigations carried on in this research problem were made entirely on oxy-acetylene welds.

#### WELDING TECHNIQUE

In the best welding literature there are several practices listed which they claim, if observed, will assure greater efficiency of airplane welds.

Cleanliness is a factor of utmost importance. Prior to welding, the parts to be welded should be thoroughly cleaned inside and out with a wire brush or emery cloth. A dirty weld can never be a successful weld. All sharp corners or projections of excess metal formed in cutting should be ground off. If left on they will burn before the base metal is melted and then will enter the weld as burnt metal.

Overheating or burned metal should be avoided as this is very often the cause of a weak weld.

The welding tip should be kept clean. There should be a soft neutral flame neither pointed or irregular.

It is advisable to always use high test welding rod. Inferior rod will cause a weak weld which otherwise would have been of normal strength.

Surplus material or excessive beads should be avoided. The results are burnt metal, excessive weight and greater opportunity for cracking.

It is very important that the tack weld be properly fused in the final weld. This precaution is often overlooked.

Tack welds should be applied to the tubes to be welded at three equi-distant points. They should be from  $3/16$  to  $1/4$  of an inch long. The tubes should have at least  $1/16$  of an inch space between them before tacking. This is to permit proper expansion and contraction.

The bead should be from  $1/16$  to  $1/8$  of an inch thick and the contour should be regular. The bead should taper evenly to each side and disappear into the base metal gradually with no sharp corners or abrupt endings.

Penetration is of utmost importance. Fusion of the base should take place completely for a distance equal to 90% of the thickness of the tube wall.

The molten metal should be worked or puddled sufficiently to cause the slag inclusions and oxides to float to the surface but great care must be taken not to work

any of the slag back into the solidifying metal. Over puddling is even more harmful than under puddling.

Particular care must be taken when finishing a weld, or when stopping during welding, to withdraw the flame slowly. This prevents the formation of blow holes or gas pockets caused by sudden solidification of the molten puddle and the consequent entrapping of some of the slag and iron oxides. When starting on an incompletd seam care must be taken to remelt into the previously made part of the weld until thoroughly clean metal is observed and thus avoid the formation of blow holes or gas pockets. Under no circumstances is it permissible to force the rod ahead of the puddle.

On tubing the weld must be thoroughly closed at the finish to make certain that the weld is thoroughly penetrated into the previously made weld. The best way to insure this is to reheat the weld zone about one fourth inch beyond the closure point.

The molten metal should not be permitted to spark to any great extent. It is a sure sign of overheating and results in excessive grain growth and blisters. Also, the sparks may fall into the puddle and thus form an inclusion.

## WELDING ROD

Through-out the tests, high test welding rod\* was used, with the exception of specimens designated as I C, in which case the welder preferred not to use it. Of the four welds made by this welder, two were above average, one about average and one was a failure, breaking in the weld with a low tensile strength. The tube had not even been fused together in some places, and in other places, fusion had taken place only in the upper portion of the weld. The inferior rod no doubt was partially the cause of this.

Claims made for the use of high test rod:--

1. Prevents reduction of carbon. When using Norway iron welding rod, much carbon is removed during welding. The carbon is removed by combination with oxygen and forming carbon monoxide or carbon dioxide. When high test welding rod is used both manganese and silicon are oxidized at the same time. Silicon is inherently more easily oxidized but the manganese is also oxidized because it is present in greater amount. The oxides formed, together

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\*The high test welding rod referred to was Oxweld No. 1 high test welding rod.

with some iron oxide, combine to form an iron-manganese silicate that readily floats to the surface in the form of a slag, which although extremely shallow protects the molten and cooling metal from the oxidizing action of the surrounding atmosphere, and thus keeps the amount of oxidation at a minimum. The presence in the specified proportions of manganese and silicon, which have greater affinity than carbon for oxygen largely prevents the union of oxygen with carbon during the decomposition of the weld metal. Thus sufficient carbon content of the weld metal is retained by the use of high test rod.

2. Prevents blow holes. With Norway iron filler rod the carbon monoxide and carbon dioxide formed during welding may not all escape before the molten metal solidifies. Hence many pin-holes and blow-holes appear through-out the weld. The use of high test filler rod will not permit the formation of carbon monoxide and carbon dioxide to any great extent, as explained above, and hence blow-holes and blisters will be prevented.

3. Reduces slag inclusions. Slag produced by high test rod is easily distinguishable from the molten weld metal. When welds are made with Norway iron filler rod this is not the case, as the film on the surface of the weld is mainly iron oxide from the base metal. The elements



that supply the fluxing action in high test rod are a part of the rod itself, providing a cleansing agent through-out the weld metal in such a way that, wherever oxide may be present, active deoxidizers are immediately available to remove impurities in the form of floating slag.

4. Assures better fusion. Since the melting temperature of iron oxide produced when using Norway iron rod is less than that of iron, welders often mistakenly believe that the metal is being melted when it is really only the oxide covering that flows over the surface to be united. This results in inclusions of oxide films, laps and poor fusion. Due to the fluxing and deoxidizing actions of the high test rod, fusion at the very bottom of the "V" is easily obtained.

5. Greater strength, hence greater economy. Mr. William Henderson of the Los Angeles Gas and Electric Corporation states: "When using low carbon rod it is necessary to build up the welds to get strength. Oxweld No. 1 high test rod costs twice as much as the low carbon rod, but flush welds can be made which means that only about 70% as much rod was required, which represents a corresponding decrease of time in welding, and, naturally, a saving in gas. The result was a stronger weld was obtained at considerably less cost, the saving, depending

upon the size of the weld, ranging from 10 to 40%".

High test rod is slightly more viscous than Norway iron rod. When properly deposited it sparks but little. Sparks from the welding iron are carriers of oxide which, if deposited in the welding puddle, are a source of oxide inclusions and blow-holes. A considerable sparking of high test rod is an indication of overheating, which must be avoided in order to secure welds of maximum strength.

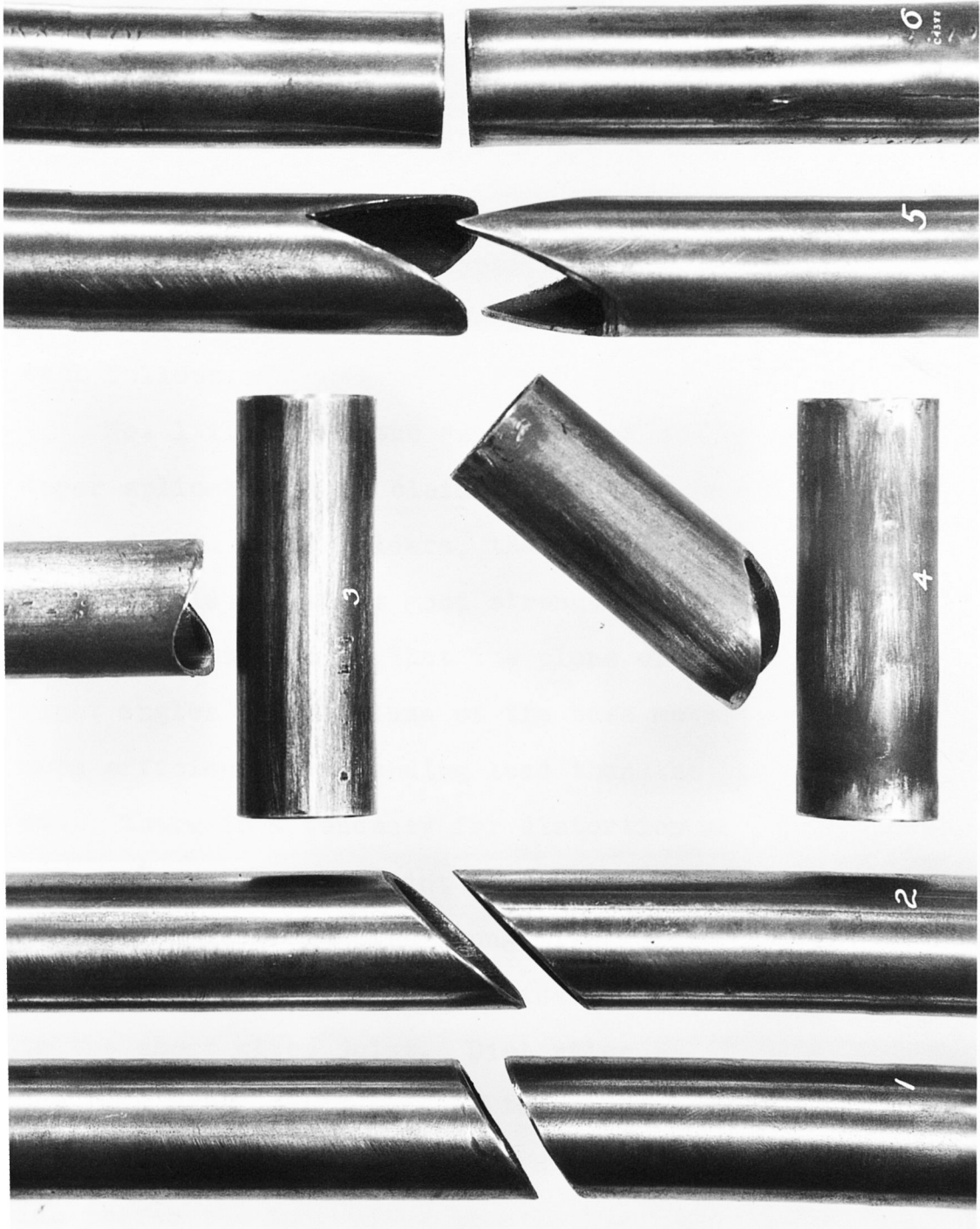


Fig. 1.  
Types of Joints

## TYPES OF WELDED JOINTS

While there exists many types of joints this research dealt with six principle types, as shown in Figure 1. A general description of these joints and claims made for each follows.

No. 1 is termed the "short miter joint" or "short taper splice". It is claimed that this is the favorite type of weld among welders, that it is easy to prepare, easy to weld and shows good strength. It has an advantage over the butt weld in that the plane of the weld is not at right angles to the plane of the base metal and that it is more efficient on a bending load than the butt weld. However, there is a tendency for distortion of the base metal when the short miter joint is used.

No. 2 is termed the "long miter joint" or "long taper splice". Its advantages and disadvantages are very similar to the short miter joint. Distortion is still greater in the long miter joint than in the short miter joint due to the longer splice. Welders inexperienced in airplane welding prefer the long miter because they can usually obtain a stronger weld on account of the greater distance that can be welded in one direction.

No. 3 is known as a "90-degree angle joint" or "tee joint". The abutting member is machined so that the end will fit the contour of the continuous member. It is a simple joint to prepare.

No. 4 is known as a "short angle joint". It is a very common joint in airplane construction. It is difficult to weld, especially on the underside and should never be attempted in actual practice by any except expert welders. Where several abutting members join the continuous member in one plane, it is known as a cluster joint.

No. 5 is known as the "fishmouth joint". It is a highly recommended type of joint where compressive strength is of the utmost importance. Those inexperienced in the art of welding tubing find it a very difficult joint to weld. In tension, the failure invariably occurs at the points of the fish mouth. This is due to the greater concentration of heat at this point when attempting to reverse the direction of welding. The angle of the "V" should be 60 degrees. The angle of the cut should be such that the axial depth of the cut from the tip to the bottom is equal to the diameter of the tube. When used in repair work, the new section is slipped over the tube to be repaired so that it overlaps at least two inches. It must obviously fit snugly over the

old section. A gap should be left between the ends of the broken tube to allow for expansion. The chief advantage of using this type of repair over merely welding the broken sections together lies in the fact that the weld is placed outside of the area under stress and in its place is new metal with greater area and hence greater strength than the original structure.

No. 6 is a straight "butt joint". The butt weld should not be used in airplane construction where the joint is subjected to a bending load. The plane of the weld is at right angles to the axis of the tube. The butt joint has fair strength in compression and tension. If this type of joint is used in a place subject to bending or vibration it is necessary to use reinforcement. This is usually accomplished by placing over the joint a section of tubing which fits snugly. The ends of the reinforcement tube should be cut at an angle so that the weld will not be in plane at right angles to the plane of the tubing. A small opening should be left between the ends of the main members to allow for expansion.

## PROPERTIES OF WELDS

The properties of welds may be divided into two classes; chemical properties; physical properties, or microstructure.

### Chemical Properties

The chemical properties of a weld will depend upon the material in the base metal and in the filler rod. Considerable carbon is lost through oxidization at the welding heat. The carbon forms carbon monoxide and carbon dioxide which passes off as a gas. If a carburizing flame was used, the carbon content of the weld would be increased. Since it is impossible to control the extent of carburizing high carbon may result and cause brittleness. In the case of using chrome-molybdenum tubing (S. A. E. 4130), both chromium and molybdenum are transferred from the base metal to the weld metal and according to Johnson, the transfer is in the same proportion as shown in the following analysis of base and weld metal.

	<u>Carbon</u>	<u>Chromium</u>	<u>Molybdenum</u>
Base Metal	0.33%	0.90%	0.23%
Oxy-acetylene Weld	0.06%	0.18%	0.05%

### CHEMICAL COMPOSITIONS

#### S. A. E. Standard

#### Carbon Steel Tubing. S. A. E. Steel No. 1020.

Carbon range	0.15% to 0.25%
Manganese range	0.30% to 0.60%
Phosphorus - maximum	0.045%
Sulphur - maximum	0.05%

#### Chrome-Molybdenum Steel Tubing. S. A. E. Steel No. 4130.

Carbon range	0.25% to 0.35%
Manganese range	0.40% to 0.70%
Chromium range	0.50% to 0.80%
Molybdenum range	0.15% to 0.25%
Phosphorus - maximum	0.04%
Sulphur - maximum	0.045%

#### High Test Welding Rod.

Percent carbon	0.17%
Percent manganese	0.80%
Percent silicon	0.50%



Percent phosphorus - maximum	0.04%
Percent sulphur - maximum	0.04%

### PHYSICAL PROPERTIES

#### Explanation of Table I, Figures 2, 3, and 4

Table I, Figures 2, 3, and 4 deal with welds which have undergone no special heat treatment. In welds II D-2; III A-2; III E-2; III E-4; and IV F-4, the tube was reheated by the torch flame.

Except in some instances where the tube had been annealed with the torch, the chrome-molybdenum tubing (S. A. E. 4130) broke very suddenly with no apparent cracking or pulling apart before the complete fracture. The tensile strength suffered in these cases.

The carbon tubing (S. A. E. 1020) pulled apart gradually, and necking was more pronounced than in the chrome-molybdenum (S.A.E. 4130) tubing. A slight fracture appeared several seconds before the final break. The fracture in both the chrome-molybdenum and carbon tubing followed the outside zone of the heat from the oxy-acetylene flame except where a defective weld or undercutting existed. In the defective welds, the fracture occurred

TABLE I

Data for Figures 2, 3, and 4. Welds Untreated.

Welder No.	Tube No.	Type of Joint	Diameter of Tube in in.	Thickness of Wall in in.	Actual Area in sq. in.	S.A.E. No.	Elastic Limit in lb.	Ultimate Tensile Strength in lb.	Elastic Limit Lb. per sq. in.	Ultimate Tensile Strength lb. per sq. in.
I	C-2	Butt	0.875	0.046	0.1219	4130	12,130	12,850	99,470	105,370
I	C-4	Short Miter	0.875	0.062	0.1595	4130	9,780	11,320	61,410	71,070
I	C-1	Long Miter	0.750	0.062	0.1349	4130	9,120	9,980	67,570	73,940
I	C-3	Fishmouth	0.843	0.046	0.1173	4130	9,490	10,950	80,870	93,310
II	D-2	Butt	0.843	0.046	0.1173	4130	11,300	12,960	96,290	110,440
II	D-4	Short Miter	0.750	0.046	0.1012	4130	10,030	10,780	99,070	106,480
II	D-1	Long Miter	0.718	0.039	0.0834	4130	10,150	11,390	121,700	136,570
II	D-3	Fishmouth	0.843	0.039	0.1039	4130	9,380	9,810	90,280	94,430
III	A-3	Butt	1.000	0.031	0.0951	1020	2,910	4,630	30,590	48,690
III	A-4	Short Miter	1.000	0.031	0.0951	1020	3,242	4,770	34,090	50,160
III	A-1	Long Miter	1.000	0.031	0.0951	1020	3,520	4,800	37,010	50,470
III	A-3	Fishmouth	1.000	0.031	0.0951	1020	3,440	4,800	36,170	50,470
IV	B-2	Butt	1.000	0.031	0.0951	1020	2,220	5,060	23,340	53,210
IV	B-4	Short Miter	1.000	0.031	0.0951	1020	3,200	5,300	33,650	55,730
IV	B-1	Long Miter	1.000	0.031	0.0951	1020	3,530	4,900	37,120	51,520
IV	B-3	Fishmouth	1.000	0.031	0.0951	1020	3,700	4,910	38,910	51,630
III	E-2	Butt	0.875	0.062	0.1595	4130	10,280	11,030	64,450	69,150
III	E-4	Short Miter	0.875	0.062	0.1595	4130	10,580	12,190	66,330	76,430
III	E-1	Long Miter	0.875	0.062	0.1595	4130	10,990	12,160	68,900	76,240
III	E-3	Fishmouth	0.875	0.062	0.1595	4130	10,950	11,710	68,590	73,420
IV	F-2	Butt	0.875	0.062	0.1595	4130	10,700	11,810	67,080	74,040
IV	F-4	Short Miter	0.875	0.062	0.1595	4130	9,550	11,050	59,870	69,280
IV	F-1	Long Miter	0.875	0.062	0.1595	4130	10,360	11,640	64,950	72,980
IV	F-3	Fishmouth	0.875	0.062	0.1595	4130	10,520	12,010	65,960	75,300

partially or entirely in the bead. Where undercutting prevailed the fracture followed the edge of the bead.

The fracture in I C-2 occurred about three-eighths of an inch from the weld and followed the outside line of the heat. The fracture was parallel to the weld.

The weld in I C-4 was defective. The fracture followed the center of the bead. Penetration was lacking and in some places fusion of the ends of the tubes did not exist. In no place did fusion penetrate the full thickness of the tube. In one place the saw marks made in cutting the joint could be distinguished. The deposited metal appeared very dirty. Photomicrograph, Fig. 8, in a later section fully explains the condition existing in this weld.

The fracture in IC-1 broke about one-half inch from the weld and followed the angle of the joint at the very edge of the heated zone.

I C-3 pulled apart in two places. One fracture occurred at the edge of the "V". This was apparently caused by overheating at the point, producing excessive grain growth in the base metal and consequent lowering of the tensile strength. The second fracture occurred about one-half inch from the bead, in the very center of the annealed zone.

The welded tube in II D-2 was heated with the torch flame for a distance of about one and one-half inches from the weld. The result was that the annealed zone was extended back from the weld instead of being in its normal position. This caused the fracture to occur at a distance, from one and one-fourth to one and one-half inches from the weld and did not follow the angle of the weld.

Specimen II D-4 broke about seven-eighths of an inch from the weld and followed the angle of the weld.

The fracture of II D-1 occurred about one-half inch from the weld in the annealed zone and followed the angle of the weld.

The weld in II D-3 had completely burned through at the end of the "V" and the fracture followed the edge of the bead of the fishmouth for some distance. The weld showed signs of being overheated and burnt along the fracture.

The fracture in III A-2 occurred about one and one-eighth inches from the weld. The welder had traveled around the bead with the torch a second time in an attempt to get a neat appearing bead and to make fusion more complete. This additional heating drove the annealed zone out some distance from the weld, causing the fracture to occur at an abnormal distance from the joint.

The fracture of III A-4 was normal in every respect, following the contour of the joint at a distance of approximately three-eighths of an inch and was in the annealed zone.

Specimen III A-1 broke near the bead. Fracture occurred either along the very edge of the bead or within approximately one-sixteenth of an inch from the bead. This was caused by undercutting. Photomicrograph, Fig. 10, appearing later explains this defect fully.

The fracture in III A-3 occurred about three-fourths of an inch from the corners of the fishmouth. The fractures in the fishmouth joints occurred in every instance on the "V" side rather than the rounded side. The cause of this was explained in the discussion relative to types of welds.

The following three welds fractured in the annealed zone and the break followed the angle of the joint. IV B-2 broke about three-eighths of an inch from the weld; IV B-4 broke about five-eighths of an inch from the weld; and IV B-1 broke about three-eighths of an inch from the weld.

The fracture in IV B-3 occurred across the ends of the fishmouth, breaking nearly straight across.

The fracture in III E-2 occurred in the weld. This specimen had been thoroughly reheated with the torch. The surface of the base metal showed a complete fusion, but penetration was lacking and the lower half of the tube was fused completely in only a very few places.

The specimen III E-4 was also apparently heated with the torch very thoroughly. The annealing temperature was undoubtedly reached for the whole tube seemed very ductile and pulled apart gradually. The fracture was nearly straight across the tube about one inch from the weld.

Norway iron filler rod was used on III E-1. The fracture followed the angle of the joint about three-eighths of an inch from the bead. A slight fracture first appeared, then the tube broke suddenly.

The fracture in III E-3 occurred about one-half inch from the corners of the fishmouth, after considerable elongation.

The fracture in IV F-2 occurred suddenly, about three-eighths of an inch from the weld and parallel to the weld.

Specimen IV F-4 was reheated with the torch. The annealing temperature was apparently reached for the tube necked greatly showing considerable ductility as a result of reheating. The fracture occurred about one and one-half inches from the weld and followed the angle of the joint.

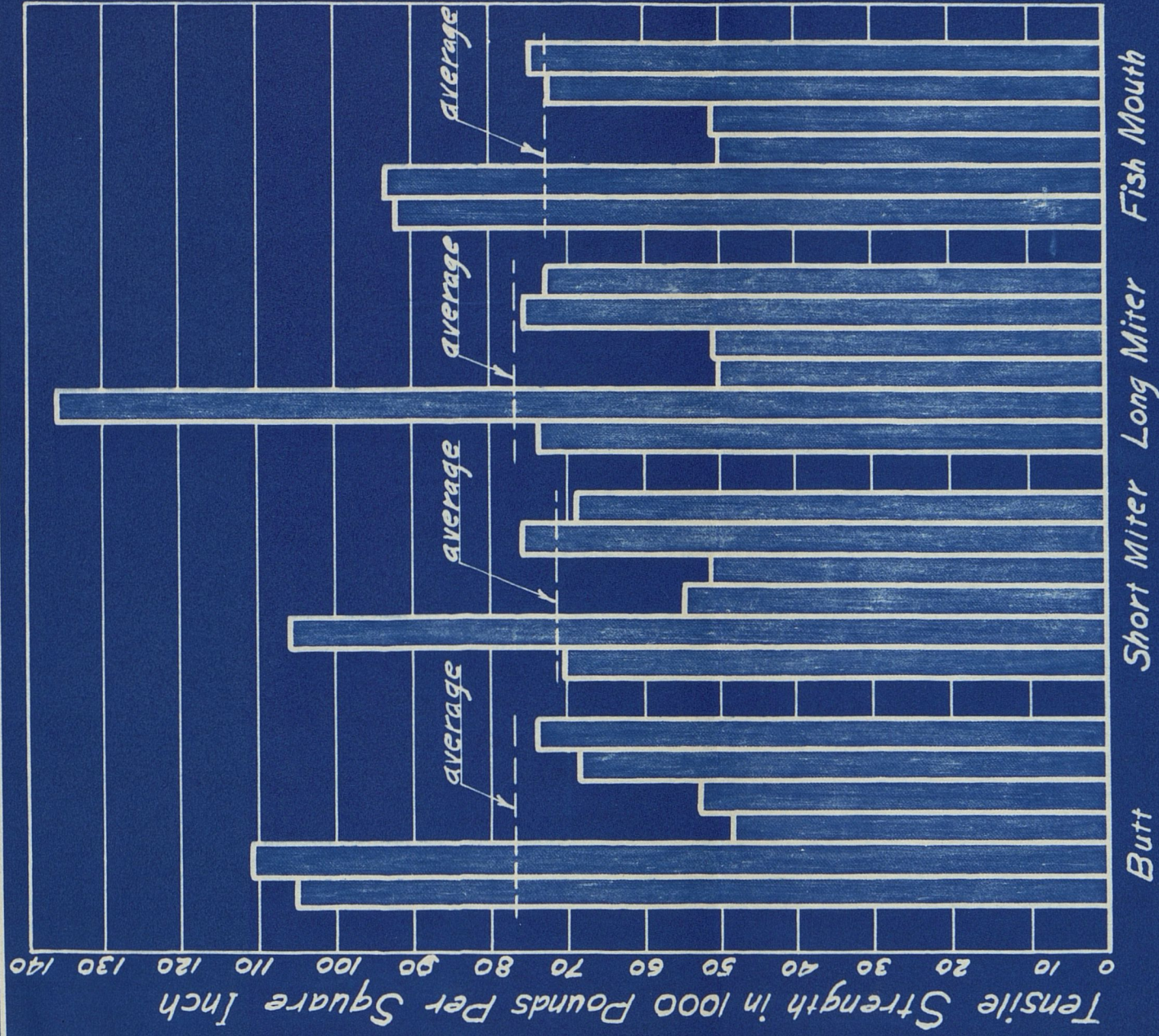


Fig. 2. Comparative Strength of Different Types of Welded Joints.

The necking began more abruptly on the side of the fracture toward the weld. On the other side of the fracture the neck was long and sloping.

The break in IV F-1 came very suddenly about three-eighths of an inch from the weld and was parallel to the joint.

Specimen IV F-3 broke straight across the tube about one and one-fourth inches from the corners of the fish-mouth.

From the above data, it can readily be seen that in airplane fabrication, it is not advisable to reheat the base metal surrounding the weld with the torch. If the annealing temperature is reached, the tube is made soft and ductile and the tensile strength is greatly reduced. It is true that strains may be removed through reheating with the torch but in general more damage than good results from the practice. When the welder has completed the weld, he should not go over it again and if any heat-treatment is desired, the heat treater should take care of it with an automatically controlled furnace.

Figure 2 shows the comparative strength of different types of welded joints. The highest tensile strength obtained in untreated chrome-molybdenum tubing (S. A. E. 4130) was 136,570 pounds per square inch. This was a long



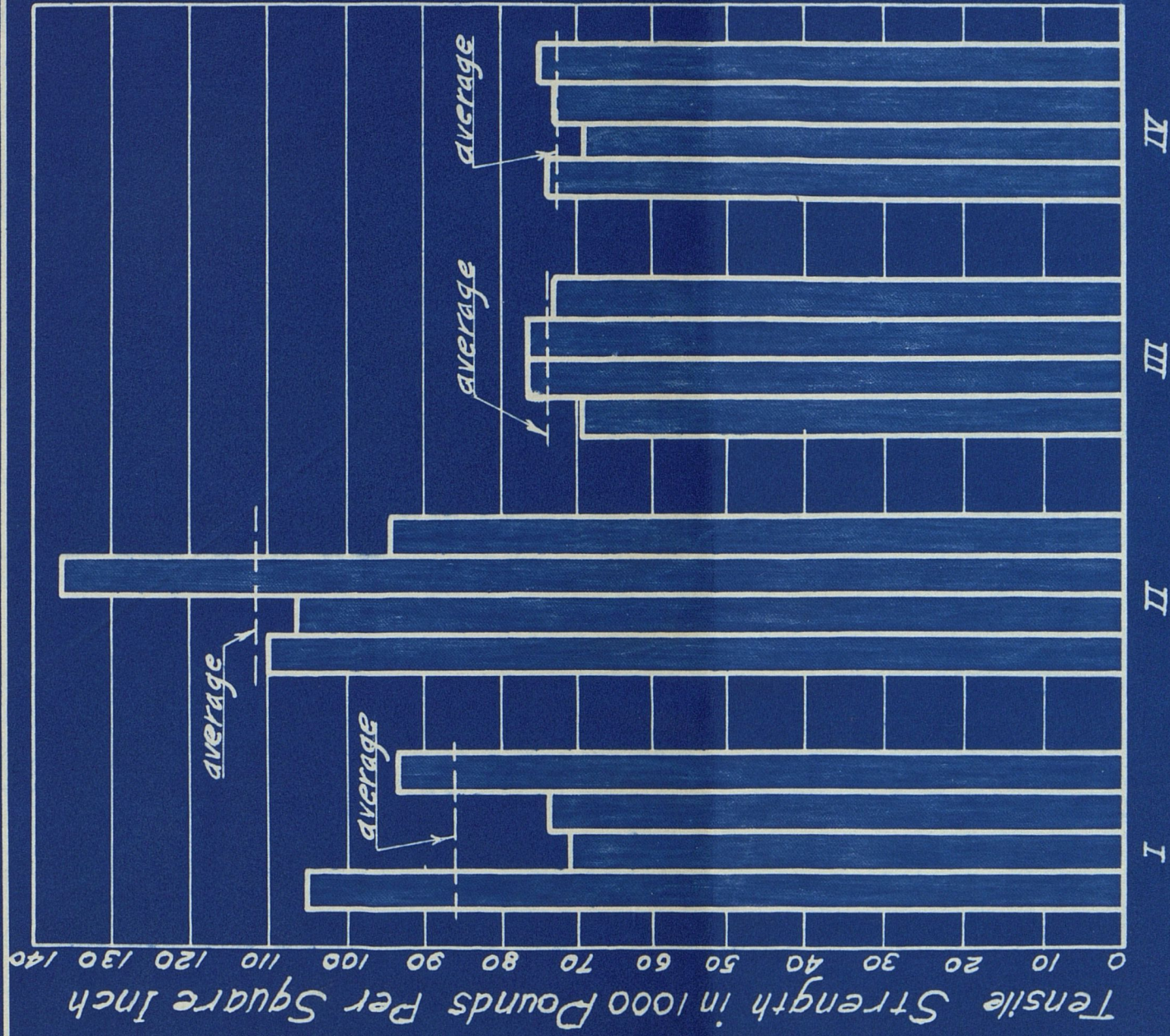


Fig. 3. Comparative Strength of Welds Made by Different Welders. S.A.E. No. 4130 Tubing.

miter joint. The lowest tensile strength found in untreated chrome-molybdenum (S. A. E. 4130) tubing was 69,150 pounds per square inch. This was a butt joint.

The highest tensile strength obtained in untreated carbon tubing (S. A. E. 1020) was 55,730 pounds per square inch. This was a short miter joint. The lowest tensile strength found in untreated carbon (S. A. E. 1020) tubing was 48,690 pounds per square inch. This was a butt joint.

Using both the chrome-molybdenum tubing (S. A. E. 4130) and carbon tubing (S. A. E. 1020), the following average tensile strength was obtained.

Butt joints	76,820 pounds per sq. in.
Short Miter joints	71,520 pounds per sq. in.
Long Miter joints	76,960 pounds per sq. in.
Fishmouth joints	73,090 pounds per sq. in.

Figure 3 shows the comparative strength of welds made by different welders using S. A. E. No. 4130 tubing. Considerable variation in the tensile strength of the welds are summarized in the following tabulation.

Welder I	85,922 pounds per sq. in.
Welder II	111,978 pounds per sq. in.
Welder III	73,808 pounds per sq. in.
Welder IV	72,899 pounds per sq. in.

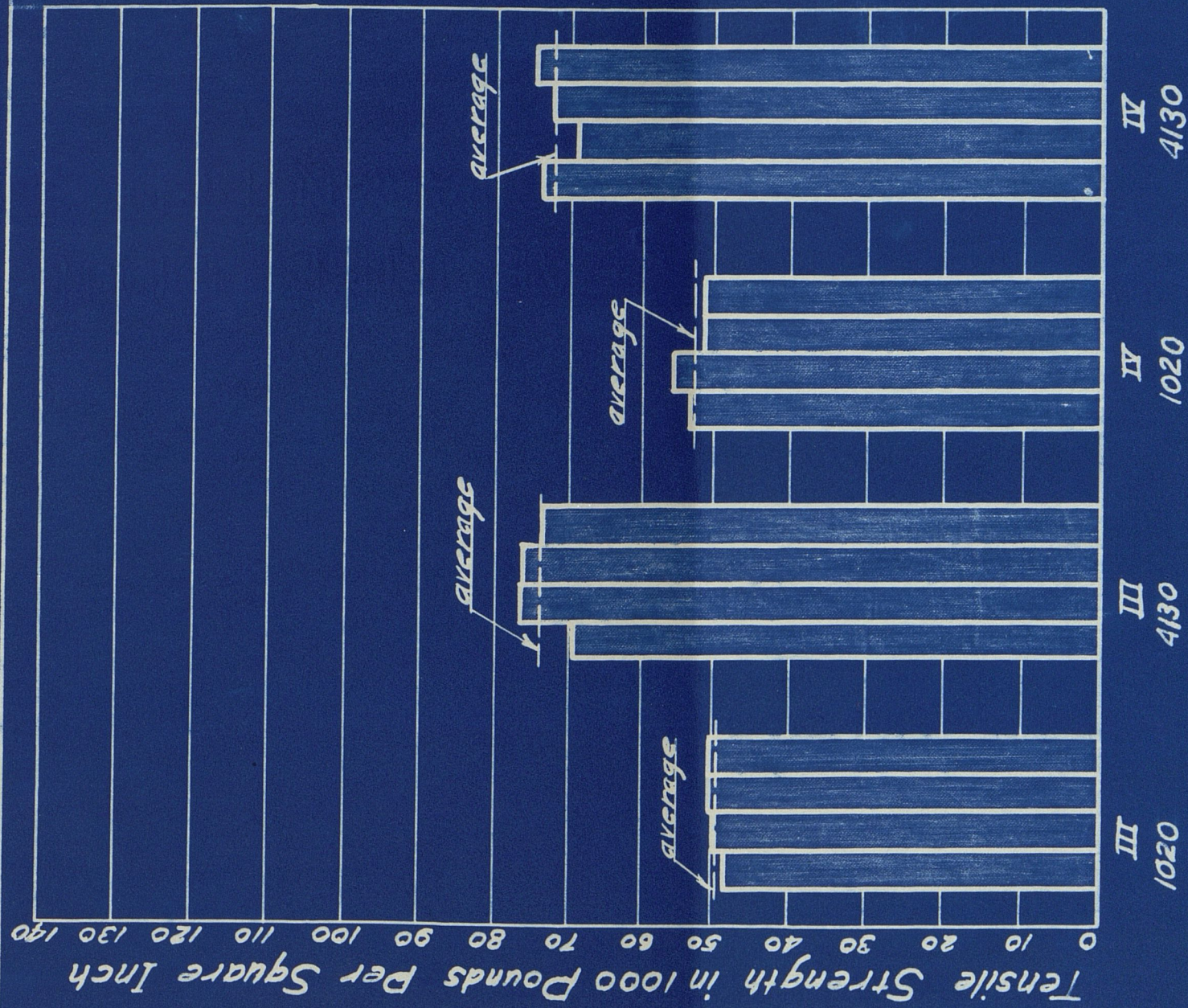


Fig. 4. Comparative Strength of Welds in S.A.E. No. 1020 and S.A.E. No. 4130 Tubing.

Figure 4 shows the comparative strength of welds in S. A. E. No. 1020 tubing and S. A. E. 4130 tubing. Comparisons were made on two different welders. The chrome-molybdenum tubing (S. A. E. 4130) averaged approximately 42 per cent greater tensile strength than the carbon tubing (S. A. E. 1020). For Welder III the increase was 47 per cent while for Welder IV the increase was 37 per cent. The following are the averages in tensile strength.

Welder III	S.A.E. No. 1020	49,947 pounds per sq. in.
Welder III	S.A.E. No. 4130	73,808 pounds per sq. in.
Welder IV	S.A.E. No. 1020	53,023 pounds per sq. in.
Welder IV	S.A.E. No. 4130	72,899 pounds per sq. in.

#### Explanation of Table II

Figures 5 and 5A summarize the contents of Table II. Figure 5 deals with the chrome-molybdenum (S. A. E. 4130) while Figure 5A deals with the carbon tubing (S. A. E. 1020).

The recommended S. A. E. heat-treatment No. VI for hardening and toughening is as follows:

S.A.E. No.	Heat to	Quench in	Draw to required hardness	Quench in
1020	1575 - 1675 F.	Water	1000 F.	Water
4130	1550 - 1650 F.	Oil	1000 F.	Water

TABLE II

Effect of Heat-Treatment on Chrome-Molybdenum  
Tubing (S. A. E. 4130) and Carbon Tubing (S. A. E. 1020)

Welder No.	Tube No.	Type of Joint	Diameter of Tube Wall	Thickness of Tube Wall	Area of Tube Wall in sq. in.	S. A. E. No.	Treatment	Actual Elastic Limit (Pounds)	Actual Ultimate Tensile Strength-lbs.	Elastic Limit in Pounds per sq. in.	Ultimate Tensile Strength in Pounds per sq. in.
IV	1	Short Miter	0.875	0.062	0.1595	4130	S.A.E. Heat-treatment No. VI	21,580	22,220	135,300	139,310
IV	2	Short Miter	0.875	0.062	0.1595	4130	Heated to critical range(1625 F) quenched in still air	13,690	13,870	85,830	86,960
IV	3	Short Miter	0.875	0.062	0.1595	4130	None	12,130	12,340	76,050	77,370
IV	4	Short Miter	0.875	0.062	0.1595	4130	Heated to critical range(1625 F) cooled in furnace	8,490	10,800	53,230	67,710
Not Welded	5		0.875	0.062	0.1595	4130	None	14,340	15,410	89,900	96,620
IV	1A	Short Miter	1.000	0.031	0.0951	1020	S.A.E. Heat-treatment No. VI	5,780	5,940	60,780	62,460
IV	2A	Short Miter	1.000	0.031	0.0951	1020	Heated to critical range(1625 F) quenched in still air	3,850	4,350	40,460	45,740
IV	3A	Short Miter	1.000	0.031	0.0951	1020	None	4,480	5,190	47,110	54,570
IV	4A	Short Miter	1.000	0.031	0.0951	1020	Heated to critical range(1625 F) cooled in furnace	2,710	2,900	28,500	30,500
Not Welded	5A		1.000	0.031	0.0951	1020	None	5,300	5,620	55,730	59,100

Tensile Strength in 1000 Pounds Per Square Inch

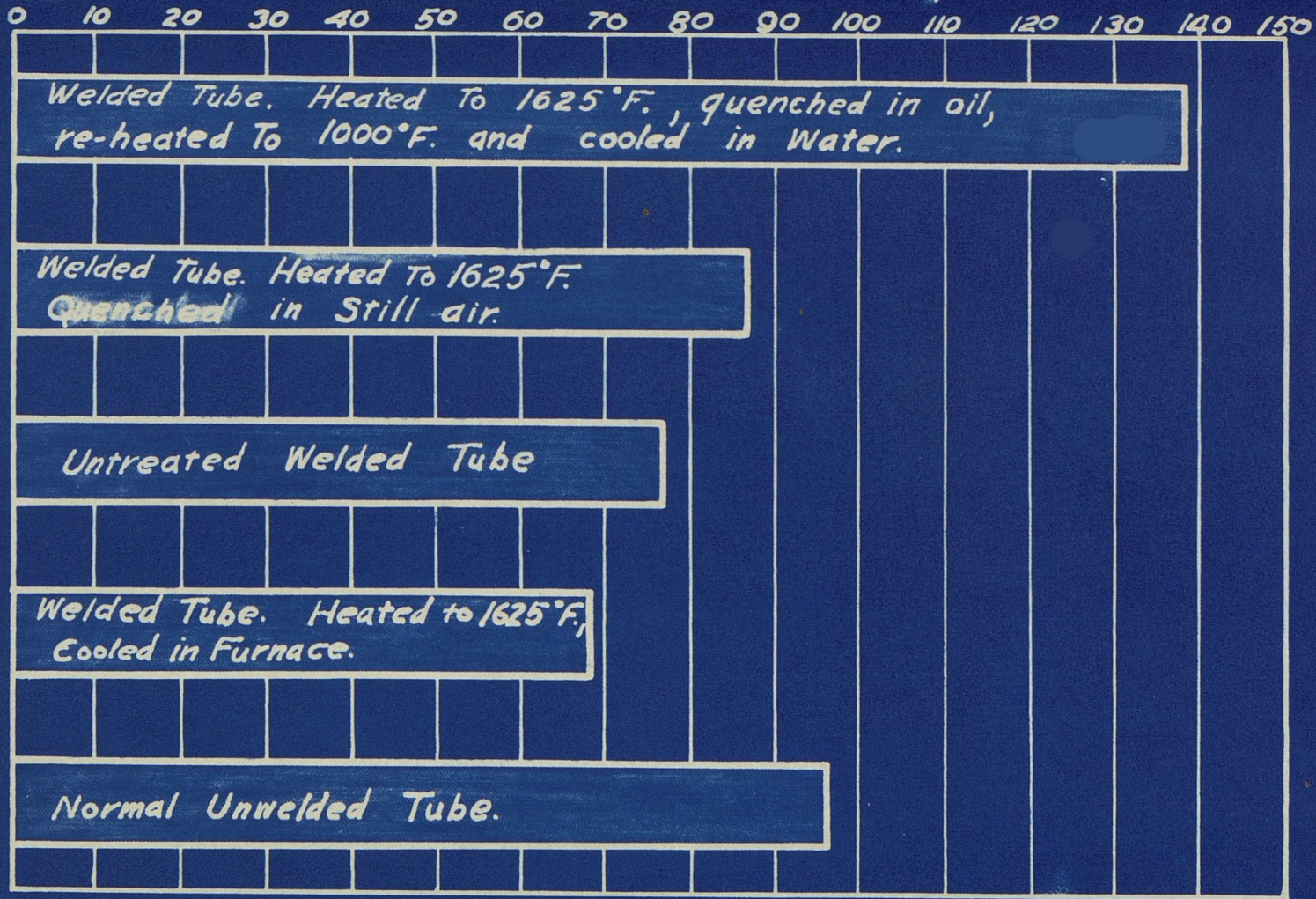
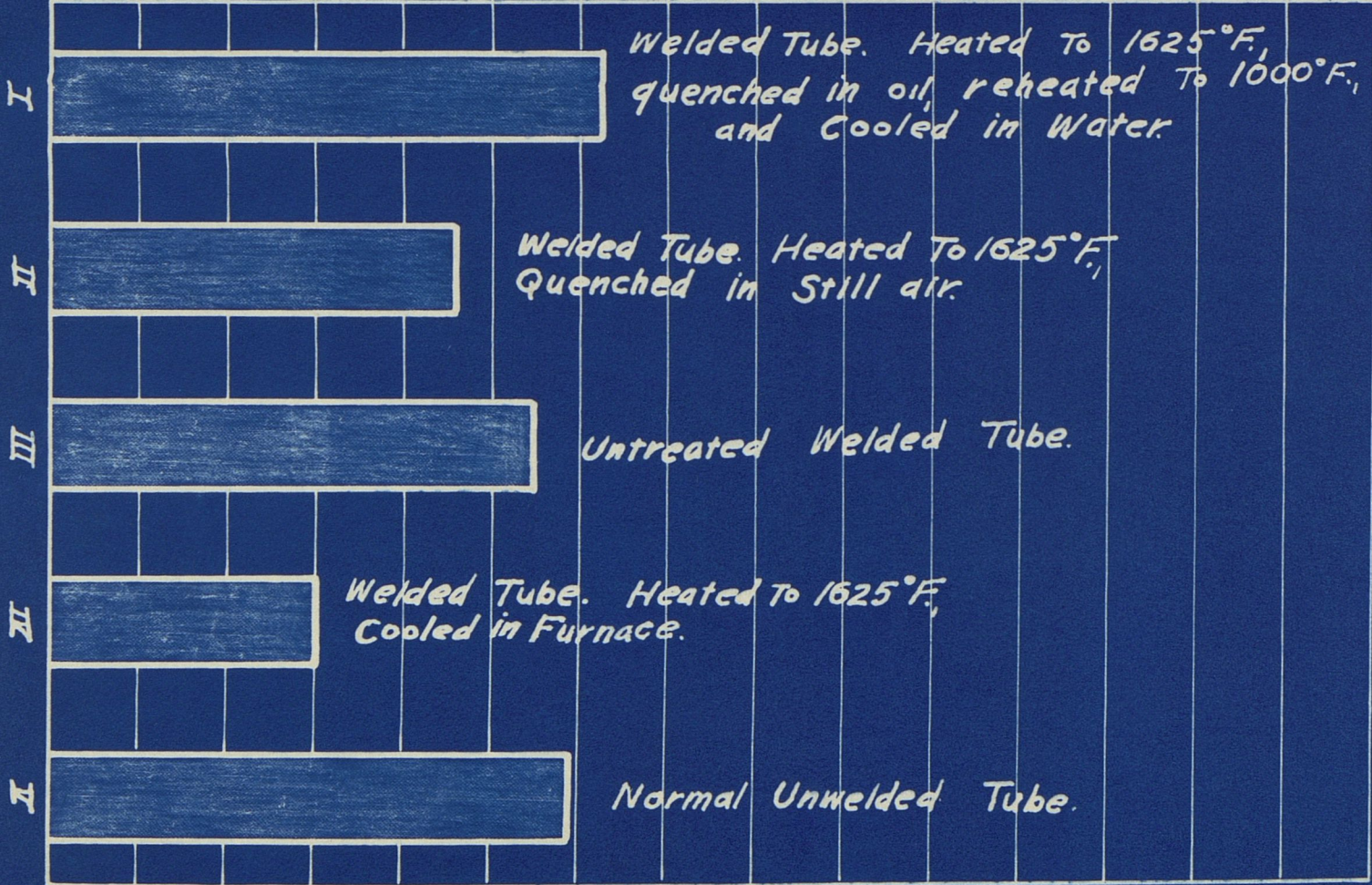


Fig. 5. Comparative Strength of Different Heat Treatments  
S.A.E. No. 4130

Tensile Strength in 1000 Pounds Per Square Inch

0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150



Welded Tube. Heated To 1625°F,  
quenched in oil, reheated To 1000°F,  
and Cooled in Water.

Welded Tube. Heated To 1625°F,  
Quenched in Still air.

Untreated Welded Tube.

Welded Tube. Heated To 1625°F,  
Cooled in Furnace.

Normal Unwelded Tube.

Fig. 5 A. Comparative Strength of  
Different Heat Treatments.  
S.A.E. Steel No. 1020

Column I, Figures 5 and 5A, represents the results of the S. A. E. treatment No. VI. In both cases, greater tensile strength resulted than that of the unwelded tube. In the carbon tubing (S. A. E. 1020) the improvement was not as pronounced as in the chrome-molybdenum tubing (S. A. E. 4130).

Column II, represents the results of heating the welded tube to the critical range (1625° F.) in an electric furnace with automatic control, and quenching in still air. In the chrome-molybdenum tubing the result was greater tensile strength than the untreated welded tubing but not as great tensile strength as with the normal unwelded tubing. In the carbon tubing (S. A. E. 1020) the results were somewhat different. The tensile strength in this case was not only less than that of the unwelded normal tubing but also, it was of considerable less strength than the untreated welded tubing.

Column III, represents the welded untreated tubing. In both the chrome-molybdenum and carbon tubing the tensile strength was less than that of the normal unwelded tubing.

Column IV, represents the results of heating the tube in the electric furnace to above the critical range (1625° F.) and allowing it to cool for 48 hours in the furnace. In both cases, the tensile strength was seriously lowered,



and was much lower than in any other treatment.

Column V, represents the tensile strength of normal tubing. In both cases the figures compare favorably with the claims of the manufacturers. The tensile strength of carbon tubing (S. A. E. 1020) is rated at 55,000 pounds per square inch while this test reveals an actual tensile strength of 59,100 pounds per square inch. The tensile strength of chrome-molybdenum tubing (S. A. E. 4130) is rated at 95,000 pounds per square inch while this test reveals an actual tensile strength of 96,620 pounds per square inch.

The fracture of tube No. 1 occurred in the heart of the weld. The S. A. E. heat-treatment No. VI raised the strength of the tubing 44 per cent above that of the normal unwelded tubing. The tube pulled apart gradually.

The fracture of tube No. 1-A was quite unusual. The tube broke away from the bead on both sides. This was due to the fact that at the very edge of the bead sufficient heat existed to reduce the carbon content and hence a greatly weakened structure resulted. While some carbon would be oxidized from the bead also, the extra thickness of the bead would counteract the decrease in strength.

Tube No. 2 pulled apart very gradually. The fracture was nearly straight across the tube and passed through the

weld on both sides of the tube. The fracture occurred at this point because the heat-treatment had increased the strength of the tube but had not increased the strength of the bead accordingly. Also, in air cooling, the heavy bead would cool slower than the thin tube and hence it would be softer and more ductile than the tube proper.

Tube 2-A, necked the most of any carbon tube tested. The break occurred extremely gradually. The fracture occurred about two inches from the weld and was very similar in appearance to the fracture in the normal tubing. While the general contour of the fracture was straight across the tube, a coarse saw-tooth edge resulted.

Tube No. 3 broke suddenly. The fracture followed the angle of the joint and occurred at a distance of about five-eighths of an inch from the weld. The cause of the location of the fracture in the untreated tubing was fully explained under the discussion on Table I.

Tube 3-A pulled apart gradually. The fracture occurred in the annealed zone about three-eighths of an inch from the weld and followed the angle of the weld.

Tube No. 4 pulled apart very gradually. The break was straight across the tube and crossed through the center of the bead at one end of the joint. This tube had the greatest reduction in area of any tested chrome-molybdenum tube.

The breaking across one edge of the weld can be accounted for by the insufficient transfer of chromium and molybdenum to give the weld as great strength as the base metal. The fracture traveling straight across the tube and the excessive reduction of area is due to the great ductility imparted by the extremely slow cooling.

Tube No. 4-A displayed the lowest tensile strength of any weld tested, namely 30,500 pounds per square inch. The fracture occurred between three and one-half and four inches from the weld and the angle of the fracture was in the opposite direction to the angle of the joint. The tube was soft and extremely ductile and gave way near the jaws of the testing machine.

In No. 5 the fracture was straight across the tube. The tube wall necked gradually each way from the fracture, and pulled down to a very thin section before parting.

Tube No. 5-A pulled in two gradually. While the general direction of the fracture was straight across the tube the edge of the fracture presented a coarse saw tooth effect. The necking was gradual and evenly distributed. The tube wall pulled down to a very thin section before parting.



Fig. 6. Types of Fractures Under Different Treatments. S. A. E. No. 1020.

### Explanation of Figure 6

Figure 6 displays the fractures occurring in S. A. E. No. 1020 tubing under various conditions.

Number 1 is Tube No. IV 3-A, a short miter joint without heat-treatment. The fracture has occurred in the annealed zone which follows the angle of the weld. The annealed zone can be readily seen on the upper side of the weld at a distance of about three-eighths of an inch. If it had been possible to have continued the pull on the upper end of the tube, the new fracture would have appeared in the annealed zone. The ultimate tensile strength of this tube was 54,570 pounds per square inch.

Number 2 is Tube No. IV B-4, a short miter joint without heat-treatment. The welder had gone around the bead a second time in order to get a smoother and better looking bead. In so doing the annealed zone was moved out a greater distance from the weld, and hence the fracture occurred at this greater distance. The fracture occurred so gradually that it was possible to stop the machine before the tube completely parted. The ultimate tensile strength of this weld was 55,730 pounds per square inch.

Number 3 is Tube No. IV B-3, a fishmouth joint without heat-treatment. The fracture occurred at the corners of the fishmouth. This was caused by excessive heating at the point in welding around the sharp corners. This excessive heating caused abnormal grain growth, slag and oxide inclusions, burnt metal, and strains when cooling at this point rather than in the annealed zone. The ultimate tensile strength of this tube was 51,630 pounds per square inch.

Number 4 is Tube No. 2-A, a short miter joint which was heated to the critical range (1625° F.) in an electric furnace and quenched in still air. The result was a very soft ductile tube whose tensile strength was far below that of untreated welded tubing. This tube necked the heaviest, and the fracture occurred the most gradual of any tube tested. The fracture was nearly straight across the tube and had the same coarse saw-tooth effect as the unwelded tubing. Excessive scaling took place during the tensile testing. The ultimate tensile strength of this tube was 45,740 pounds per square inch.

Number 5 is Tube No. 4-A, a short miter joint which was heated to the critical range (1625° F.) and allowed to cool slowly in the furnace. The tube was so soft and extremely ductile from the very slow cooling that it gave way near the jaws. This tube had the lowest tensile strength

of any welded tube tested, namely, 30,500 pounds per square inch.

Number 6 is Tube No. 5-A, a piece of normal unwelded tubing. The ultimate tensile strength was 59,100 pounds per square inch. This was higher than the welded tubing either untreated or heat-treated with the exception of the tubing which underwent the S. A. E. heat-treatment No. VI. The tube pulled down to a very thin section before parting. The necking was gradual and evenly distributed.

Number 7 is Tube No. 1-A, a short miter joint which was given the S. A. E. heat-treatment No. VI. This tube developed the highest tensile strength of any S. A. E. No. 1020 tubing tested, namely 62,460 pounds per square inch. The tube broke away from the bead on both sides. The fracture resulted at these points because sufficient heat existed along the edges of the bead to probably cause a reduction in the amount of the carbon, resulting in a greatly weakened structure at these points. The heat-treatment had restored the annealed zone to its normal strength and hence along the edges of the bead was the natural place for the fracture to occur.

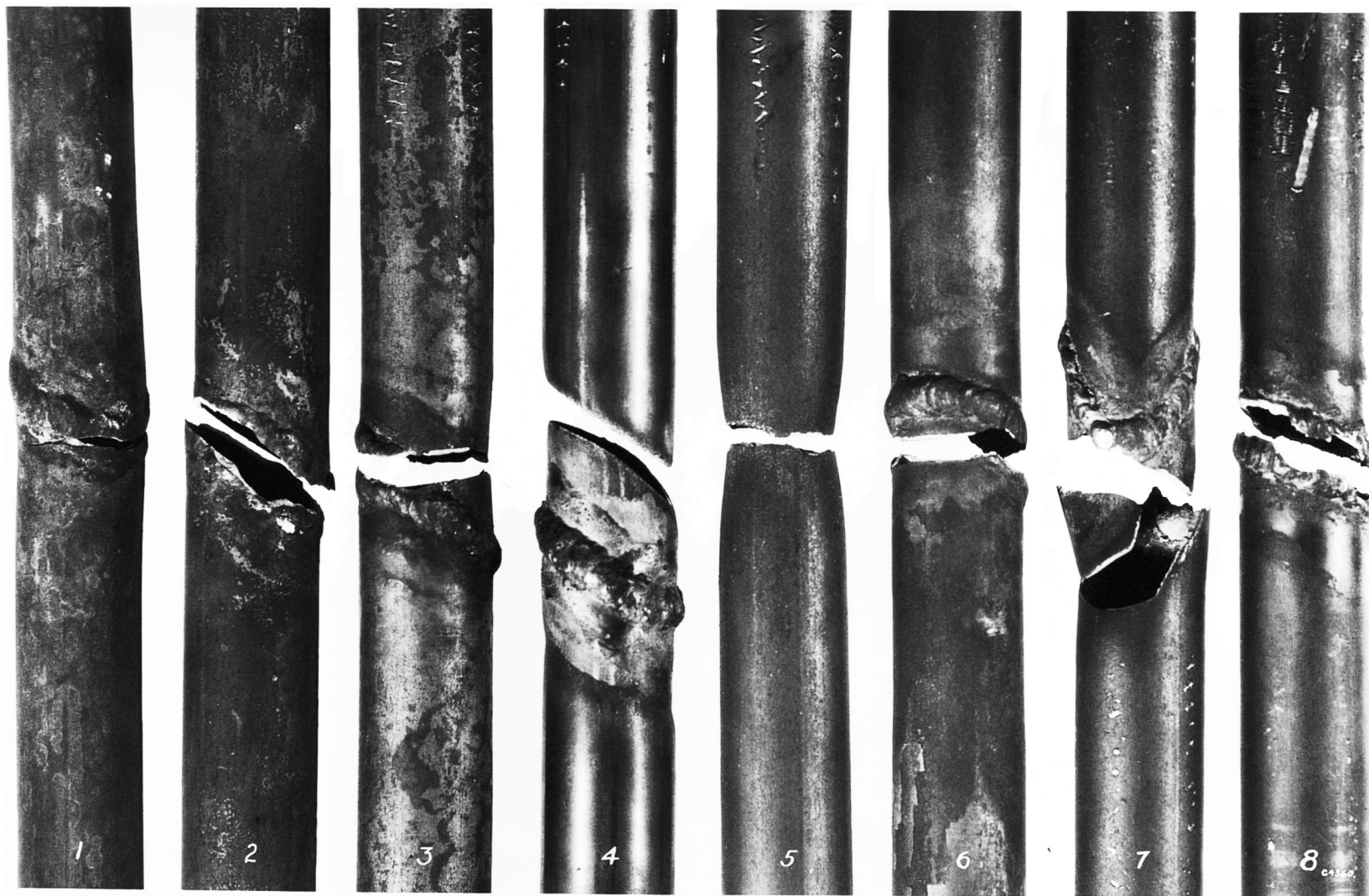


Fig. 7. Types of Fractures Under Different Treatments. S. A. E. No. 4130.



### Explanation of Figure 7

Figure 7 displays the fractures occurring in chrome-molybdenum tubing (S. A. E. 4130) under various conditions.

Number 1 is Tube No. 4, a short miter joint which was heated to the critical range (1625° F.) in the electric furnace and allowed to cool slowly in the furnace. The tensile strength was greatly lowered, in fact was lower than any other heat-treatment. The ultimate tensile strength of this tube was 67,710 pounds per square inch. The tube pulled apart very gradually, and had the greatest reduction of area of any chrome-molybdenum tube tested. The breaking across one edge of the weld was because an insufficient amount of the alloying elements had been transferred to the weld to give it strength equal to that of the tube. The slow cooling had increased the ductility of the tube to a considerable degree.

Number 2 is Tube No. 11, a short miter weld made without reinforcement, that is, with as little bead as possible. The tube was given the S. A. E. No. VI heat-treatment. The fracture occurred in the weld because of the absence of any reinforcement. The fracture shows perfect penetration, although the base metal can be distinguished from the weld

metal. The ultimate tensile strength of this tube was 121,000 pounds per square inch. This was unusually high considering the fact that little or no bead existed on the weld.

Number 3 is Tube No. 1, a short miter joint having been given the S. A. E. heat-treatment No. VI. An excessive bead existed, hence the fracture did not completely follow the weld. The ultimate tensile strength of this weld was 139,310 pounds per square inch.

Number 4 is Tube No. 14, a short mitre joint having no heat-treatment. The ultimate tensile strength of this weld was 71,720 pounds per square inch. The fracture was normal in every way, having followed the annealed zone, the cause of this being previously explained. Excessive necking took place in the other annealed zone.

Number 5, is Tube No. 5, a piece of untreated chrome-molybdenum tubing (S. A. E. 4130). The ultimate tensile strength of this tube was 96,620 pounds per square inch. The tube wall became very thin before fracturing.

Number 6 is Tube No. 2, a short miter joint which was heated to the critical range (1625° F.) and quenched in still air. The tensile strength was greater than that of untreated welded tubing. This was because chrome-molybdenum alloys have air hardening properties which greatly increase

their strength if heated to the critical range and let cool in still air. The ultimate tensile strength of this tube was 86,960 pounds per square inch. The fracture was nearly straight across the tube and passed through the weld on both sides. The fracture occurred at this point because the heat-treatment had increased the strength of the tube but had not increased the strength of the bead accordingly.

Number 7 is Tube No. I C-3, a fishmouth joint without heat-treatment. There are two fractures, one in the annealed zone, the other at the edge of the "V". The fracture at the edge of the "V" was due to over-heating at this point, resulting in excessive grain growth, burnt metal and oxidization. The ultimate tensile strength of this specimen was 93,310 pounds per square inch.

Number 8 is Tube No. I C-4, a short miter joint without heat-treatment. The fracture followed the weld. While the weld appeared excellent on the outside, very little fusion had taken place. Saw marks were still visible on the edges of the base metal. This was truly a poor weld. The ultimate tensile strength of this weld was 71,070 pounds per square inch.



Fig. 8.

Transverse View of the Tubes at Fracture.

S. A. E. No. 4130.

### Explanation of Figure 8

Figure 8 displays the cross-sections of the fractures occurring in chrome-molybdenum tubing.

Number 1 is Tube No. I C-4, a short miter joint without heat-treatment. This weld was defective, poor fusion having taken place. The weld metal broke away completely from the base metal in several places and the saw marks still show on the base metal. In the photomacrograph, the weld metal can be readily distinguished from the base metal.

Number 2 and Number 6 are of the two sections of Tube No. 13, a short miter joint having undergone S. A. E. heat-treatment No. VI. The ultimate tensile strength of this tube was 115,990 pounds per square inch. The weld metal pulled away from the base metal not only in the center of the weld but at the base of the bead also.

Number 3 is Tube No. 1-A, a short miter joint having been given the S. A. E. heat-treatment No. VI. The fracture occurs partially in the weld and partially in the base metal. Excellent fusion has taken place. The excessive bead prevented the fracture following the bead entirely.

Number 4 is Tube No. 14, a short miter joint without heat-treatment. This is a normal fracture, occurring in the annealed zone which is about three-eighths of an inch

from the weld. The tubing pulled down very thin before fracturing.

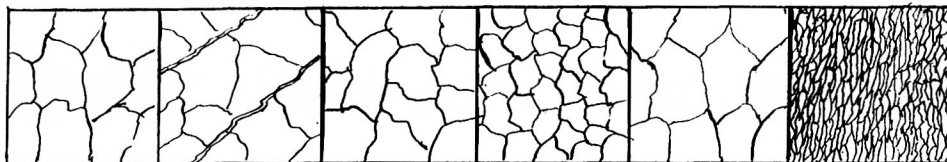
Number 7 is Tube No. 11, a short miter joint without reinforcement. While the fracture occurred in the weld, splendid fusion has taken place. In the photomacrograph, the base metal can readily be distinguished from the weld metal.

## MICROSTRUCTURE

No other tests give as definite a means of identifying the quality of a weld as does the microscope. Not only can the comparative size of the grains be noted, but also the constituents are more or less readily revealed. The degrees of fusion can be clearly seen as well as any slag inclusions, burnt metal or gas inclusions.

While the deposited metal is a casting, it cannot be justly compared with a steel casting. The deposited metal has a much finer grain than a steel casting because of the more rapid cooling.

The variation in the size of the grains from the center of the deposited metal to the unaffected base metal can readily be seen from the following graph.



Zone 1 Zone 2 Zone 3 Zone 4 Zone 5 Zone 6

The various grain sizes and their causes can readily be divided into five distinct zones. Johnson gives the following excellent explanation of this phenomena: "Zone

No. 1 is the deposited metal and is a coarse-grain, low carbon steel. The initial freezing at the edge of the weld is indicated by the columnar structure. Zone No. 2 is the steel which has been heated to the plastic state and has cooled with the formation of large, irregular grains under an internal strain, since it is the last of the thin sections to cool and must absorb the strains due to contractions of the steel in the zones on the right. The area of the weld metal is so much greater that generally the unit strain is less in the weld metal (Zone No. 1) than in Zone No. 2. Cracks due to the restraint of members which are welded without sufficient allowance for contraction invariably occur in this zone. Fatigue cracks also start there. Zone No. 3 and 4 are examples of the effect of temperature on grain growth above the critical temperature. The hotter portion adjacent to Zone No. 2 has a larger grain, and the portion was heated just over the critical or re-crystallization temperature. The zone to the right of this (No. 5) is the softest and weakest zone and represents the original steel annealed just below the critical range without re-crystallization and with the formation of pearlite and free ferrite. It is very narrow. Tension failures invariably occur in this zone". Zone No. 6 represents the normal base metal.



This explanation compares very favorable with the results of this test. Unless heat-treated the welds invariably break in Zone No. 5, if the weld was defective, the break occurred in the weld.

Burnt metal is a condition seldom found in welds. No heat-treatment or rewelding will overcome the burnt condition should it exist. Over heating is a condition which very often exists in welds. The chief results of over heating are enlarged grains and excessive expansion and subsequent contraction. If no bead existed, the enlarged grain structure would seriously weaken the tensile strength of the weld. However, the welder who is so inefficient as to over heat the weld usually deposits excessive bead which counteracts the diminished strength of the excessive grain size. It is far better to have excess heat and fusion than not enough heat and simply a layer of oxide holding the parts together. A good airplane welder must be able to lay a bead not to exceed 20 per cent of the thickness of the base metal, have penetration through at least 90 per cent of the thickness of the base metal, a bead whose width is from four to six times the thickness of the base metal and must have at least 80 per cent of the strength of the normal untreated tubing.

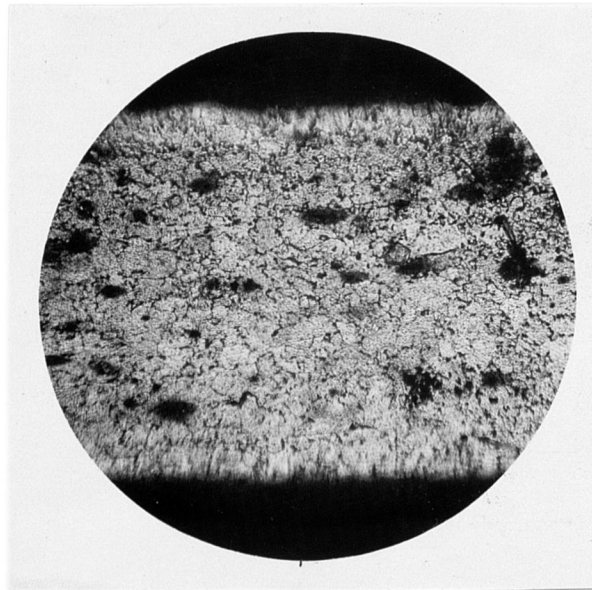


Fig. 9

III A-1. S. A. E. No. 1020

Etched in 4% Nital. Magnification, 100 x.

Photomicrograph of Base Metal.

The grain structure is normal, although slightly enlarged due to heating from the welding. The large black splotches are polishing pits. The white grains are ferrite. The long dark areas at the edges of the ferrite grains are pearlite. The rounding of the edges of the tube wall due to polishing makes the grain structure appear indistinct.

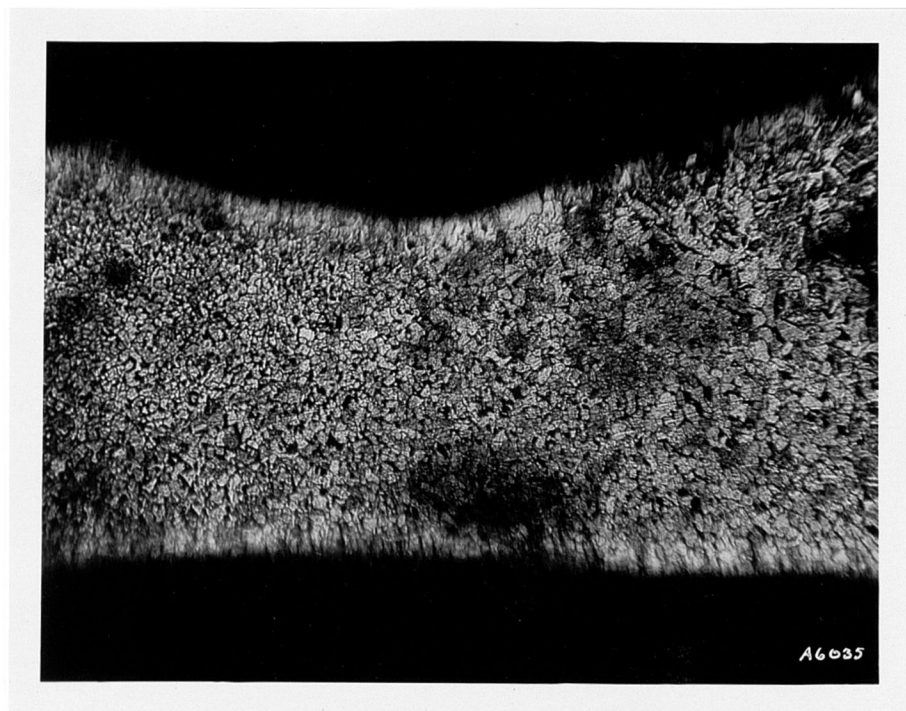


Fig. 10.

III A-1. S. A. E. No. 1020.

Etched in 4% Nital. Original Magnification, 100x.

Photomicrograph in the Juncture of the Weld

To the right is the weld metal, to the left is the base metal. The extreme left shows the normal thickness of the tube wall. The wall is cut down at the edge of the bead to a lesser thickness than the original base metal. This shows insufficient reinforcement and probably improper handling of the welding torch. This condition is very common in welds and is a frequent cause of low tensile strength of a weld which is otherwise sound. The grain

structure is identical with that of Fig. 9. However, the grain size gradually increases from the base metal to the weld metal. This was due to the gradual increase in temperature from the base metal to the weld metal.

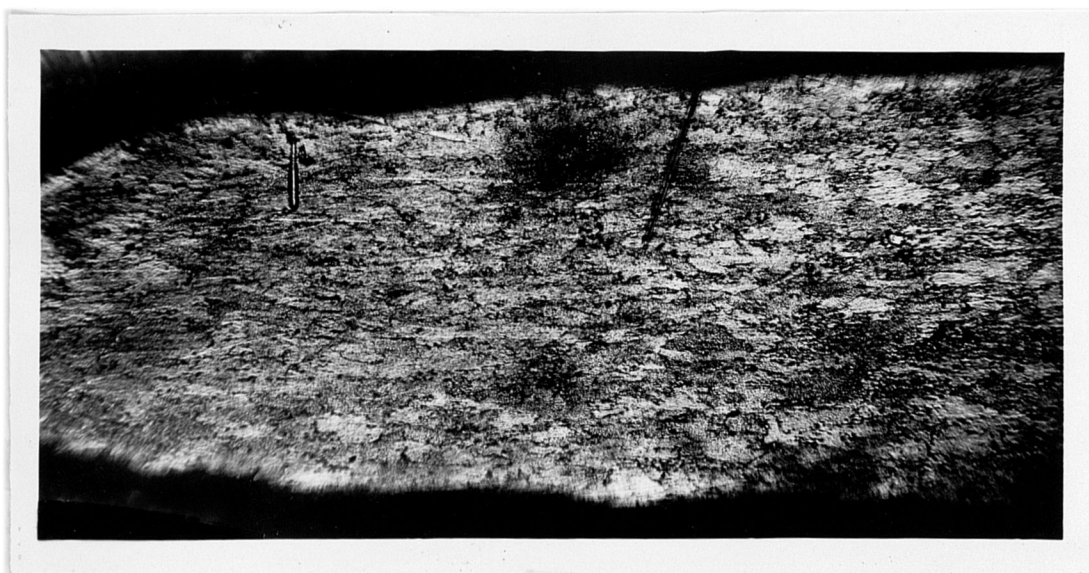


Fig. 11.

III A-4. S. A. E. No. 1020.

Etched in 4% Nital. Magnification, 100x.

Photomicrograph of a Longitudinal Section of the Tube  
Pulled in Two in the Tensile Testing Machine.

To the right the grain structure appears to be elongated although a definite grain structure can readily be detected. These grains show that the elastic limit has been passed but the ultimate tensile strength has not been reached. The large white grains are composed of ferrite

grains. To the left the grains have been ruptured and the ultimate tensile strength has been passed. This specimen was very difficult to polish since the grain structure was so broken down that even with the slightest pressure scratches would continually be made.

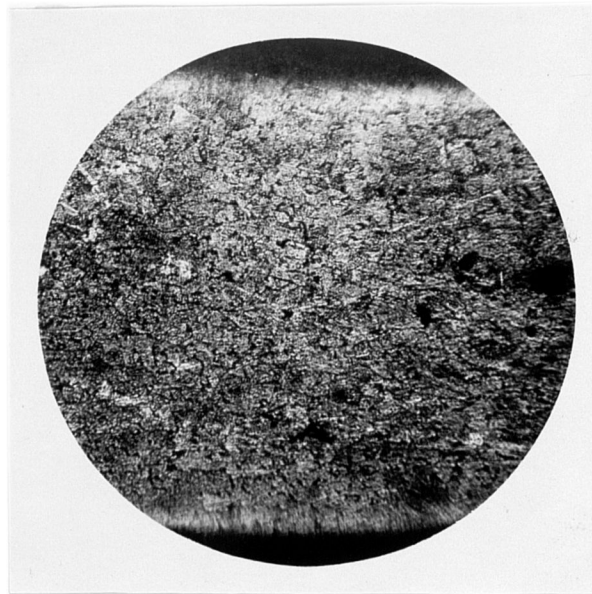


Fig. 12.

III A-4. S. A. E. No. 1020.

Etched in 4% Nital. Magnification, 100x.

Photomicrograph Was Taken About Three-eighths of an Inch from the Very Tip of the Fractured Metal Pulled Apart in Tensile Testing.

The grain structure appears nearly normal in size and shape although some distortion is present. Considerable difficulty was encountered in completely removing the

scratches since the distortion has weakened the wear resistance of the metal. The large white grains are ferrite while the small black streaks appearing at the edge of the ferrite grains are pearlite.

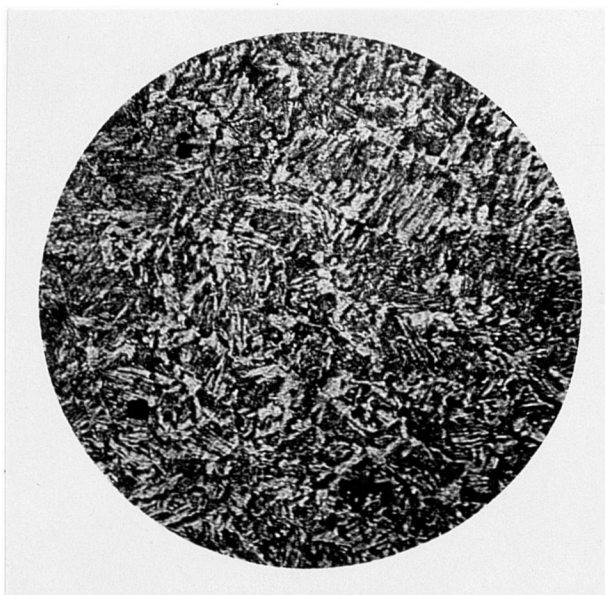


Fig. 13.

II D-3. S. A. E. No. 4130.

Etched in 4% Nital. Magnification, 100x.

Photomicrograph Taken in the Base Metal of the

S. A. E. No. 4130 Tubing Nearly Out of the

Influence of the Heat from the Torch.

This is a typical chrome-molybdenum steel structure. The dark spots are merely polishing pits. The size of the grains are slightly larger than normal due to the heat from

the torch. Metallurgists have not definitely named the constituents of chrome-molybdenum steel, although it is known that the grains of this alloy steel completely disappear. Therefore, no attempt shall be made to identify the various constituents of the grain structure. The grain structure is extremely fine and it is very difficult to recognize the constituents.

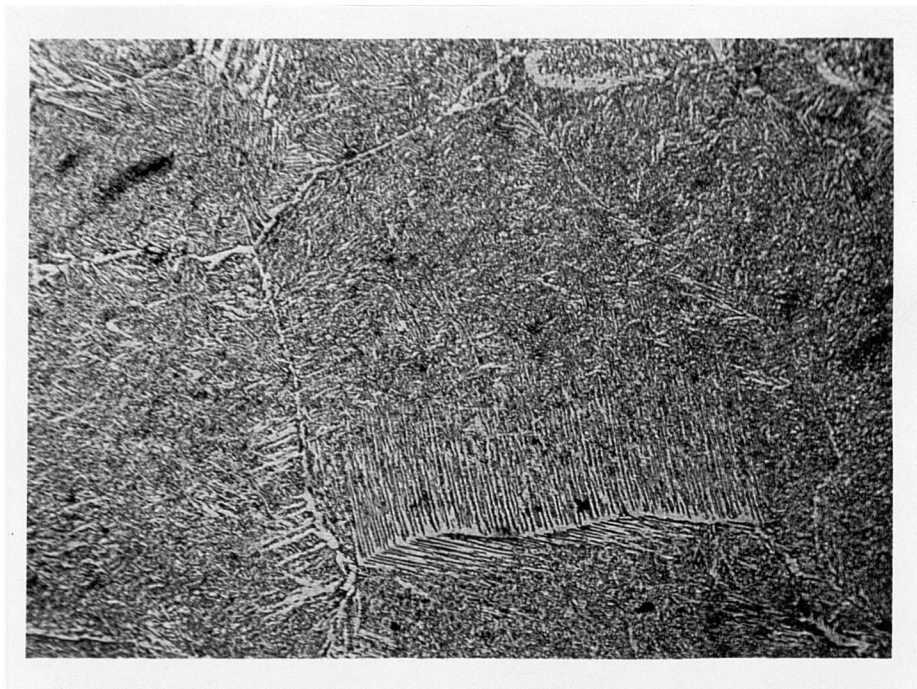


Fig. 14.

II D-2. S. A. E. No. 4130.

Etched in 4% Nital. Magnification, 100x.

Photomicrograph Taken at the Center of the Weld.

The fusion of the weld metal and the base metal was excellent. Only a very slight trace of slag was found. No gas inclusions or blisters are present. However, grain growth has been very pronounced. Special attention should be given to the large grain appearing in the center. The upper portion of this grain is the structure of typical chrome-molybdenum steel. The lower portion of the grain shows the numerous ferrite lines typical of cast steel. The grains form a ferrite network or matrix. This excessive grain growth was due to heating the metal to the molten state and slowly cooling. This photomicrograph is excellent proof of the claims made by many authorities that in welding chrome-molybdenum steel the chromium and molybdenum are transferred to the deposited metal in sufficient quantities to give the weld metal nearly the same composition as the base metal. This weld shows splendid penetration and presents an excellent weld.



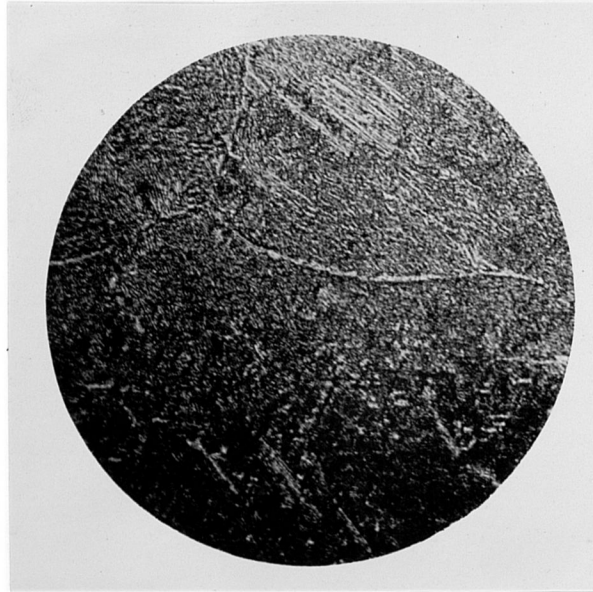


Fig. 15.

II D-3. S. A. E. No. 4130.

Etched in 4% Nital. Magnification, 100x.

Photomicrograph Taken at the Junction of the  
Base Metal and Weld Metal.

An excellent fusion of the base metal and the weld metal is apparent. The weld metal shows excessive grain growth. Only a slight trace of slag exists in the weld.

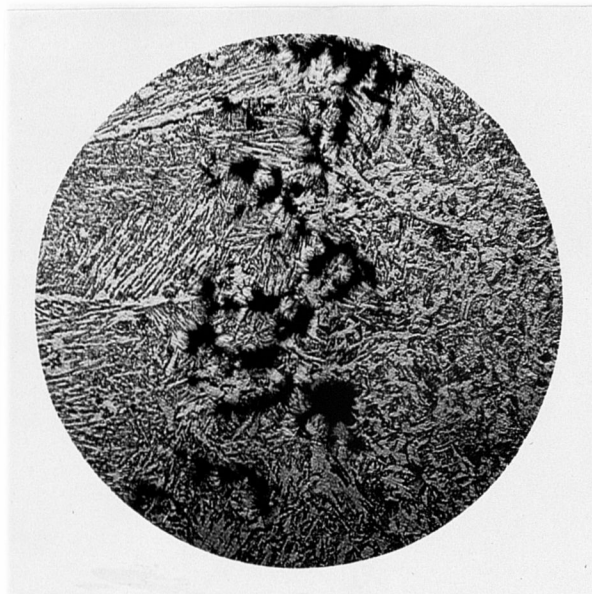


Fig. 16.

II D-4. S. A. E. No. 4130.

Etched in 4% Nital. Magnification, 100x.

Photomicrograph Taken at the Juncture of the  
Base Metal and the Weld Metal.

The right-hand portion is the base metal while the left-hand portion is the weld metal. The grain size of the weld is far greater than the grain size of the base metal. This was probably due to the weld metal being heated to a higher temperature than was really necessary. The chromium and molybdenum seems to have been well transferred into the weld metal. Pearlitic or sorbitic areas appear at the lower edge of the large grain at the left side of the weld metal. The grains of the matrix are ferrite. A very large

slag inclusion exists throughout the central portion of the weld metal as well as the base metal. This could no doubt have been removed to a considerable extent by puddling and working the molten metal by the filler rod. This would have caused the slag to have floated to the surface of the weld where it would have been harmless.

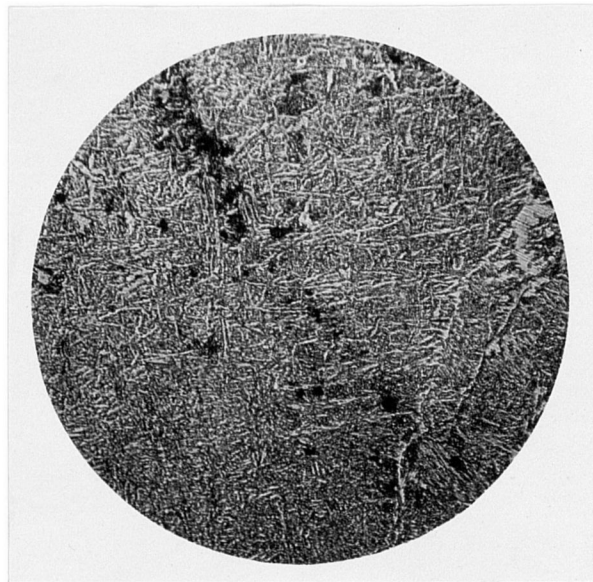


Fig. 17.

II D-1. S. A. E. No. 4130.

Etched in 4% Nital. Magnification, 100x.

Photomicrograph of a Weld Showing Splendid Distribution  
of the Chromium and Molybdenum in the Weld Metal.

The base metal is the portion to the right of the slag  
inclusion while the weld metal is the portion to the left.

Grain growth has not taken place to any appreciable extent. The slag inclusions form a line at the juncture of the base metal and the weld metal. This will cause an inherently weak line passing directly through the weld. This slag inclusion could have probably been eliminated to a great extent by puddling the molten metal a longer time, but this would also have caused considerable grain growth. On the lower right side of the photomicrograph is found two very pronounced slip lines due to cooling, passing across both the base metal and the weld metal.

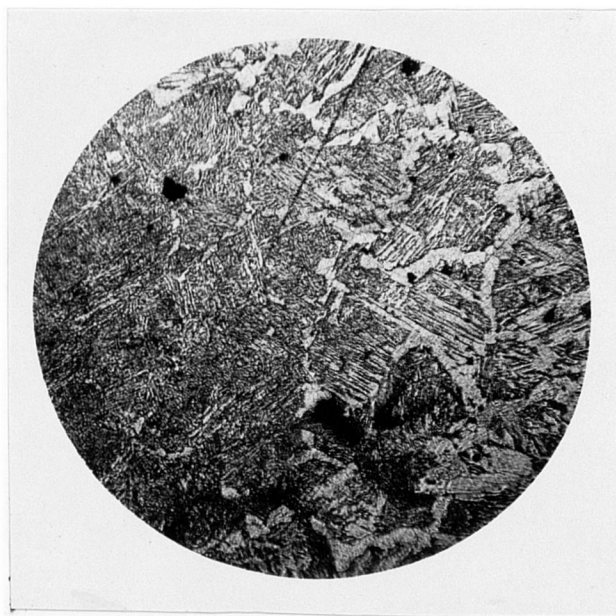


Fig. 18.

II D-1. S. A. E. No. 4130.

Etched in 4% Nital. Magnification, 100 x.

Photomicrograph Taken at the Juncture of the Weld.

The left portion is the base metal while the right portion is the weld metal. The chromium and molybdenum does not seem to have been transferred into the weld metal to the extent it should have. This weld was apparently well puddled for most of the slag inclusions have been removed. The grains of the weld metal are much larger than those of the base metal. The grain structure of the weld metal is identical with the grain structure of cast steel. The grains are a matrix of free ferrite. The grains are composed of pearlite, the dark lines of the pearlite being ferrite while the light lines are cementite which is also called iron carbide.

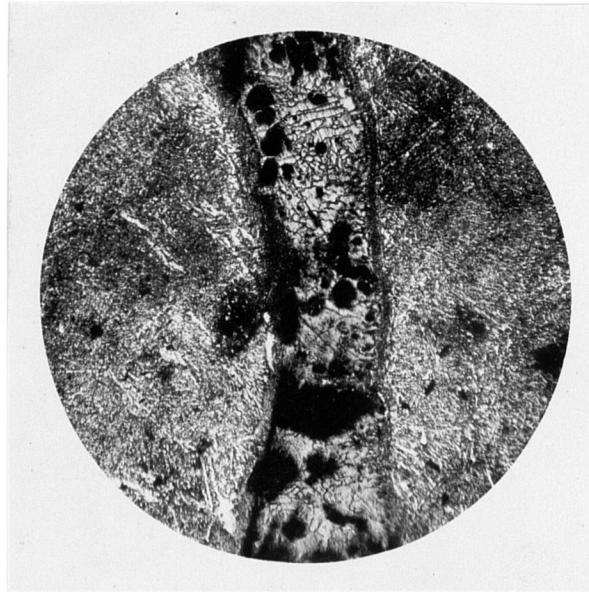


Fig. 19.

V E-1. S. A. E. No. 4130.

Etched in 4% Nital. Magnification, 100x.

Photomicrograph Showing the Ends of the Tubing and  
Apparently No Fusion Has Taken Place

The molten filler rod has been cast between the ends of the cold base metal. An excessive amount of slag has been carried down with the molten filler rod. Much of this foreign material appearing in the weld may be dirt, rust and scale which was on the base metal or filler rod. It is very essential that all scale, rust and dirt be removed from both the base metal and the filler rod for they have a very pronounced injurious effect upon the quality of the weld.



Fig. 20.

V E-2. S. A. E. No. 4130.

Etched in 4% Nital. Magnification, 100x.

Photomicrograph Showing Poor Fusion

This weld on the outside appeared apparently perfect. However, the photomicrograph reveals that the weld metal and the base metal in this section has not fused in the least. The upper portion is the weld metal while the lower portion is the base metal. This section was taken near the outer edge of the bead. The slag was undoubtedly the scale and foreign matter which was on the base metal before welding.



Fig. 21.

V E-3. S. A. E. No. 4130.

Etched in 4% Nital. Magnification, 100x.

Photomicrograph Showing the Cross-section of a Poor Weld.

This weld appeared sound to the un-aided eye, yet under the microscope, the poor union of the weld metal and the base metal is very easily seen. The lower portion is the base metal while the upper portion is the weld metal. The carbon content of the weld metal is much lower than the carbon content of the base metal. If proper fusion had taken place between the base metal and the weld metal, the carbon as well as the chromium and molybdenum would be much more evenly distributed. A great amount of slag exists in



the weld metal. This was probably the scale and dirt which existed on the base metal and was absorbed by the molten metal.

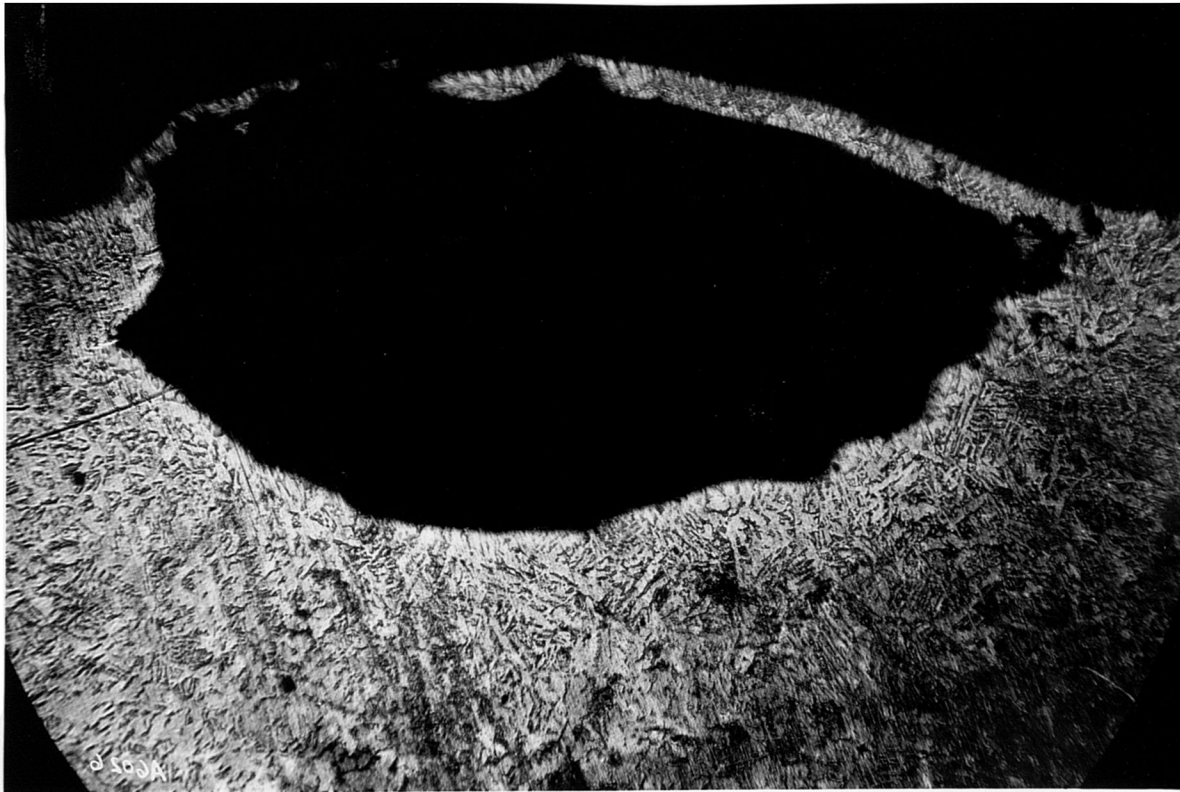


Fig. 22.

II D-2. S. A. E. No. 4130.

Etched in 4% Nital. Magnification, 100x.

Photomicrograph of a Blister.

The blister shown, with another just below it, occupied more than one-third of the thickness of the tube wall. This was caused by bridging over of the molten metal, possibly aided by entrapped gases. No hint of this condition was shown on the surface of the weld. Numerous other blisters were found through-out the weld. Such blisters seriously decrease the tensile strength of the weld. This bridging was no doubt caused by welding too fast, not permitting time for proper fusion of the filler rod and the molten metal. There is a pronounced reduction in the carbon content at the edges of the blister. Numerous slag inclusions appear through-out the weld and segregation occurs in several places.

### SUMMARY AND CONCLUSIONS

A study of the graphs reveal several very interesting facts. The long miter joint averaged the greatest tensile strength. This increase over the tensile strength of the short miter joint was probably due, in part, to the inexperience of welders in the welding of airplane tubing. When welding the long miter joint the welder is able to weld a longer period before finding it necessary to stop welding and turn the tube to a new position. After turning the tube to a new position, the end of the weld was probably not fully melted before proceeding around the joint. The greater frequency in stopping the welding in the short miter and butt welds, no doubt was partially the cause of the tensile strength of these welds being lower than the longer miter joint. The fishmouth joint, while being an excellent joint in repair work, is a difficult type for the inexperienced operator to handle. The tendency is to overheat or even burn the metal when reversing the direction of the weld at the "V".

The strength of the welds produced by the different welders varied greatly. The lack of uniformity in the strength of the welds was due to the welders not really

understanding the welding process and the structure and properties of the metals. Average commercial welders trust to luck to a great extent for the quality of his weld. He usually does not fully understand the requisites or the characteristics of a good weld. If the job does not come back, he says it was a good weld. If, when the weld is put into service, it breaks it will probably break in the annealed zone. The welder declares his weld was good but the base metal was no good. The facts are that if the welder had understood the welding process and the structure and properties of metals, the weld would have been much better.

The average welded chrome-molybdenum tubing (S. A. E. 4130) had 43 per cent greater tensile strength than the average welded carbon tubing (S. A. E. 1020). The outstanding reason for this condition after welding is due to a considerable extent to the air hardening properties of chrome-molybdenum steel. Some authorities claim that the air hardening properties of this steel so strengthens it that heat-treatment is unnecessary.

It may be true under present conditions that the factor of safety is sufficiently high without heat-treatment but eventually, with more powerful and larger planes, the complete welded fuselage may be placed in a heat-treating

furnace and given a standard heat-treatment as S. A. E. VI.

The S. A. E. heat-treatment No. VI proved to be very desirable in both the S. A. E. No. 4130 tubing and the S. A. E. No. 1020 tubing. The tensile strength was raised more than 60 per cent in some instances in S. A. E. No. 4130 welded tubing over that of normal unwelded tubing. The increase in the tensile strength of S. A. E. No. 1020 welded tubing was about 6 per cent more than normal unwelded tubing.

Heating to the critical range and quenching in still air proved beneficial to the chrome-molybdenum welded tubing (S. A. E. 4130), due to its air hardening properties. The tensile strength was greater than the untreated welded tubing. This was not true in the welded tubing (S. A. E. 1020). The tensile strength was less than that of untreated tubing.

The untreated welded tubing (S. A. E. 1020) had approximately 93 per cent the tensile strength of normal unwelded tubing.

The untreated welded tubing (S. A. E. 4130) had approximately 80 per cent the tensile strength of normal unwelded tubing.

Heating to the critical range and cooling in the furnace lowered the tensile strength of both kinds of tubing

used. The tensile strength was far lower than under any other condition studied in this research. The S. A. E. No. 1020 tubing had approximately 50 per cent normal tensile strength while the S. A. E. No. 4130 tubing had approximately 70 per cent normal tensile strength.

The outstanding defects found in the welds were as follows: Lack of penetration and incomplete fusion; slag inclusions; blisters; gas pockets; oxide films; undercutting; overheating with resultant grain growth; and slip lines due to contraction of the metal from the molten state. Burnt metal was rarely found, although some authorities claim this to be a common defect. If the ragged edges, formed in cutting the joints, are removed, burnt metal is not so apt to occur. Fractures occurring in the weld often resulted from the welder not completely melting the end of the weld when resuming the welding operation after changing positions. This is very essential.

Untreated welds, unless the weld was defective, always broke in the annealed zone, since this area is inherently the weakest section. Reheating with the torch drives the annealed zone further from the weld but it will not remove it. These tests furnish ample proof that heating with the torch after welding did not prove beneficial and in some instances proved very detrimental to the tensile strength of the tube.

Going over the bead a second time with the torch moved the annealed zone a greater distance from the weld. Also, considerable oxide was introduced into the metal by this process, which weakened the weld to some extent. When the torch is removed from the molten metal an oxide film immediately forms. The bubbling metal absorbs this film before the surface is solidified. This can be prevented by removing the torch gradually and permitting the surface of the metal to solidify before fully removing the torch.

Human lives depend upon the soundness of welds made in the airplane structures. Guess work must be eliminated if the safety of these lives are to be assured. In order to eliminate guess work as nearly as possible and be assured of continual production of sound welds in airplane fabrication, the welder must have a good understanding of the technique of welding thin tubing, a thorough knowledge of the structure and properties of metals and be capable of applying this knowledge in actual practice.

It is the writer's sincere desire that in the near future other students may carry on the study of which this is only a beginning.



## ACKNOWLEDGMENT

The writer desires to express his appreciation of the assistance and information given by Professor W. W. Carlson, Head of the Shop Practice Department; Professor G. A. Sellers, Professor of Metallurgy and Metallography; and Mr. F. F. Greeley, Instructor in Airplane Fabrication. The constructive criticism offered by these collaborators has made the work a pleasure.

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