1953

The holding strength of crimps on tubes

Aydin Cansever

THE HOLDING STRENGTH OF CRIMPS ON TUBES

BY

AYDIN CANSEVER

A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

Degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

Rolla, Missouri

1953

Approved by ____________________
Professor of Mechanical Engineering

ACKNOWLEDGEMENT

I wish to express my sincerest thanks to Dr. Aaron J. Miles, Dean of the Mechanical Department, for his suggesting the problem and for his advice and guidance throughout this investigation.

I am also grateful to Prof. R. F. Davidson for his help as to the use of the Mechanics Laboratory. To Prof. E. C. Chase and Prof. A. V. Kilpatrick, I am indebted for the use of the machinery of the Mechanical Engineering Laboratory.

CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

INTRODUCTION

The object of this thesis is to determine by analytical means and laboratory tests the holding force of various crimp methods of fastening sheet metals and special tubing. The study is conducted with heat treated Aluminum alloy 243.T3.

The problem of joining relatively thin walled tubing of high strength material or the application of a plug to such a tube has been investigated by many manufacturers, but the literature in this field is limited and still there are many cases where a better method may prove very useful. At the suggestion of Dr. Aaron J. Miles, the author decided to investigate the possibilities of using a crimp for closing or rather plugging tubes.

In the present day of industrial production, the common practice is to use a material that is easily machinable by methods most common in engineering use. In case it is necessary to use a tough material heat treating is applied to bring the material into a more workable state. Most of the time this means extra expenses, skilled work and sometimes poor quality. When welding is used, the handiest means of the production engineer, the material next to the weld is critically damaged in crystal structure and physical properties which leads to higher safety factors, more material, and weight. Furthermore, to assure a satisfactory weld, extremely well skilled welders are required, specially in light alloy industry.

Almost any kind of joint results in a natural weakening of the material either by reducing the section of the material as in the use of threaded joints, and residual stresses due to cold working or by the application of heat. Therefore, a method for closing the ends of a tubing where the possibility of a reduction in the strength of the material is minimized fully utilizing its physical properties, that would still prove simple and cheap, will certainly be very useful.

In this paper a mechanical kind of joint is investigated, that may be as strong and safe, and which does not require heat treatment, skilled labor, or expensive tooling, and yet be adoptable to mass production.

The objection to heat treatment is that, when long tubing is to be handled, there always is a weak section in-between the old and new heat treatments at the point where they join.

Therefore, any kind of heat application is not tolerated in the forming operations of this thesis, although the material is too brittle to accept any appreciable deformation.

The problems, faced with in this matter, are how to form a crimp, what kind of tools or means to use, and how to form the crimp, so that it will have the strength needed for the particular use.

In general, crimps are applicable to frame structures, push and pull rods, in joining tubes for liquid or gas transmission, and for tubes used as pressure vessels. However, they are mostly limited to thin and soft materials. They have a wide application in bottle caps, can-forming, detachable tubing and other equipment. Its use on thicker sections of heat treated high strength materials is very new and unknown. Application of this kind of crimping may bring about great savings and new possibilities in the field of mechanical production.

REVIEW OF LITERATURE

Making use of crimps for heavy duty joints on high strength material is practically new in industry. Likewise, literature on such applications is confined to only a few articles.

A method for the use of such a crimp was developed by "Les Etablissements Aviac" for building Aluminum alloy bicycle frames.[1]

---

(1) Davies, Graham, The Light-Alloy Bicycle in France, Light Metals, Vol. xi, pp.452-459, August, 1948.

Tubes of A-U4G, forming the frame, are built up in die cast lugs of A-U5G7. The lug extension taking the tube end is bored to make a tight fit on the tube and has three grooves recessed in it. (See Fig. 1, p.5). Where the tube has been forced into the lug a special expanding tool, provided with a ring of steel balls, is driven in from the interior of the lug. This pushes the wall of the tube outwards into the rounded grooves, forming a very satisfactory joint. Compression and tension tests have proved that the Aviac joint will stand up to a tractive effort of 2,000 kg.

The Aviac system results in a very neat looking machine and it should be well adapted to quantity production, as no specially skilled labor is called for. The idea was developed in the first instance, from a method employed for very many years past, in fixing boiler tubes by means of an expanding tool.

In general, so far, cold joining by mechanical means seems infinitely preferable to welding when assembling alluminum-cycle frames.

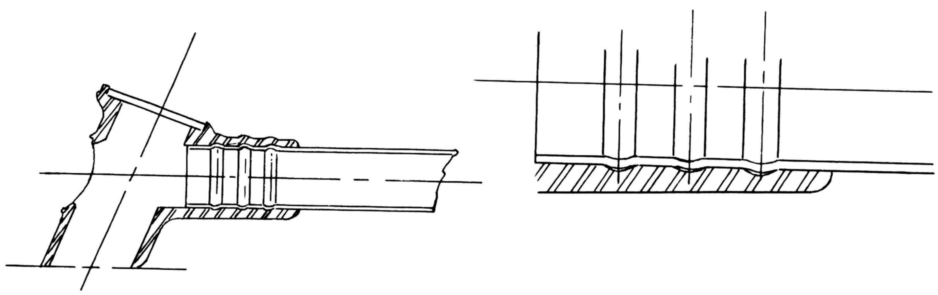


Fig. 1 Crimps on Aluminum Frame Joints

Another article on the subject of crimping is the only material available that has really investigated the problem of crimp joints and is the result of careful research and observation.(2)

---

(2). Simpson, Frank R., Research Engineer, The Franklin Institute Laboratories, Assembly of Thin-Walled Parts By Rubber Crimping, Product Engineering, pp.144-148, March, 1950.

A lot of valuable information is available as to the best form of crimps, their proportions, sketches of tools and some crimp plugs. Specifications for the best kind of rubber for this applications are given. As we come to the particular matter of interest we will refer to this article as a valuable source.

Besides these two articles, books on sheet metal working were found to be full of information as to the working properties of the material, and of greatest value in the preparation of this paper. (3(4)

(3). Sacks, George, Principles and Methods of Sheet Metal Fabricating, Reinhold Publishing Company, 1949.

(4). Schulze, R. Burt, Aluminum and Magnesium Design and Fabrication, McGraw Hill Book Company, 1949.

ABOUT CRIMPS

The formation of a crimp is a complicated affair. Its successful formation without cracks depends on many factors such as the shape of the groove, kind of material, its properties, thickness, surface conditions, kind of tool or means used for crimping, and kind of lubrication used.

When ductile materials are used, these simply elongate as is the case in any drawing operation and take the form of the crimp.

On the other hand, this elongation leads to failure in less ductile materials. Moreover, the shape of the groove begins to influence the formation of the crimp since the material can only be bent to a minimum radius of so much. According to these limitations, the depth and the width of the crimp must be so proportioned that the total elongation will not exceed the ductility limit of the material. The corners of the crimp must be so rounded that they have a larger radius than the minimum bend radius of the material.

With these points in mind, when designing a die, every consideration must be given to give a chance to the metal to flow into the groove to form the crimp. This we can illustrate in the following sketches:

A. At these locations the rubber locks the sheet due to high pressure. Hence the sheet is sheared as shown, since the corners were already sharp.

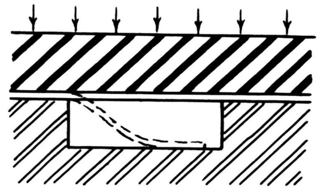


Fig. 2a Blanking Failure

B. Since the edges are rounded, the metal is not sheared. But, since the metal on the sides cannot flow into the groove and its maximum elongation is exceeded, it breaks.

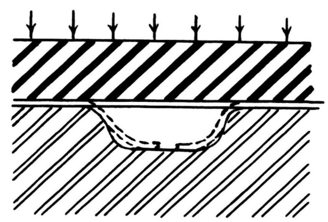


Fig. 2b Excessive Elongation Failure

Assuming nothing can be done about this locking action of the rubber, a solution for the groove to form without failure is seeked by studying its proportions.

Considering that the sheet of metal is locked by the pressure of the rubber and the crimp is successfully formed, the total elongation of the metal would be roughly "2h" and the percent elongation would be 2h/ .

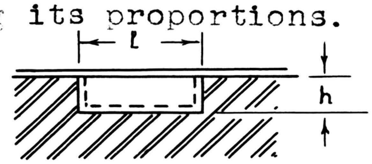


Fig. 3 Rectangular Groove

The percent elongation should never exceed the ductility, since it would result in failure. Hence, -2h/ .

For any other form of groove the difference of the length of the groove surface and the unsupported length of metal over the groove " " over " ", would give the $^{o}/_{o}$ elongation which should not exceed " " for the successful formation of a crimp.

To form a crimp that is deeper than the amount found by the above relation, the metal has to flow in the groove from the sides, reducing the amount of elongation to a minimum. The following suggestions may help achieve or approach such a result.

a. Use a lubricant between the rubber and the sheet metal, and between the sheet and the groove block.

This was tried, but at the high pressures necessary to deform such a high strength metal the lubricant film was too thin to reduce the friction or the locking action.

b. A layer of shimstock between the rubber and the sheet proved to be very successful in the case shown in Figure 2b. in the previous page.

c. Use rubber only on the groove area and cover the rest of the sheet by a metal guard. (See Fig. 4 below).

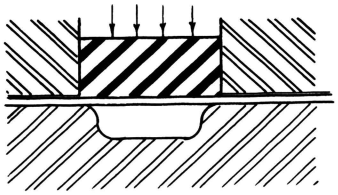


Fig. 4 Restricted Rubber Pressure

This method gives a far better result than both of the above suggestions. In this case, only one side of the sheet may be guarded and hence expected to feed in the crimp while the other side may be kept locked by the rubber pad.

d. Find a way for helping the metal to flow, such as a mechanical means of pushing the metal in the groove. (See Fig. 5).

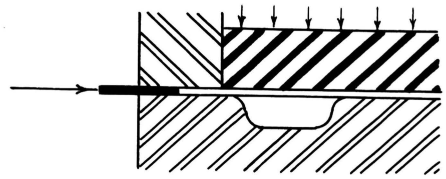


Fig. 5 Helping Sheet Flow

THE MINIMUM BEND RADII

The minimum bend radii plays an important role in the formation of crimps. If a relatively thick sheet of metal is bent, cracks develop on the outside surface followed by failure. Every sheet metal has a minimum radius to which it can be bent successfully without the formation of cracks. This radius was found to have some relation to the thickness of the metal and a relation called the R/T ratio was developed.

"The ratio of the minimum bend radius to metal thickness R/T has been found for most metals to be independent of the thickness of the metal. Exception are some Aluminum alloys, where the ratio between the minimum bend radius R, and the thickness, T, usually increases with the metal thickness." (5)

The Minimum Bend Radii of the Aluminum Alloy 24S-T3 are given below. (5)

Sheet Thickness	0.016"	0.032"	0.064"	0.128"	0.182"	0.258"
Min. Bend Radii	$1\frac{1}{2}$-3T	2-4T	3-5T	4-6T	4-6T	5-7T

---

(5). Sacks, p.43, Table 2, Op.cit., p.6

The limitations put on by the Minimum Bend Radii compels the use of a certain radius at the edges of the crimp. This radius is also necessary to prevent the blanking action of the rubber discussed later.

When a sheet of metal is being bent into a corner, the outside fibers tend to elongate developing tension strains, while the inner fibers tend to form compression strains. As soon as the outside fibers reach the maximum strain, which is determined by the ductility of the material, cracks start to form on the tension side as shown in Figure 6.

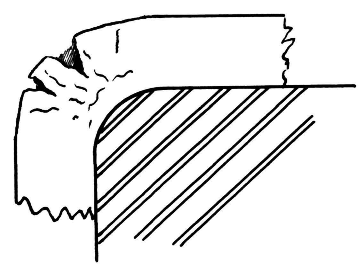


Fig. 6 Small Corner Radius Failure

In this respect, "Part types, the limitations of which depend on compression type failures, can be fabricated in many metals to nearly identical limits. On the contrary, the limitations of a part type that is susceptible to a tension type failure generally depend greatly on the particular material used." (6)

(6). Sacks, op. cit., p.6

From this argument it may be concluded that any means of reducing tension stresses and increasing compression stresses in locations where tension stresses are likely to develop may result in sharper corners and higher R/T ratios.

Therefore, the suggestion "d" in the previous discussion will not only help the metal feed in the crimp but also help form sharper corners without failure by developing compression in the sheet metal, neutralizing the tension stress in bending.

COMPARISON OF RUBBER AND MECHANICAL CRIMPING ON SHEET METALS

Rubber and mechanical crimping are two fundamental different operations, although they are both used to achieve the same purpose -- a simple crimp. By discussing the manner in which these two systems shape a crimp a comperative idea as to the preference between the two may be obtained.

Rubber Hydro-Press Crimping:

A uniform pressure is applied all over the sheet locking both sides. (Figure 7a).

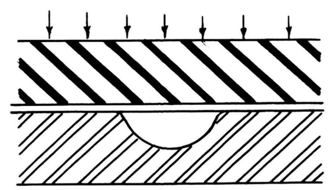


Fig. 7a

The unsupported part of the sheet elongates slightly and sinks level, since the pressure is uniform like a ristricted end beam. The rubber acts like a solid punch with no side clearance. (Figure 7b).

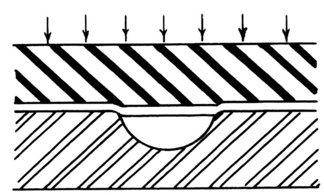


Fig. 7b

The sheet is blanked and has failed to form the crimp. Due to excessive elongation. (Figure 7c).

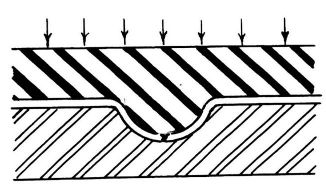


Fig. 7c
Stages in Rubber Crimping

Mechanical Crimping:

The pressure acts only at the center giving a maximum chance for elongation. (Figure 8a).

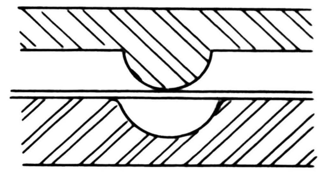


Fig. 8a

The male die bends the sheet in a V-form, feeding extra metal in the groove. (Figure 8b).

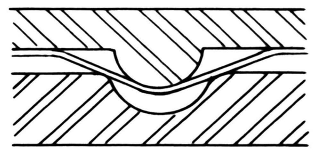


Fig. 8b

It then pulls the sides down giving the final form to the crimp. (Figure 8c).

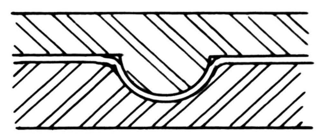


Fig. 8c
Stages in Mechanical Crimping

CRIMPS ON SHEET METAL STRIPS

The holding strength of a crimp on a sheet metal strip may be a valuable lead in determining the strength of a similar crimp on a tubular section. Although crimps on sheet metal have almost no value as a mechanical fastener, experiments on this kind of crimp may give some valuable clues as to the best shape or number of crimps to be used with a certain sheet metal.

In conducting the experiments, three sizes of crimps, namely, 1/4", 3/8", 1/2", were started with. The edges of the crimp groove had just enough radius to prevent cracks or failure due to blanking action. In preparing the samples, it was found that the mechanical crimping, where a male die was used, worked better than rubber crimping and should always be preferred on sheet metals where the die required is simple to build.

The samples are of heat treated Aluminum alloy 24S-T and are 1 inch by 0.064 inches. The crimp is formed on one end and its strength tested on a tensile testing machine with the tool shown in Figure 9 on the following page.

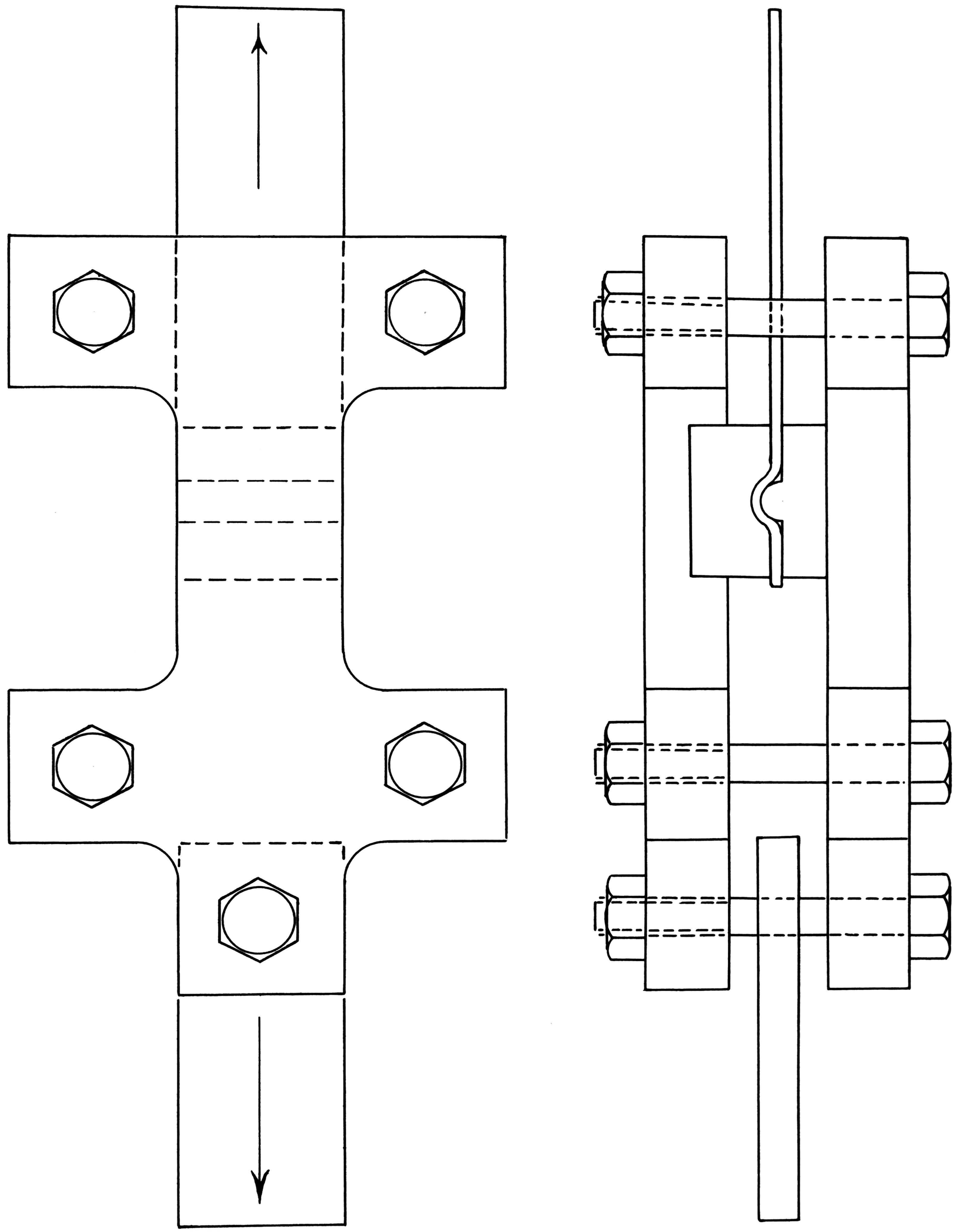


FIGURE 9. TOOL FOR TESTING STRENGTH OF A CRIMP ON SHEET METALS.

STRENGTH OF CRIMPS ON 24ST-AL SHEET STRIPS

Samples 1" x .064" and 4" long. All crimps mechanically formed.

Crimp Diameter

1/4"	1200 - 1235 - 1050 lbs.
3/8"	1085 - 1435 - 1300 lbs.
1/2"	1325 - 1125 lbs.
1/2"	1250 - 1225 lbs. (Rubber formed)

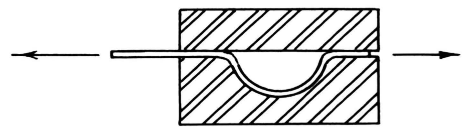


Fig. 10a Crimp Form With Plain Holder

1/4"	2400 - 2350 lbs.
3/8"	2400 - 2440 lbs.
1/2"	1875 - 1875 lbs.

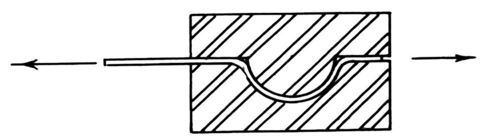


Fig. 10b Crimp Form With A Male Holder

RECOMMENDED TEST PROCEDURE FOR SHEET METAL CRIMP STRENGTH

1.	1/2"	Full groove depth
	3/8"	
	1/4"	
2.	1/2"	Half groove depth
	3/8"	
	1/4"	
3.	1/2"	Double groove
	3/8"	
	1/4"	
4.	1/2"	Triple groove
	3/8"	
	1/4"	
5.	1/4" - 3/8" - 1/2"	Triple groove
	1/4" - 1/4" - 3/8"	Triple groove
	3/8" - 3/8" - 1/2"	Triple groove

PROCEDURE

The experiments of this thesis were done with aluminum alloy tubing specified as 24S-T3. The tubes used and their specifications are given below:

1" Outside Diameter by 0.035" Wall Thickness

1" Outside Diameter by 0.065" Wall Thickness

1½" Outside Diameter by 0.035" Wall Thickness

2" Outside Diameter by 0.065" Wall Thickness

24S-T3 Drawn Aluminum Tubing

Mechanical Property Specifications as given by Aluminum Company of America.(7)

24S-T3

Diameter 1/4" to 2" Wall Thickness	Tensile Strength psi. Minimum	Yield Strength offset 2°/o psi. minimum	Elongation % in 2"
0.018-0.024	64,000(8)	42,000	10
0.025-0.049	64,000	42,000	12
0.050-0.259	64,000	42,000	14
0.265-0.500	64,000	42,000	16

---

(7). Alcoa Aluminum and its Alloys- Aluminum Company of America, 1950, Table 36, p. 133.

(8). Tensile test on 1" O.D x 0.035 Wall Thickness Tubing proved about 73,600 psi. Tensile Strength.

The crimps used for the purpose of closing the ends of the tubes were formed by the "Rubber Hydro-Press process", where a rubber ring acts like a hydraulic fluid under high pressures in a closed container and deforms the tube to the form of the particular crimp. (See Appendix, Figure 17).

Samples two inches long are plugged at both ends and various sizes and shapes of crimps are used for securing the plugs.

The strength of the particular crimp is tested by pulling the plugs by means of studs on a tensile testing machine which gives a fair idea about the pressures that it can stand without failure. The results of these tests are given in tables 1 to 4 in pages 27 to 30.

All crimp grooves in table 1 are of circular section 1/4", 3/8", 1/2", in diameter and these grooves were made 1/8", 1/16", and 1/32", deep, amounting to twenty seven samples altogether. The 1/8" deep grooves have a corner radii of 3/64", the 1/16" deep grooves have a corner radii of 1/64", and 1/32" deep grooves have no corner radii. These corner radii were found to form successfully. In manufacturing, the corner radii were made by hand and carefully checked by template gauges although a perfection was not achieved in spite of all the care given. On the 2" tube, due to 0.065" wall thickness, the corner radii were increased to 1/16".

The plugs were made 5-10/1,000 less than the inside diameter of the tube to make handling and assembly easier.

Factors such as strain hardening due to cold working, residual stresses, and others like invisible tiny internal cracks are of great importance in determining the final strength of a particular crimp.

When using crimps in making tube joints or plugs a totally dependable and predictable means is required so that it can safely be applied to design with low factors of safety and still give a failure-free service.

A crimp with a large deformation such as a deep groove or one with sharp corners would stand a greater pressure or pull than a crimp with round edges or less deformation. However, this heavy duty crimp will break at the groove edge while a light service crimp will pull out but will not break. Therefore, two of the heavy service crimps may not be any stronger while two of the light service crimps may double, and three may almost triple the holding strength of the joint or plug. When space is limited, one heavy duty crimp would do, but when space is not limited it is safer and better to use a number of light crimps with a smaller deformation. This plug would have a more predictable holding strength, being free of cracks or stress concentrations.

Furthermore, with a mechanical crimping tool the tube is more subject to cold working, straining, and shearing at the corners. Rubber does the job with the least possible straining, although the crimp may not altogether match the form of the groove.

All plugs were made of Aluminum alloy, rather than steel, to increase the speed of production and also with the idea that a softer plug would scratch the tube less than a harder material at the crimp corners. To give any appreciable weight to this argument, softer grades of aluminum should be used than the heat treated alloy that the author has used which was the only kind available at that time.

The plugs used should have enough skirts on both sides of the groove (1/4" at least) to protect the uncovered part of the tube against the rubber pressure. (See Appendix Fig. 17). However, when the plugs are designed for hydraulic pressure, a second groove is needed for the o-ring. In that case an o-ring is an absolute necessity and without it the plug would not be of much use even against small hydraulic pressures. This second groove may be relatively small and of rectangular shape but would add a considerable amount to the plug length.[(9)] This o-ring also has the property of protecting the crimped area from the expending stress of the internal pressure in the tube.

Three special dies were manufactured for 1", $1\frac{1}{2}$", and 2" tubing to properly form the crimps in question.(See Appendix Fig. 17).

---

(9). The strength of our plugs were tested on a tensile testing machine. The author recommends the use of hydraulic pressure for further investigations, which would give more useful results. In that case the use of o-rings for the purpose of hydraulic sealing is a necessity.

Pressures used were of the order of 15,000 to 30,000 pounds per square inch, although the tons of load necessary to deform the tube varied from 10 tons to 45 tons.

The source of pressure was an Atlas press of 75 tons capacity, which was used for forming the crimps. (See Appendix Fig. 23).

Crimps of greater diameter and depth were found to form with smaller pressures and greater ease, due to the presence of a larger unsupported area over the groove.

Six more plugs were made for the 1-inch tube with rectangular grooves 1t and 2t deep and 4t, 6t, and 8t wide. The grooves with 2t depth blanked the tube and did not form. The results of the others are given in Table 2, page 28. The corners of these grooves were left without any radii. These should actually be tried with enough radii to form and would most probably result in greater strength than the others, since the corners of a rectangular groove would have a greater tendency to grip the metal than that of a circular groove.

As a third possibility, rings of 1-inch tubing were expended and were again compressed after being inserted in the crimps over the tube. Due to the lack of time for manufacturing, the product was rather poor. In some cases the ring was appreciably weakened and in others the tube was damaged. The samples that were tested proved that this method would be a satisfactory solution for high strength plugs if accurately and carefully tooled and manufactured. The results of these tests are on Table 3, page 29.

As a fourth possibility, rings of 3/4" width were expended from 1" tubing and inserted over the tube that already had its plug in and the crimp formed. The author did not have any success in forming a crimp on this second outside piece by the rubber hydro-press process although it is entirely possible. Therefore, he used a simple tube cutter for crimping this ring by simply replacing the cutter roller by a 1/4" thick roller of circular profile and 5/8" diameter. (See Appendix Fig. 25). This proves to be a very handy tool for use in the field where the hydro-press method could not be applied. Since there is no way of regulating the pressure of the roller and account for the various shapes of grooves, crimps on the inner tube were severly cold worked and overstrained. However, they were principally successful as a means of increasing the strength of a crimp. The results are given on Table 4, page 30.

CALCULATION OF REQUIRED PLUG STRENGTH

For thin walled tubing the tensile stress on the wall is,

$$S_t = \frac{pD}{2t}$$

The tensile strength of the tube material is,

$$S_t = 70{,}000 \text{ psi.}$$

Since the holding strength of the crimps are tested it would be useful to determine the value for the strength of the plug that could stand the pressures that the tube itself can take.

$$p = \frac{2S_t t}{D} = \frac{2 \times 70{,}000 \times 0.035}{1} = 4{,}900 \text{ psi}$$

$$\text{Plug Area} = \frac{D^2}{4} = \frac{\pi \times (.930)^2}{4} = 0.680 \text{ in.}^2$$

$$\text{Required Plug Strength} = 0.680 \times 4{,}900 = 3{,}330 \text{ pounds}$$

For 1" O.D x 0.035 Wall Thickness Plug Strength =

$$\mathbf{3{,}330 \text{ lbs.}}$$

For 1" O.D x 0.065 Wall Thickness =

$$p = \frac{2 \times 70{,}000 \times 0.065}{1} = 9{,}100 \text{ psi.}$$

$$\text{Plug Area} = \frac{\pi \times (0.870)^2}{4} = 0.593 \text{ in.}^2$$

$$\text{Required Plug Strength} = 0.593 \times 9{,}100 =$$

$$\mathbf{5400 \text{ lb.}}$$

For $1\frac{1}{2}$" O.D x 0.035" Tube

$$p = \frac{2 \times 70{,}000 \times 0.035}{1.5} = 3{,}270 \text{ psi.}$$

Plug Strength:

For $1\frac{1}{2}$" O.D x 0.035" Wall thickness 1.6 x 3,270 = <u>5,240 pounds</u>

For 2" O.D x 0.065 Tube

$$p = \frac{2 \times 70{,}000 \times 0.065}{2} = 4{,}550 \text{ psi.}$$

$$\text{Plug Area} = \frac{\pi \times (1.870^2)}{4} = 2.74 \text{ in.}^2$$

Plug Strength.

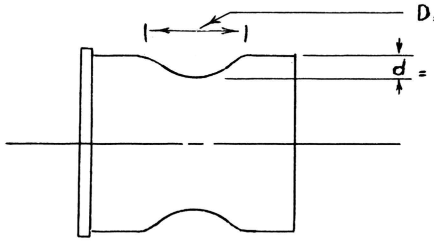
For 2" O.D x 0.065" Wall Thickness 2.74 x 4,550 = <u>12,500 lb.</u>

TABLE I

HOLDING STRENGTH OF CIRCULAR CRIMPS

TUBE	CRIMP DIAM.	CRIMP DEPTH 1/32"	1/16"	1/8"
+ 1" O.D. .035"	1/4"	900 lbs.(10)	2200 lbs. (10)	3425 lbs.(11)
	3/8"	1450 lbs.(10)	2680 lbs. (10)	3075 lbs. (11)(12)
	1/2"	1590 lbs.(10)	2690 lbs. (10)	3200 lbs. (11)(12)
++ 1½" O.D. .035	1/4"	1850 lbs.(10)	1250 lbs. (10)	2850 lbs. (10)
	3/8"	1850 lbs.(10)	3175 lbs. (10)	5400 lbs. (11)(12)
	1/2"	1675 lbs.(10)	2815 lbs. (10)	4950 lbs. (11)(12)
+++ 2" O.D. .065	1/4"	REQUIRED PLUG STRENGTH		2225 lbs. (10)
	3/8"	+ 3,330 lbs.		5880 lbs. (10)
	1/2"	++ 5,240 lbs.		8300 lbs. (10)

+++12,500 lbs.



D= Crimp diameter 1/2"

d= Crimp depth 1/8"

1/2" - 1/8" Plug for 1" tube

(See Appendix, pp. 50, 51, 52)

Corner Radii: 3/64 for 1/8" deep crimp
1/32 for 1/16" deep crimp
0 for 1/32" deep crimp

---

(10) Type of failure: Pulled out without fracture.

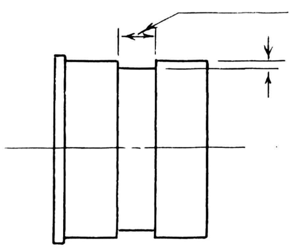
(11) Type of failure: Failed by fracture of the tube.

(12) Longitudinal flutes formed inside the crimp. Six heavy flutes on 1/2 - 1/8" crimp and three lighter flutes on 3/8 - 1/8" crimp and (Appendix, fig. 24).

TABLE 2

STRENGTH OF RECTANGULAR CRIMPS

TUBE	GROOVE DEPTH	GROOVE WIDTH 4t .140"	GROOVE WIDTH 6t .210"	GROOVE WIDTH 8t .280"
1" O.D. .035"	1t(14)	515 lbs.(13)	1690 lbs.(13)	1670 lbs.(13)
	2t	(15)	(15)	(15)
	3t			
1½" O.D. .035"				



Groove Width 6t

Groove Depth 1t

(See app. Fig. 27)

REQUIRED PLUG STRENGTH

1" x .035 = 3,330 lbs.

1½" x .035 = 5,240

2" x 0.065 = 12,500

(13). Plug pulled out without fracture of tubing.

(14). t is equal to the wall thickness of the tubing and is .035"

(15). Crimp failed to form due to sharp corners.

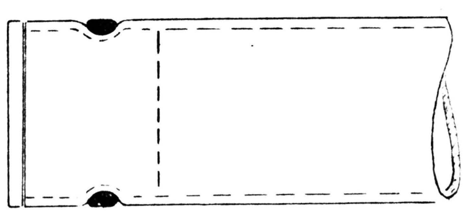
TABLE 3

STRENGTH OF RING REINFORCED CIRCULAR CRIMPS

TUBE	CRIMP	CRIMP DEPTH		
	DIAM.	1/32"	1/16"	1/8"
1"O.D. .035"	1/4"	0 lbs.(16)	3050 lbs.	
	3/8"	2275 lbs.(17)	2850 lbs.(16)	
	1/2"	1850 lbs.(17)		
1½".O.D. .035"				

REQUIRED PLUG STRENGTH

3,330 lbs.



---

(16). Type of failure= Broken tube.

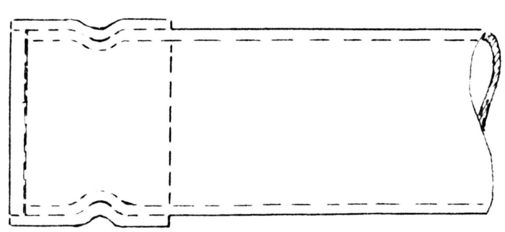
(17). Type of failure= Broken ring.

TABLE 4

STRENGTH OF SLEEVE REINFORCED CIRCULAR CRIMPS

TUBE	CRIMP DIAM.	CRIMP DEPTH 1/32"	1/16"	1/8"
1" O.D. .035"	1/4"	3200 lbs.	3125 lbs.	
	3/8"		3025 lbs.	
	1/2"	3300 lbs.	3125 lbs.	
1½"O.D. .035"				

REQUIRED PLUG STRENGTH
3,330 lbs.



(See Appendix, Fig. 27)

TUBE CRIMPING TOOLS

The author has used a relatively simple die working on the rubber hydro-press principle for forming the particular crimps on the tubes. (See Appendix Fig. 17).

A separate tool is required for each tube diameter while the thickness of the tube makes no difference. The die is of cylindrical form in which the tube end fits. On the top part the inside diameter enlarges and a rubber ring is set inside and around the tube. Over this a piston fits whose inside diameter is the same as the tube and the outside diameter is exactly the same as the die with a very close tolerance. The whole gadget is put under the press and pressure is exerted over the piston, which transmits the pressure to the rubber which in turn pushes the tube to form the crimp.

The clearance between the tube and the die parts and the piston and the die parts should be a minimum since under these high pressures the rubber element (in our case of extremely poor quality) leaks around the tube and the piston, ruining itself and the sample. These tools were made of already heat treated alloy steels and great care was taken in the manufacturing of $1\frac{1}{2}$" and 2" dies. The 1-inch die brought forth all the troubles of a bad tool manufactured by an unexperienced lathe operator.

The rubber ring should be of good quality and relatively hard. A D-735-48T- Shore hardness 70 and tensile strength 18,000 psi is recommended.[18]

---

(18). Simpson, Op. cit., p.5

A harder rubber has less tendency for fringing and leaking around the tube or the piston and hence lasts more and makes the removal of the tube from the die easier.

The thickness of the rubber should be only slightly larger than that of the crimp groove width. This results in a shorter plug and a better crimp. Since a thinner rubber ring reduces the locking of the metal around the crimp and makes the metal flow easier, the plug should have a long enough skirt to cover the area of the rubber pressure to prevent the failure of the tube below the plug or leak of rubber about the tube. Therefore, a thinner ring of rubber would be an advantage, whichever way we look at it.

A lubricant on the rubber helps in handling, although it has no appreciable advantage in forming the crimp. Even highly damaged rings of rubber was found to form crimps satisfactorily with properly built dies that were close enough to prevent any leakage.

Numerous designs for rubber and mechanical crimping tools can be thought of that would be suitable for a particular case. Some of these possibilities thought of by the author or used by other investigators are shown in the Appendix Figures 17, 18, 20, 21, 22,

CONCLUSIONS AND RECOMMENDATIONS

The experiments done with sheet metals showed that a male piece filling the groove of the crimp almost doubled the strength of the crimp. In a tube, the holding strength comes from the circumferential strength of the tube as the first factors and the form or deepness of the groove as the second.

If we consider the circumferential strength of a particular tube as constant we can search for the best form of crimp groove that would give us the greatest strength. With this procedure we find that the strongest crimp is a relatively deep one, but this greatly reduces the strength of the material by excessive deformation.

As a second possibility we can increase the circumferential strength of the tube and keep the crimp deformation to a minimum. This can be done in a number of ways: 1- Insert a ring in the groove. 2- Put a relatively long tube, about the length of the plug, over the tube already crimped and crimp the second one over the first. 3- Put a ring that is cut on one side in the crimp groove and insert the tube over this. 4- Wind steel wire over the groove.

The first two of these have been used with some success improving the results by more than 50 to 100% in some cases and promising to be far better with carefully built samples.

The last two may be more satisfactory since there is a smaller chance of bruising the material in the process of manufacturing.

All these methods add to the circumferential strength of the tube and hence increase the holding power of the crimp. Therefore greater strengths can be reached with smaller deformations thus reducing cold work and material weakening to a minimum.

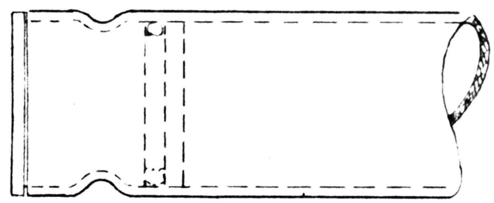


Fig. 11 Circular Crimp

The results of the limited number of experiments that were done show that increasing the crimp diameter results in an increase of plug strength. Likewise an increased crimp depth has the same effect. There is an improvement of more than 1,000 pounds between the 1/32-inch deep and 1/16-inch deep grooves. These crimps pull out of the plug without fracturing the tube. When the crimp depth increases to 1/8" there is an increase of 1,000 to 2,000 pounds, but this time the crimp no longer pulls out but rather fractures the tube when failing. (Figure 11).

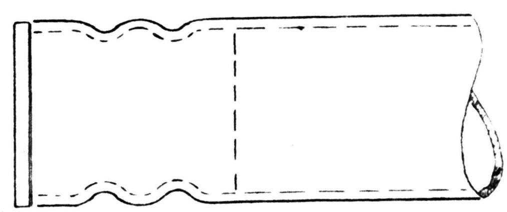


Fig. 12 Double Crimp

In putting these crimps to application, consideration must be given to outward appearance, type of failure, required strength, and permissible plug length.

For high strength and limited plug length it would be preferable to use a 1/8" deep crimp. For a higher strength a number of crimps only 1/16" deep would be more suitable although this would require a longer plug. Due to lack of time no experimentation was done with multiple crimps which would be of great value and importance. (See Fig. 12).

The use of a ring over the crimp proved to be a very effective means in increasing the strength of the plug, at the same time improving the looks. This resulted in an increase of about a 1,000 pounds in tension strength. In almost all cases the failures started with a broken ring, since these rings were made of the same tube material and severly cold worked and roughly handled. It is the belief of the author that a ring of the correct profile made of a stronger material such as steel and used on a crimp not over 1/16" deep will result in very satisfactory crimp with greater strength than many others. (Figure 13).

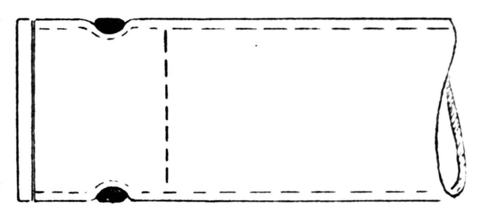


Fig. 13 Crimp & Ring

Use of a 3/4" wide tube over the crimp and crimping this tube over the first one results in a stronger and more consistent and dependable plug, although it increases the diameter by additional material. It would be preferable to form the second crimp again with a rubber hydro-press method since mechanical crimping seriously

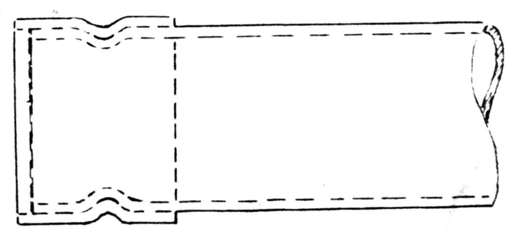


Fig. 14 Sleeve over Crimp

damages the tube by cold working. (Figure 14).

These tubes that fit over the first one are made by passing a cylindrical plug of about 5° taper and an outside diameter of 1.005 inches and about 4 inches long, through the 1"ODx0.035" tubes and thus expanding them to fit the outside of the 1" tube.[19]

Setting an aluminum or steel ring in the crimp groove would be a simple operation if this ring was already split at on place. To hold the ring in place we could use a short length of expanded tubing we have defined above. This method is not only very simple but also of great advantage. (Figure 15).

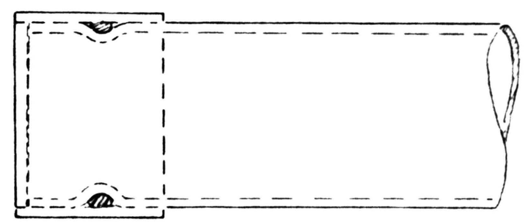


Fig. 15 Sleeve over Ring

The author did not find time enough to apply the idea of winding a steel wire. As most of us know, this was applied on gun barrels very successfully. Carefully winding a few rows of thin steel wire in the

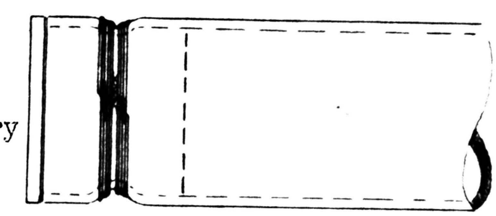


Fig. 16 Wire wound Crimp

(19). Here the author calls attention to the fact that a tube cut with a regular tube cutting tool receives enough cold working to prevent it from expanding into the above stated limit and would rather crack. However, if cut with a regular saw blade it can successfully be expanded to even greater limits.

crimp groove will not do any cold working on the tube. Moreover, since it is hidden in the groove it will not be projecting over the tube surface and would have a very pretty appearance. The matter of winding wire could be easily mechanized and would be a simple operation. (Figure 16).

Some ideas about possible plugs are also shown in the Appendix Figure 18, with suggested crimp shapes by other investigators in Figure 21. Thinking that they would be of value to others that may work in the same field they have been included in this paper.

MECHANICAL PLUG

Before concluding this paper the author wishes to mention a new type of mechanical plug that proved itself superior to any other kind that has been thought of. The idea for this plug was suggested by an application in assembling light alloy bicycles in France. "The frames of the bicycles are provided with an ingenious form of cone joint. The tube end is slightly coned, as also the interior of the lug, and a thin liner is introduced between the two, within the tube the coned alloy nut of an expender bolt is provided with a steel bush, drilled and tapped to take the bolt which is tightened up from within the lug by means of a special tool." [20]

---

(20). Davies, op. cit., p.4

This idea of a cone joint and the jaws of a tensile testing machine suggested to the author a much more simplified design which consists of a steel ring internally coned and a plug of the same angle that fits in the tube. (See Appendix Figure 19). As long as the outside ring is made of sufficiently strong material this kind of plug can stand far greater pressures than what the tube is expected.

Due to the nature of the design, with increasing pressures and loads, the plug gets firmer and seals better. Due to its natural sealing character it does not need any o-rings, no special seals, no forming presses, and it is easily and cheaply manufactured and assembled.

One design for a 1" tube was used on a tensile testing machine and the tube failed at 8,100 pounds in tension while the plug showed no sign of weakness, a far smaller plug could have stood the same load. Another design for a 1½" cube was made only ½" wide and an outside diameter of 1 3/4" only 1/4" larger than the tube diameter. This plug failed by pulling out at 9,900 pounds tension due to an inaccurately manufactured ring. These two plugs proved to be most satisfactory and promising and better than any others. Another ring was made for 1½" tube. This time with greater care and the end that stood up to 9,900 pounds failed at 11,800 pounds by breaking off the tube just below the plug, giving a full amount of 71,600 psi of material which is 5,600 psi higher than the tensile strength specified by the manufacturer, Alcoa, of the tubing.

Considering that only half this amount would be applied to the plug in any case of internal pressure, this 100% efficient plug has a factor of safety of 2 with reference to the strength of the tube in the trensverse direction.

This plug has the following advantages=

1. Consists of only 2 pieces.
2. Shapes are very simple and applicable to mass production.

3. No tools are needed for assembly.

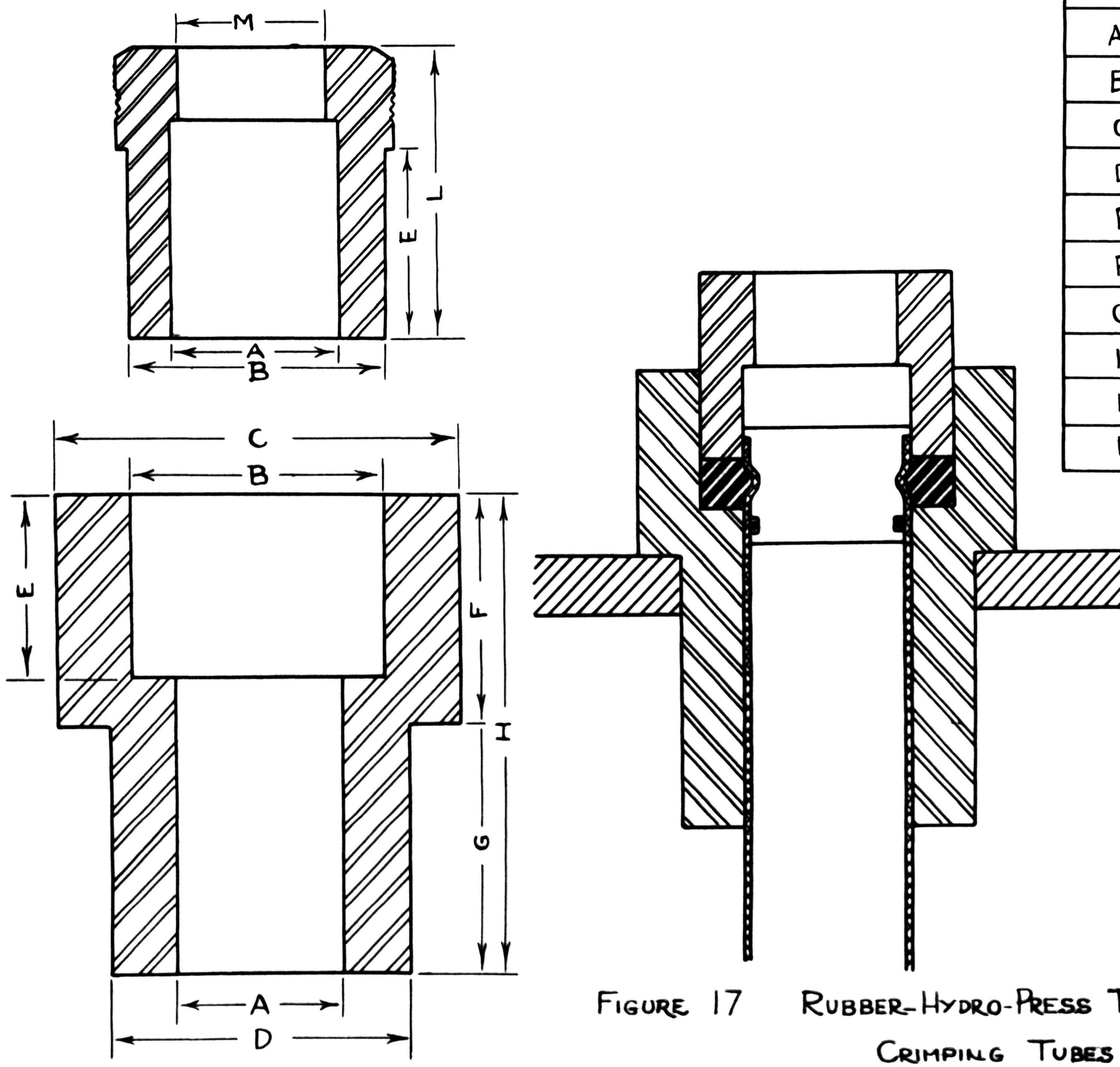
4. Needs no kind of seal, is self-sealing.

5. Deformation of tubing material is a minimum and produces almost no cold work or residual stresses.

6. Occupies a minimum space with respect to width and diameter.

7. It is the only kind that can use the full strength of the material with 100% efficiency.

APPENDIX



Notation	1" Tube	1½" Tube	2" Tube
A	1.00	1.50	2.00
B	1.50	2 3/16	2 7/8
C	2 3/8	3 3/16	3 7/8
D	1 3/4	2 3/8	3.0
E	1.0	1 9/16	1 3/8
F	1 1/4	2.0	1 15/16
G	1 3/8	1 1/4	1 1/2
H	2 5/8	3 1/4	3 7/16
L	1 9/16	2 1/2	2 3/8
M	7/8	7/8	1.0

Figure 17 Rubber-Hydro-Press Tool for Crimping Tubes

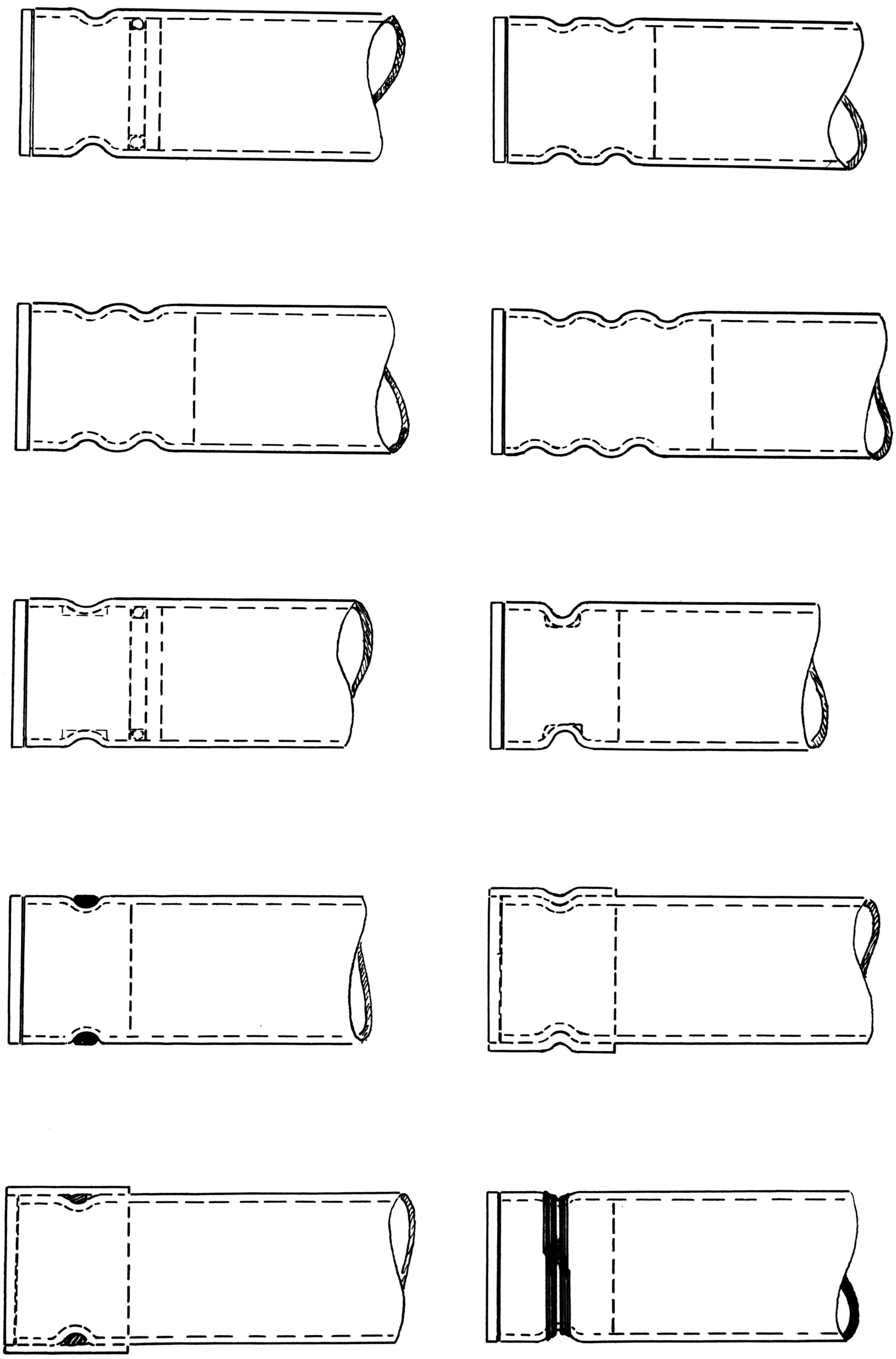


Fig. 18

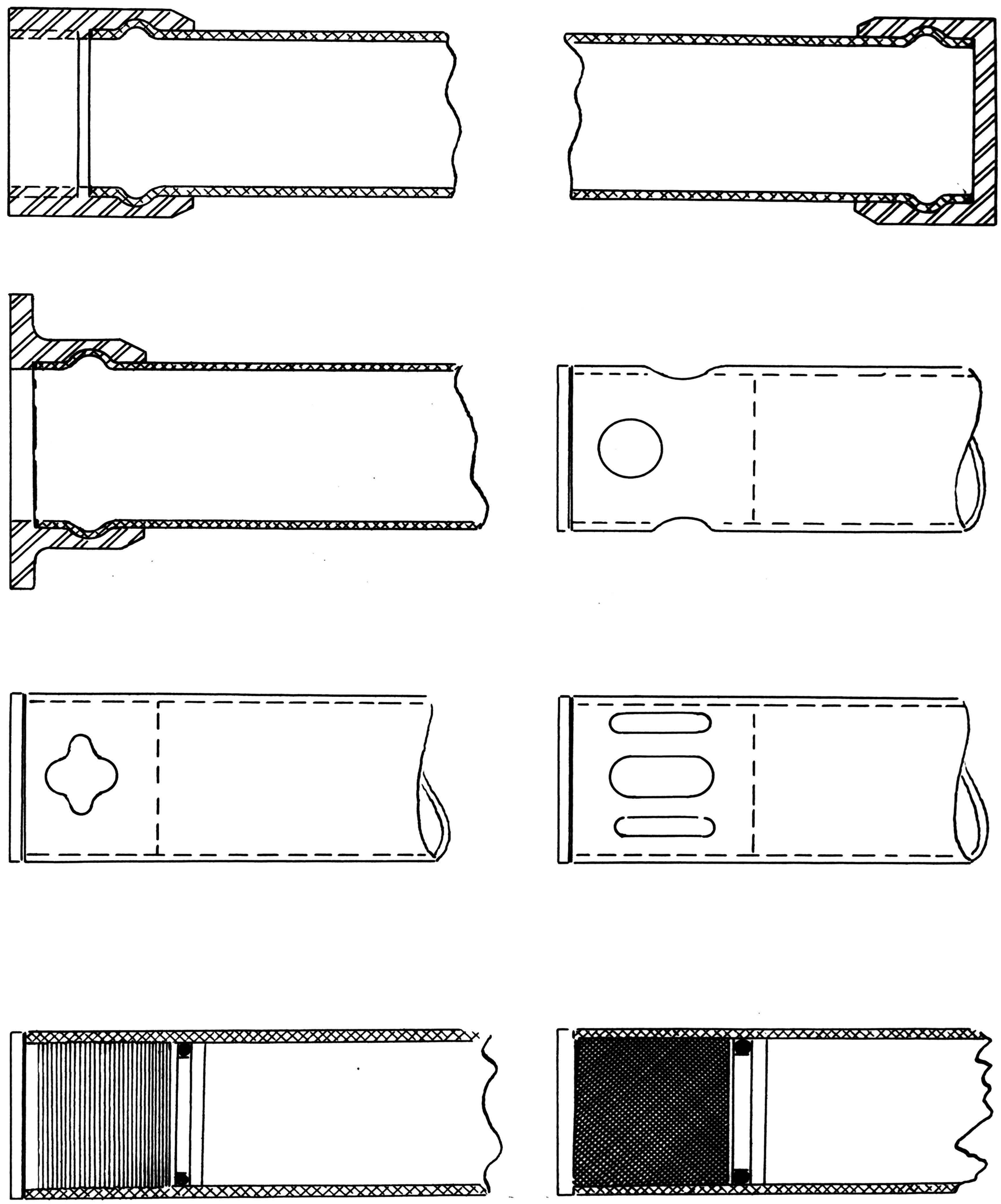
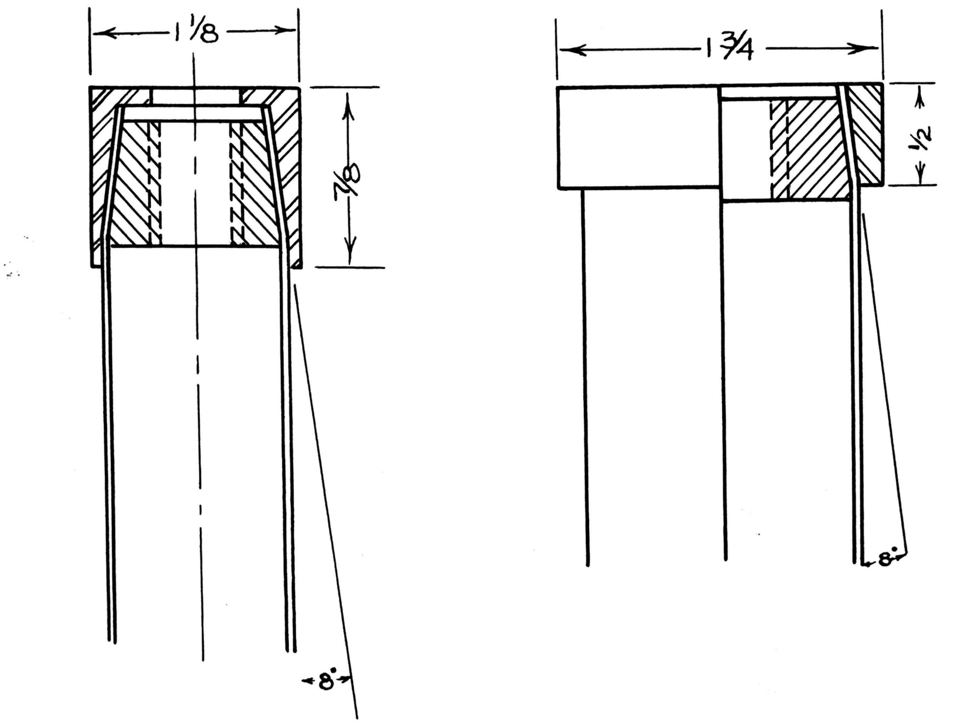


Figure 18 – Seventeen Possibilities for Crimped or Other Types of Plugs ~.



1" TUBE 0.035" TUBE FAILED
AT 8100 lb. TENSION
73,600 PSI.

1 1/2" - TUBE 0.035" TUBE FAILED
AT 11,800 lb. TENSION
71,600 PSI.

FIGURE 19.

MECHANICAL PLUG

FIGURE 20

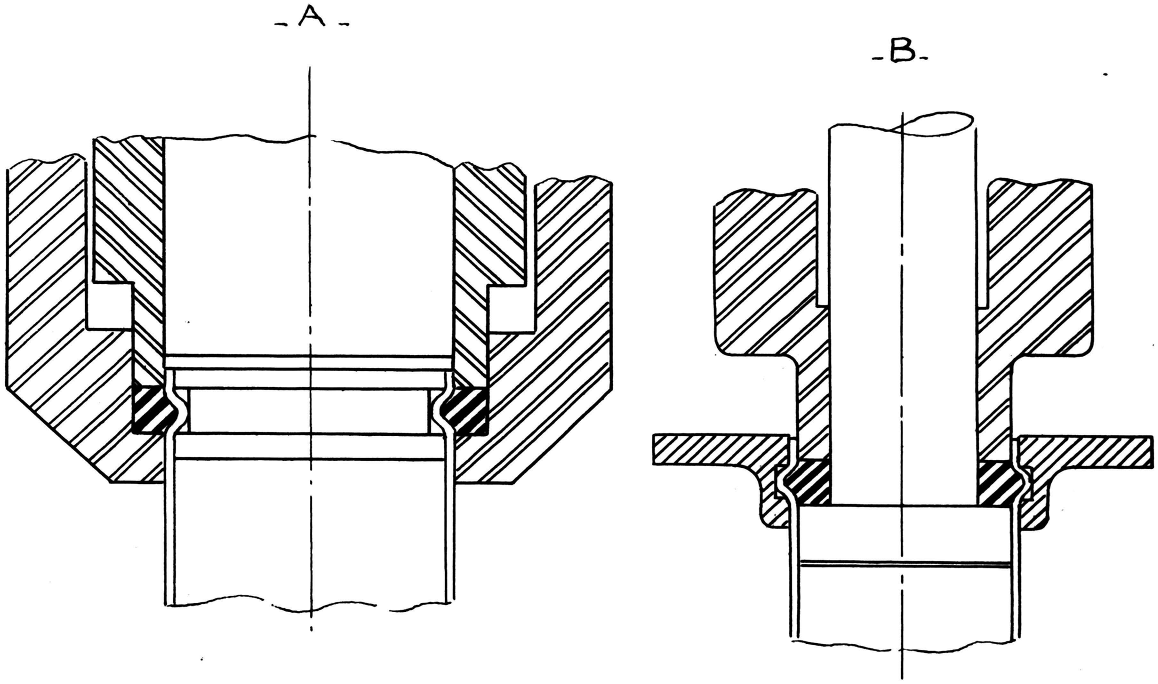
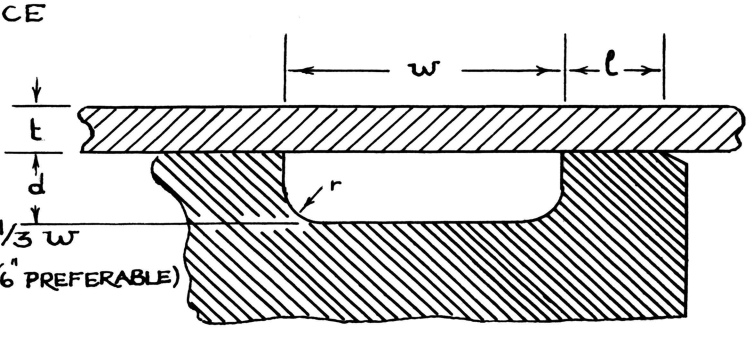


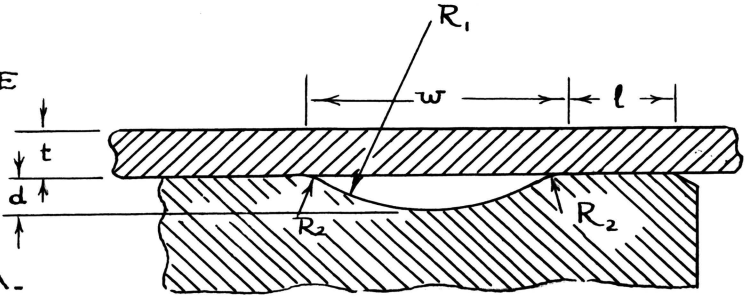
FIGURE 21

A- FOR SEVERE SERVICE



t = 0.010 in. MAX. d = 1/5 to 1/3 w
w = 4t to 8t l ≥ 1/8 in. (3/16" PREFERABLE)

B- FOR LIGHT SERVICE



R_1 = TO SUIT w & d
R_2 = 4t MAX.
OTHER DIMENSIONS AS IN -A-

SOME TOOLS & CRIMPS RECOMMENDED BY F. R. SIMPSON - RESEARCH ENGR.
FRANKLIN LABS. PRODUCT ENGINEERING, PP. 144-148 MARCH - 1950 -

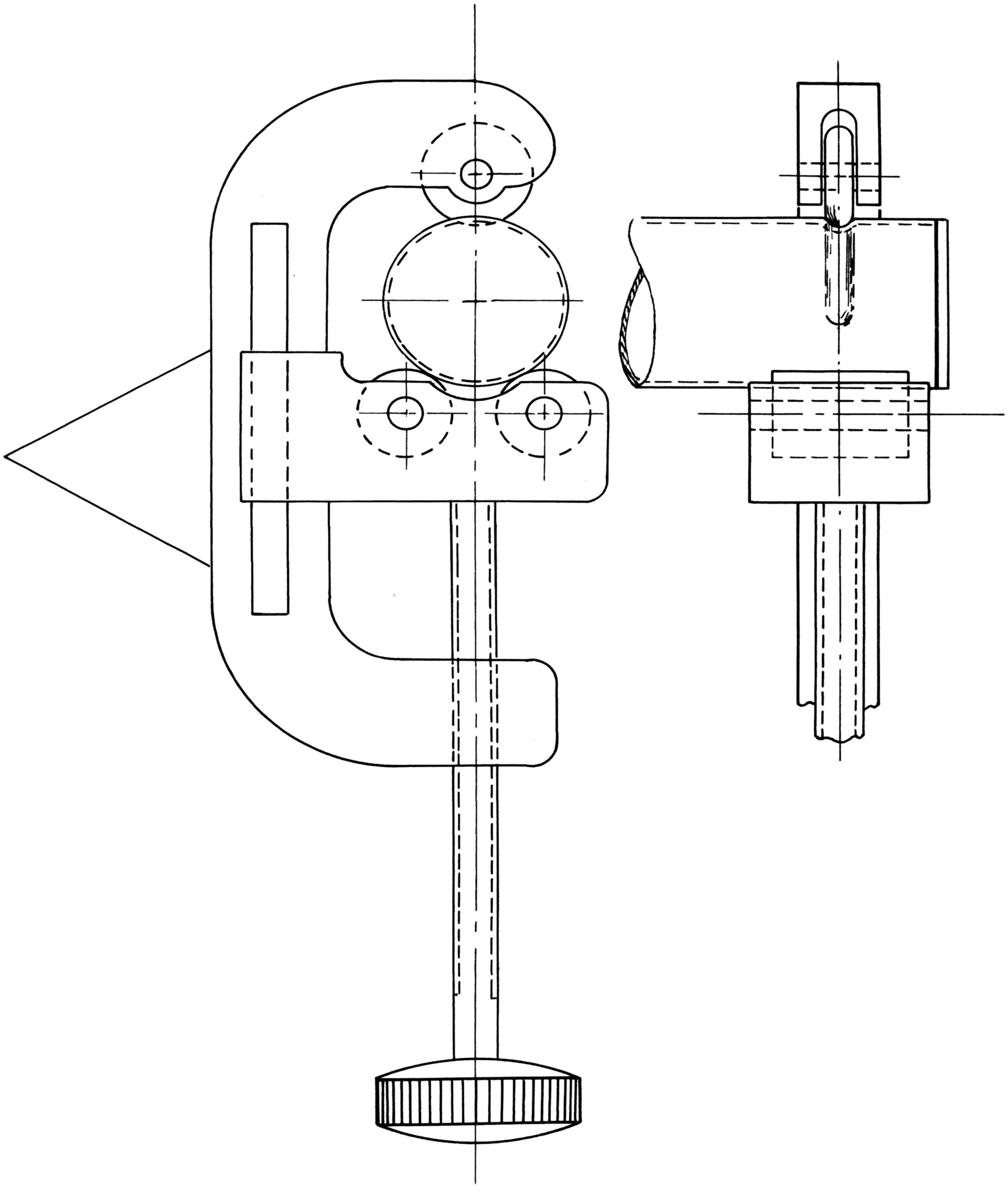


FIGURE 22 ~ A MECHANICAL CRIMPING TOOL ~
~MADE FROM A TUBE CUTTER~

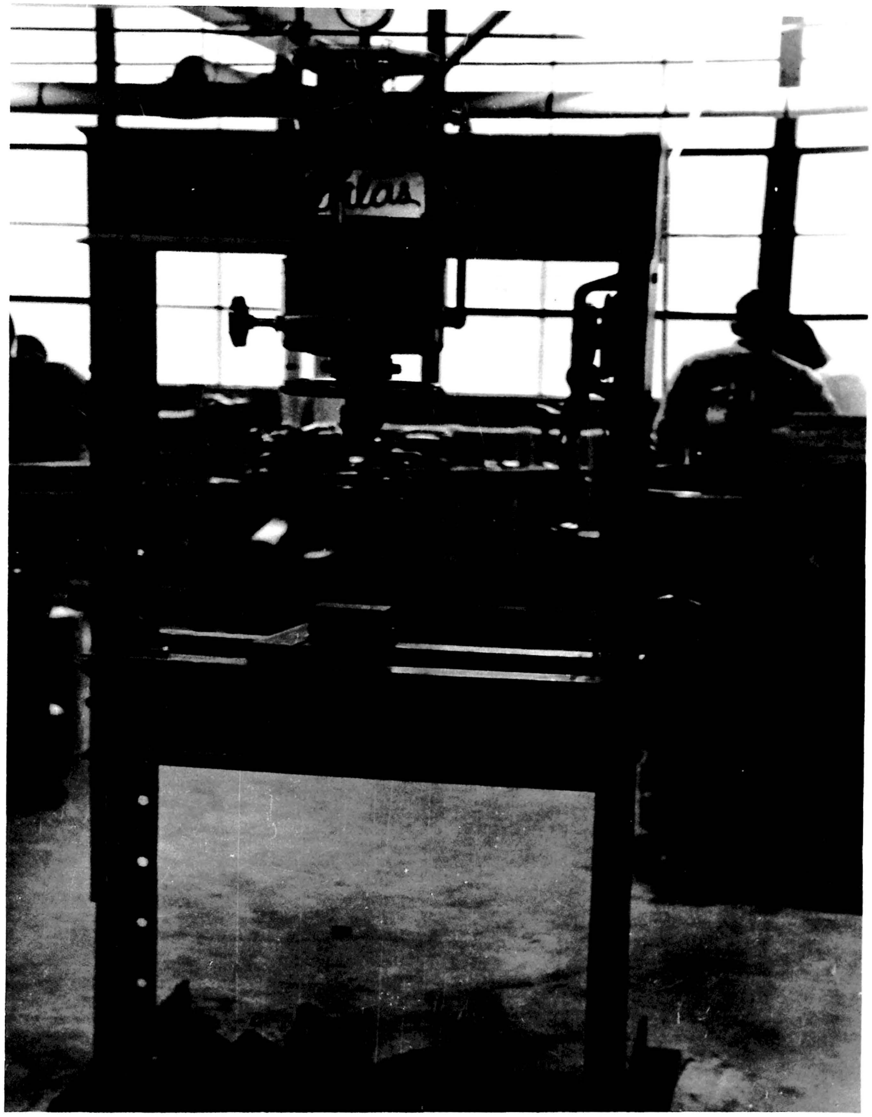


Fig. 23 75-ton Atlas Press used for crimping the tubes with rubber pressure.

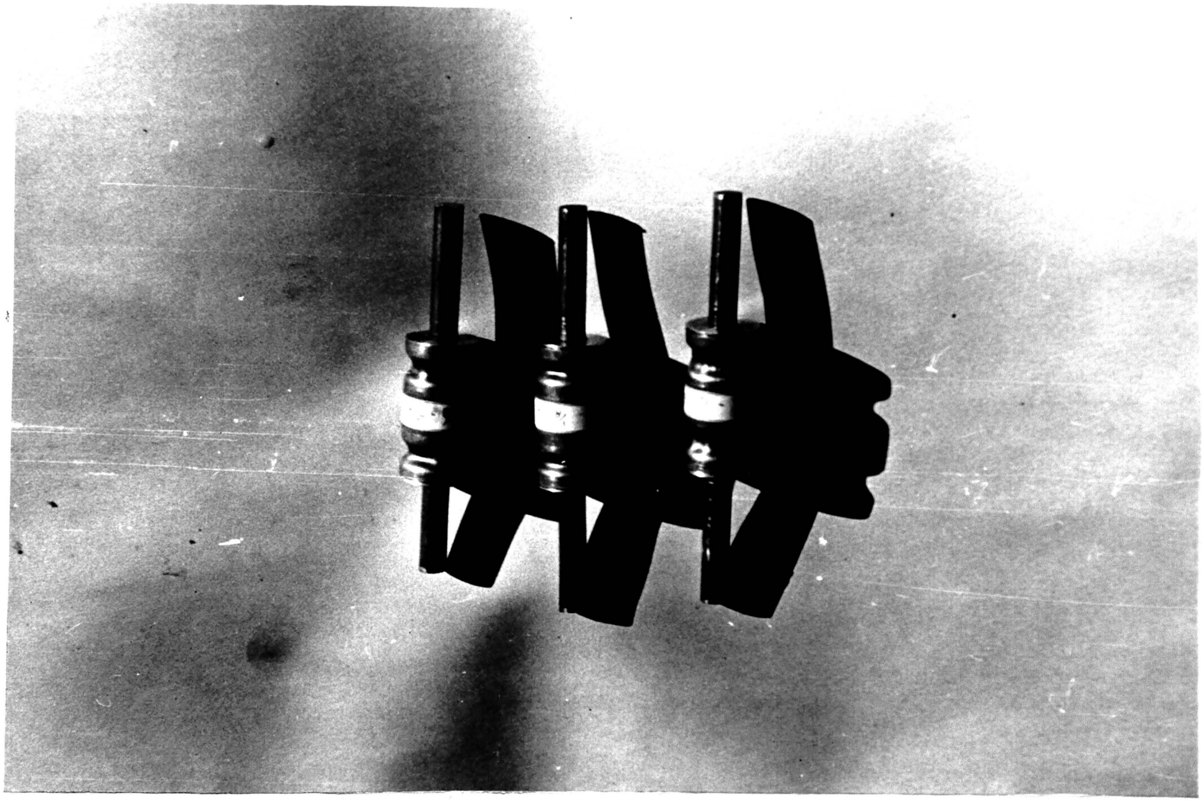


Fig. 24 Crimps on 1" O.D. x 0.35 24S-T3 Aluminum Tubes.

Crimp grooves are 1/8" deep. Flutes (wrinkles), that form due to excessive deformation, are clearly seen on 1/2" and 3/8" diameter crimps. The studs extending through the plugs are for testing the plug strength in tension.

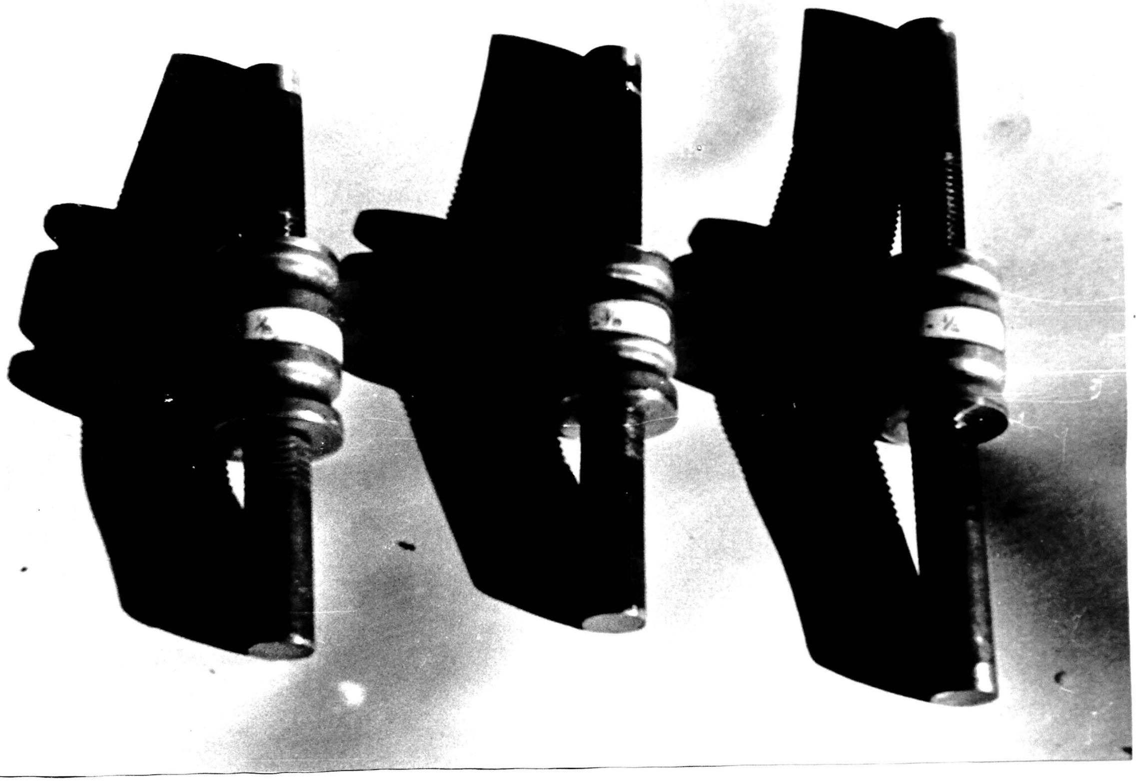


Fig. 25 Crimps on 2" O.D. x 0.065" 24S-T3 Aluminum Tubes.

All crimps are 1/8" deep and 1/2", 3/8", and 1/4" in diameter respectively. When tube and wall thickness increases, flutes disappear and greater deformations are possible.

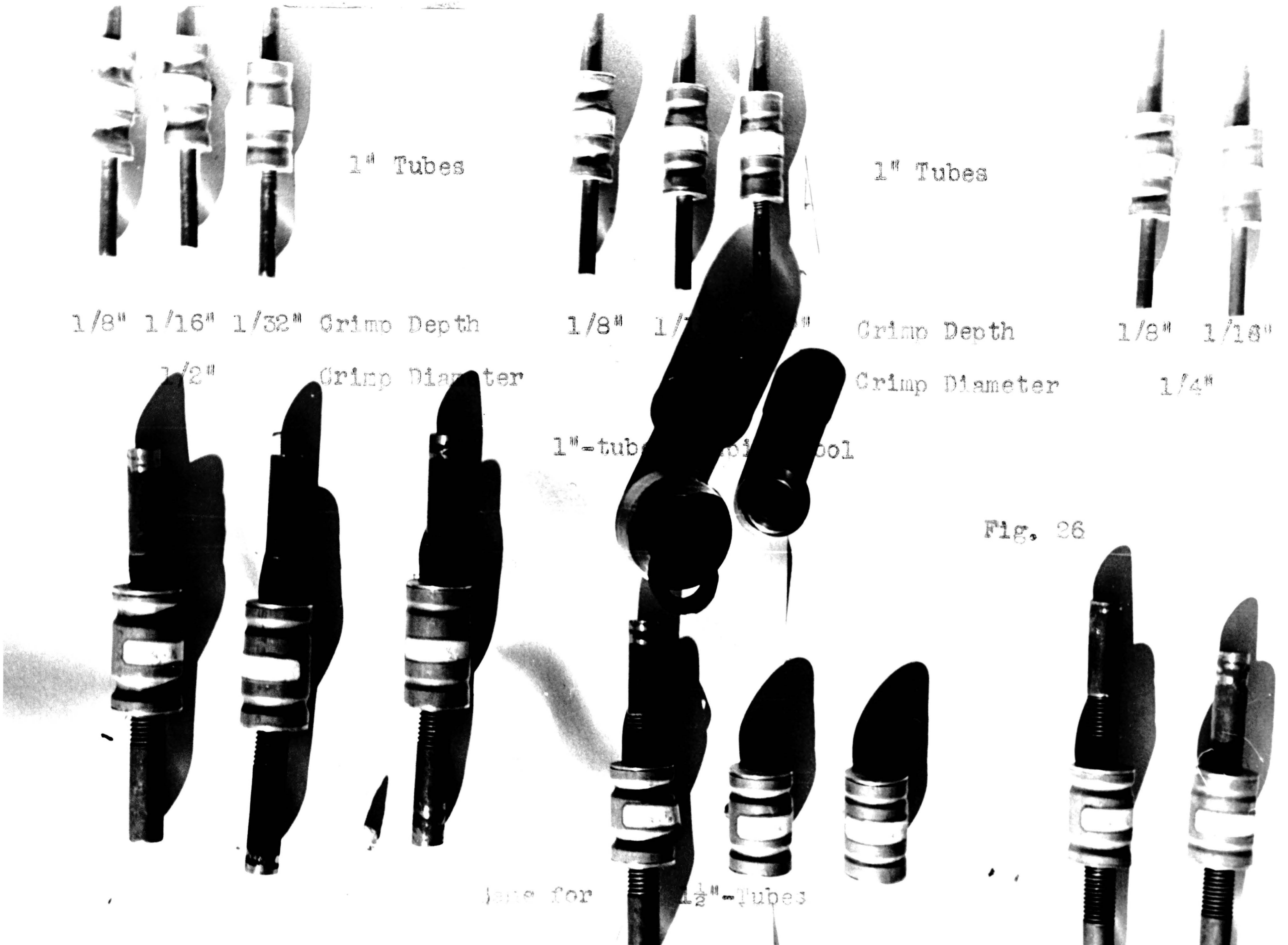

1" Tubes
1/8" 1/16" 1/32" Crimp Depth
1/2" Crimp Diameter
1" Tubes
1/8"
Crimp Depth
Crimp Diameter
1/8" 1/16"
1/4"
1½"-Tubes

Fig. 26

Crimps on 2" O.D. x 0.065 tubes

Crimped Plugs with Sleeves

Rectangular Crimps

Mechanical Plug showing the type of failure

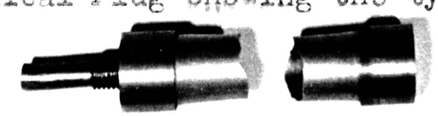


Fig. 27

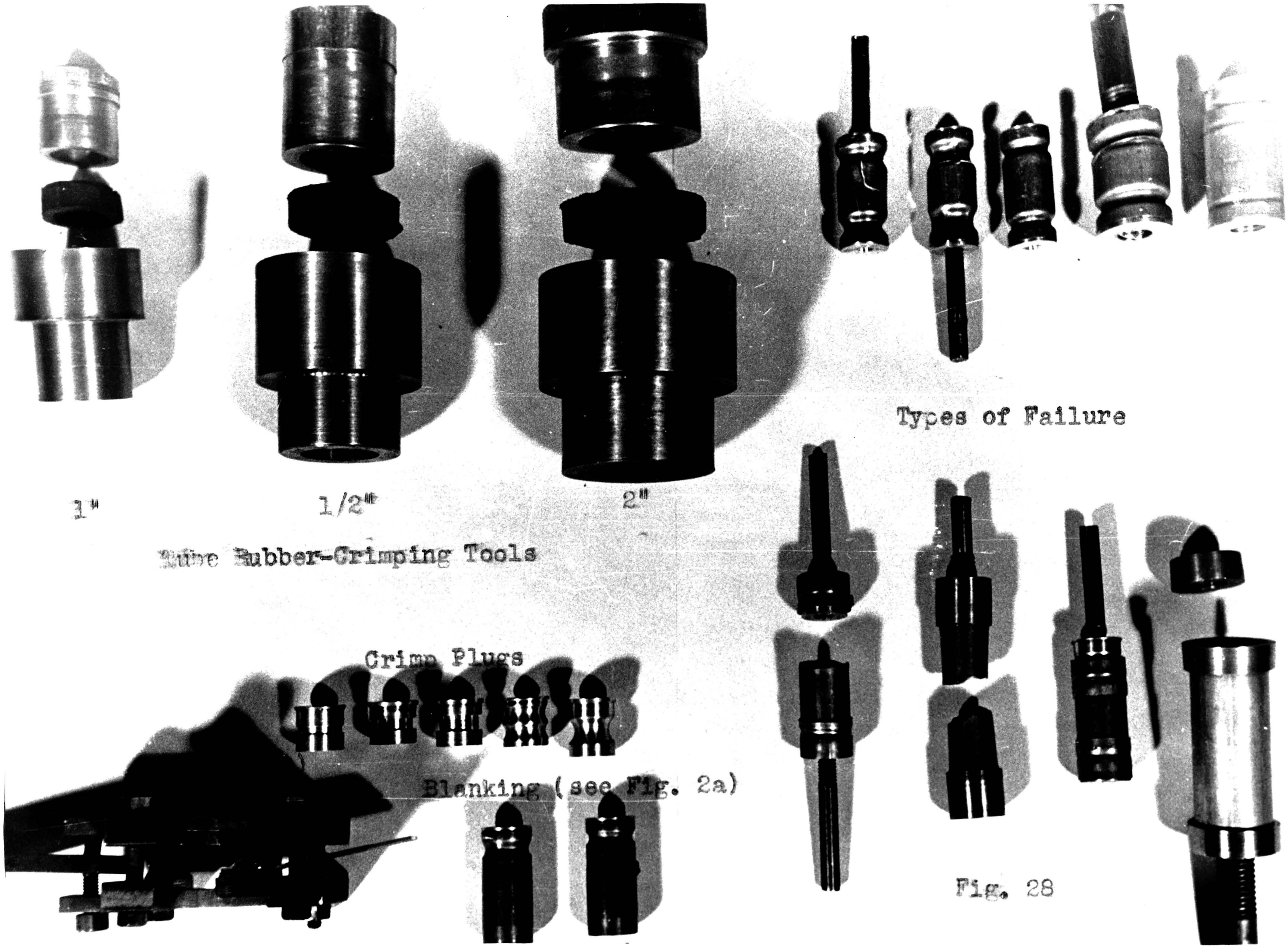

1"
1/2"
2"
Tube Rubber-Crimping Tools
Types of Failure
Crimp Plugs
Blanking (see Fig. 2a)

Fig. 28

BIBLIOGRAPHY

1. Books:

Sacks, George, Principles and Methods of Sheet Metal Fabricating. Reinhold Publishing Co. 1951

Schulze, R. Burt, Aluminum and Magnesium Design and Fabrication. McGraw-Hill Book Co. 1949

2. Periodicals:

Davies, Graham, The Light-alloy Bicycle in France Light Metals, Volume xi, August, 1948, p.452-459

Simpson, Frank. R., Assembly of Thin-Walled Parts by Rubber Crimping. Product Eng., March, 1950, p. 144-148.

VITA

The author, Aydin Cansever, was born on November 21, 1927 in Ankara, Turkey.

His elementary schooling was received in Istanbul. He entered Robert College, in Istanbul, Turkey, in 1939. In 1944 he selected the field of Mechanical Engineering and he graduated from the Engineering School of Robert College with a Bachelor of Science Degree in Mechanical Engineering in June 1948.

He has worked as assistant in the Heat Power Laboratories of Robert College, Engineering School until June 1949.

From June 1949 until September 1951, he was employed as the Maintenance and Repair Shop supervisor at the construction of the International Air Port of Yesilkoy, Istanbul, Turkey.

Realizing the necessity of a more extensive knowledge in the profession of Mechanical Engineering, the author has enrolled in the School of Mines and Metallurgy in November 1951, and since then he has been pursuing concurrently a course of studies leading to the degree of Master of Science in Mechanical Engineering.