THE EFFECT OF THE FORMING PROPERTIES OF ALUMINUM ALLOY 75S ON AIRCRAFT CONSTRUCTION

by

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INTRODUCTION

Many years of research by a number of scientists and engineers back up the aluminum alloy products used in today's airplanes. For a long time 24S-T, the naturally age-hardened condition of 24S metal, was used almost exclusively in most structural members consisting of formed sheet. This same alloy also had satisfactory qualities when produced as extrusions. Cold working and accelerated aging by means of precipitation heat treatment produced 24S materials with increasingly better mechanical properties. The alloy 14S-T was introduced in the extrusion class in recent years because of its higher strength. These two aluminum alloys contain copper as their hardening element. After much work and failure a similar metal has been produced with zinc and magnesium as the chief hardening elements. This is 75S. Its full strength is obtained only through artificial hardening. Its mechanical properties are such that its use can be substituted for that of 24S and 14S in most places. At the same time the forming characteristics of 75S are effecting numerous changes in aircraft structural design. These same characteristics have forced research into new production methods and tool design.

The object of this paper is to draw together some of the facts in existence about the new metal itself and the effects of its physical properties on present day aircraft construction.

GENERAL

The first large production lot of the aluminum alloy 75S was produced in the fall of 1943. Leading to this first success in manufacturing the strongest aluminum alloy in use today was nearly twenty years of research in both this country and abroad (2, p. 13). The Germans in 1926 announced the development of "Constructal". This was heat treated aluminum alloy with zinc and magnesium as the hardening elements. The lack of success of this material was attributed to susceptibility to stress corrosion cracking. The same fault greatly limited the use of a British developed alloy of the same general type, first made in about 1937. Ludwig J. Weber received a United States patent in 1933 for a zinc-magnesium type aluminum alloy with an exceptionally high yield strength - 80,000 pounds per square inch. However, this material was not acceptable for structural applications, due to its other characteristics. Further research added improvements until in 1939 the United States military authorities were called in on the project. Their interest was such that the government issued contracts to several aircraft manufacturers to find means to decrease the still present susceptibility to stress corrosion cracking. By 1943 the problem was solved to the extent that 75S aluminum alloy was made available in large quantities for use in aircraft construction.

Everyone connected with aircraft construction early recognized the increased horizons made visible by the new material. The possibility of higher structural strength plus saving in weight for military aircraft seemed within reach. But during the early years of World War II little was known about 75S except its characteristics derived from ordinary means of mechanical testing. The new metal followed the usual trend; higher tensile properties, and lower formability. The forming problems were of such serious nature that the government, through the War Production Board, organized an extensive research program to find answers to the problem. A wealth of informative material was compiled in classified reports. Little of the knowledge was put to practical use in the manufacture of combat planes, however, since at the end of the war, only a few of those were carrying any 75S. As a matter of fact, the close of the war saw some of the investigations just being completed.

The wartime accelerated research has been valuable in supplying data for improved structural design. Some of the new military aircraft now flying have much of the 75S alloy in them. Other military type and commercial type airplanes under construction have been designed for extensive use of this high-strength metal.

It would be well at this point to review briefly some of the latest trends in aircraft structural materials, then make note of their effect on one or two typical airplanes in existence.

High compressive yield strength of structural material is greatly influencing design (2, p. 1). The demands of increased size and weight of aircraft, thinner airfoils requiring thicker sections and a gradual evolution in engineering viewpoint regarding the mechanical characteristics required in a structural material have focused attention on this property. Earlier design practice required high tensile strengths in comparison with yield strengths. Present day design of tension members practically eliminates the use of materials having yield strengths as low as two-thirds of their tensile strengths. Much has been done through heat treating methods to adapt the familiar alloy 24S to the newer design requirements. Improvement of some mechanical characteristics was gained at the expense of creating shortcomings in other respects. Alloy 75S is remarkably suited to use in eliminating the problems posed by these shortcomings.

Figures 1 and 2 are illustrative of the changes in mechanical properties during the development of ultra-high strength aluminum alloy materials. These properties are government specification minima. Notice particularly the line connecting the yield strengths. In Figure 1, 24S-T is the alloy 24S after solution heat treatment and room temperature aging. The effect of cold work on the same alloy is indicated by the flat sheet columns. When 24S-T is artificially aged the designation is changed to 24S-T80. Approximately five to six percent cold reduction after the solution heat treatment changes 24S to 24S-RT. Alclad 24S-T flat sheet artificially aged becomes 24S-T81. Next to last in progression along the chart is 75S-T. The designation 75S-T always refers to the artificially aged state of the alloy 75S. Its high yield strength of 62,000 pounds per square inch and very high tensile strength of 72,000 pounds per square inch give the most favorable yield - to - tensile strength ratio of any of the products when the latest design criteria are considered. Artificially aged 24S-RT

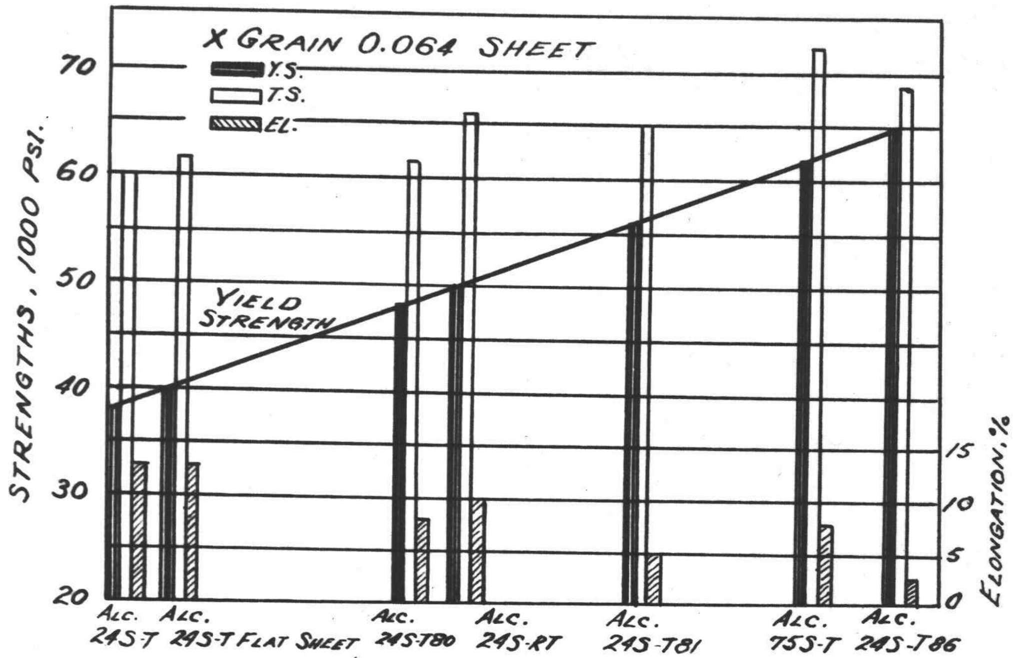

Fig. 1 - High Strength Aluminum Alloy Alclad Sheet. (Minimum Specification Values) (2, p.15).

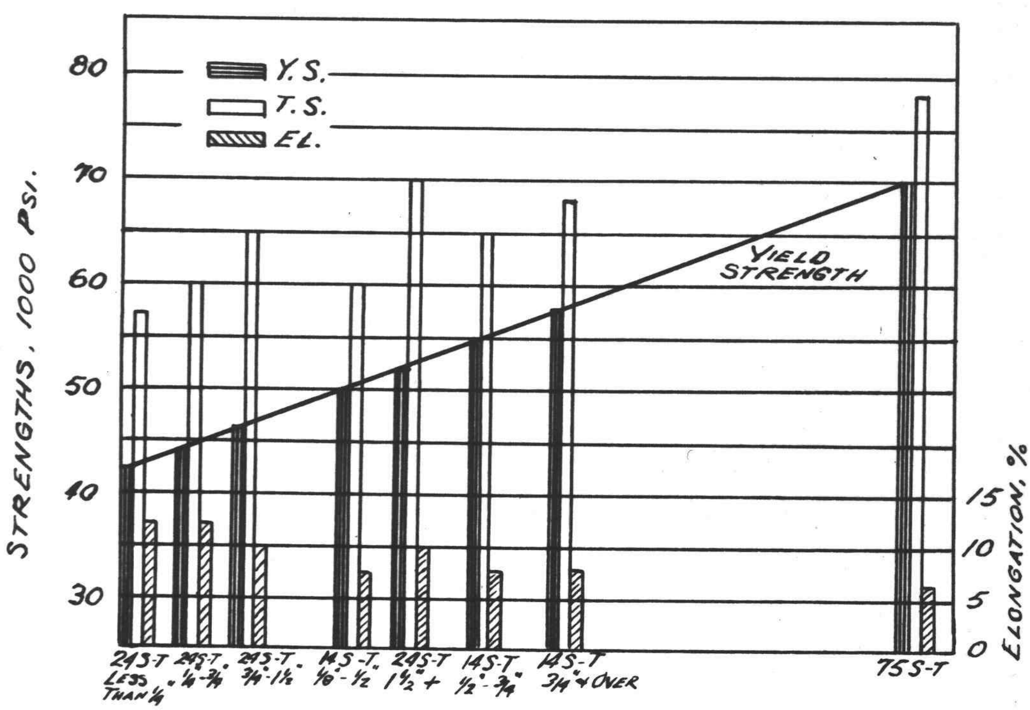

Fig. 2 - High Strength Aluminum Alloy Extrusions (Minimum Specification Values) (2, p.16).

sheet (23S-T86) has the highest yield strength, but the very high yield - to - tensile strength ratio, and the very low elongation reduce its usefulness. All of the products included are in strengths equal to their tensile yield strengths, except 24S-RT sheet.

With the requirement of high compressive strength in mind, the aircraft structures engineer is faced with choosing between 75S-T sheet and 24S-T86 sheet. His decision will depend on the importance he attaches to the yield - to - tensile strength ratio and the elongation. The 24S-T86 alloy will usually be rejected because there is little possibility of forming the metal in that temper. The structural part would have to be made from 24S-RT then artificially aged. The greater spread between the tensile and yield strengths of 75S-T plus its higher elongation would often permit the forming of this metal in its fully hardened condition.

Figure 2 provides a means of comparing the effect of section thicknesses on strengths. The yield strengths of 14S-T and 24S-T show a definite change upward with increase in section thickness. Extrusions from 75S-T have a constant yield strength of 75,000 pounds per square inch for all section thicknesses.

Background material has now been presented from which can be made conclusions concerning the advancement of aircraft structural design. It has been discovered that the newer high strength aluminum alloys can increase airplane payload on long range flights from ten to twenty percent (8, p. 66). The proportions, size, and weight of an airplane are determined by a compromise of compression member bulk and the extent of its support. Here, then, is the valuable contribution made by increased permissible yield strength.

Another important mechanical property of a structural material is its modulus of elasticity. It is a measure of a material's resistance to most types of instability failure. It is the property that determines the amount of maximum stress that can be obtained from a compression member with a given amount of support. Extruded 75S-T has the highest modulus of any aluminum alloy, 10,400,000 psi (8, p. 66; 9, p. 925). In the sheet metal class Alclad 24ST-86 has the highest modulus of elasticity.

Structural components made of extrusions taking compressive loads should be of 75S-T. Sheet metal stringers and stiffeners should be 24ST-86 if it is possible to first form the parts in 24S-RT, then artificially age them. If artificial aging after forming is impractical, 75S-T can be substituted.

The B-29 wing was redesigned to make use of 75S-T. As a result the wing was made sixteen percent stronger and 650 pounds lighter (15, p. 33). The changes were made in the basic structure only, and in the spars and inter-spar surfaces. The 0.156 inch thick Alclad 75S-T skin withstood more load in tests than bare 24S-T, 0.188 inch thick. Because of this all upper surface inter-spar skin on the inboard wing was changed from 24S-RT (bare) to Alcald 75S-T and reduced one gage in thickness. A reduction was made in stiffener area. One lower skin reinforcement plate was formed in 0.188 inch 75S-O, then heat treated to 75S-T. This one part replaced the three parts originally used. The original reinforcement was 24S-T plate further reinforced with steel plate (14,p.62).

Another example of reduction of structural weight was recently accredited to the redesign of one Lockheed airplane. The wing was made 920 pounds lighter, and the total saving in weight for the entire airplane was 2,000 pounds. This was made possible through judicious use of higher strength alloys, including 75S (8, p. 66).

FACTORS RELATING TO FORMING

The number of different parts that make up the structure of an airplane is practically limitless. It would be futile to attempt to list all of them. Necessity for greater control over forming processes was made imperative by the development of very high strength aluminum alloy products with their accompanying forming limitations. Considerable work has been done toward this end, and consequently much is now known about metal properties affecting the mechanics of forming operations. As a further result, all of the more commonly known parts have been classified under headings descriptive of the forming operations by which they are made. The recent development that is having the greatest effect on production processes is that of forming at elevated temperatures. Much still needs to be done toward tool redesign in order to make full use of this method.

There are certain fundamental properties that determine the forming characteristics of any metal (12, p. 469). These are:

1. The yield strength and tensile strength as illustrated by the stress-strain curve in tension, Figure 3. This curve yields the forming stresses, not only for straining by

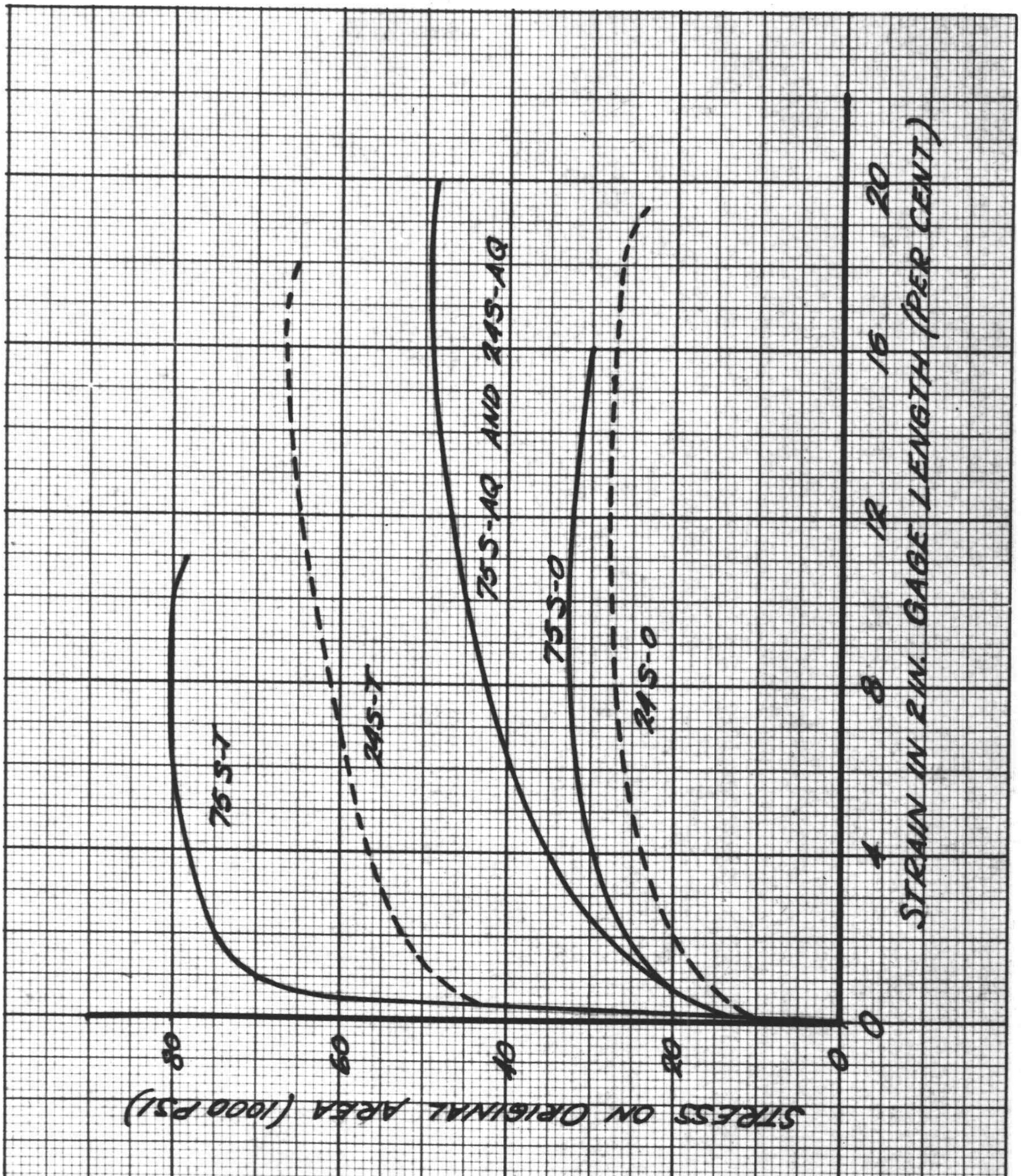

Fig. 3 - Typical tensile stress-strain curves for Alclad 75S and 24S in various conditions (12, p.474).

tension, but also by compression, shearing, and any complex stress state (according to the laws of plasticity).

2. The capacity to strain uniformly under load conditions that produce uniaxial or biaxial tension. Necking down in tension limits this capacity, causing uniform straining to terminate and further deformation to become localized.
3. The ductility, primarily under tension loads. This is the strain that can be attained without separation of the metal particles leading to fracture.

The comparative values of these fundamental properties during a forming operation are influenced by the geometry of the part. This is because the shape controls strain distribution, and in turn the stress state, which determines the metal properties.

Besides the fundamental properties mentioned there are more factors that influence forming. These are sheet thickness and often surface and edge conditions. Wide sheet tends to fail in bending at the center, while narrow strips showing sensitivity to edge condition will usually fracture at the edge.

HOT FORMING 75S, GENERAL

It is possible to form the annealed temper of this alloy (75S-O) at room temperature. Its formability is similar to that of 24S-O, but there are slight differences between the two metals unfavorable to 75S-O (9, p. 923). Higher forming pressures are necessary for 75S-O. The springback of 75S-O is greater, the shrinking properties poorer. Forming of this alloy in the annealed temper is inadvisable because both solution heat treatment and precipitation heat treatment (artificial aging) are necessary to obtain maximum strength. Experience has shown that parts formed in 75S-O, then heat treated, distort considerably more than 24S products. This distortion is harder to eliminate from the finished 75S-T part.

Cold forming of 75S-T is greatly limited (12, p. 472). There are several good reasons why. It has been observed that the residual ductility in cold-formed 75S-T may be below a safe value for service. This, coupled with development of small cracks during forming operations such as dimpling, may cause rupture after the part has been made integral with a complete assembly. The permissible bend radii for 75S-T sheet are nearly twice those for 24S-T sheet in the thinnest sections used. However, bend radii for 75S-T do not increase as rapidly with increase in sheet thickness as do those for 24S-T. Consequently, 75S-T sheet in thicknesses in the vicinity of 0.25 of an inch and over may often be bent cold. Parts designed to be bent in metal this thick seldom require small bend radii, however. Further limiting factors in the cold forming of 75S-T are high values of springback, high forming pressures, and great sensitivity to surface and edge scratches (Figure 4). This latter characteristic is attributed to low ductility. Tests have shown that for a 0.010 inch deep edge notch in 0.125 inch 75S-T, the bending radius was reduced from 3t to 15t. A similar surface notch reduced the same bending radius to 24t (12, p. 477).

The forming of 75S-T at elevated temperatures is very practical insofar as the improved characteristics of the metal itself are

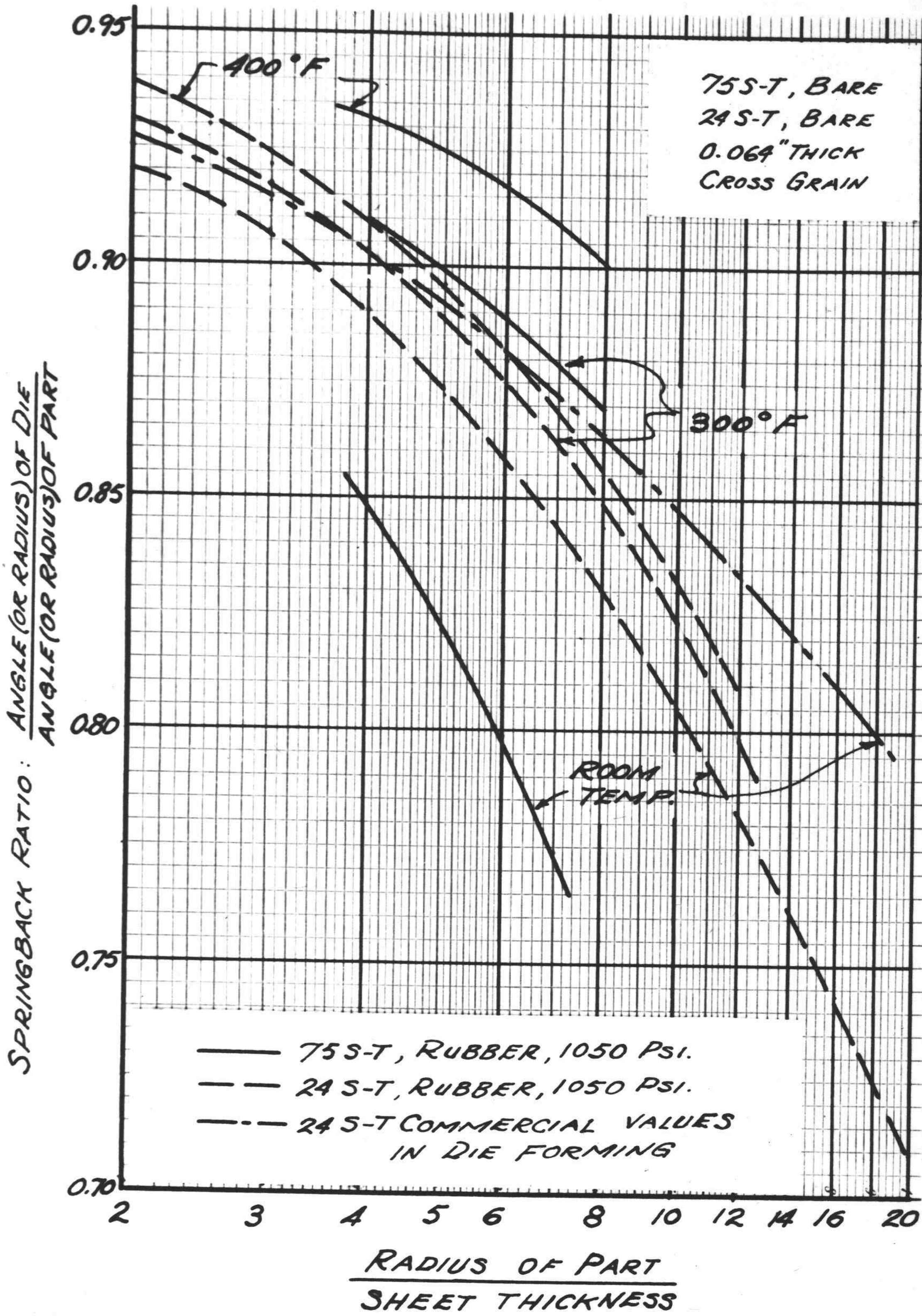

Fig. 4 - Springback of 75S and 24S at room and elevated temperatures (12, p.479).

concerned. Figure 5 illustrates the improvement in bend radius in roll forming when temperature during forming is increased. All other forming operations depending on ductility are similarly improved by increase in temperature (12, p. 473).

Difficulty in the development of methods to hold the metal at the required temperature during forming has caused the greatest delay in making extensive use of 75S. The material itself can easily be preheated by means of an air furnace, oil bath, or otherwise. But if the preheated metal is placed in contact with cold forming tools, the advantage of the elevated temperature is immediately lost due to rapid and uneven cooling. Experimental work in the field of hot forming has been relatively easy because of the small size tools required. Extensive application of hot forming processes in aircraft manufacture will mean re-design of large and expensive machines. An example of one of the simpler changeovers was the wiring of a Guerin hydraulic press for electrically heating the platen while forming operations were in progress (10, p. 20).

Government sponsored investigations during World War II produced data on satisfactory forming temperatures for several aluminum alloys. The effects of holding a metal that had already been artificially age hardened at a high temperature, then subjecting it to stress at room temperature, were found. Unquestionably, if a material had very much lowered mechanical properties after forming at high temperature, the advantage of greater ease of forming would be discredited. Tests carried out at the University of California resulted in the strength - temperature curves in Figure 6. These

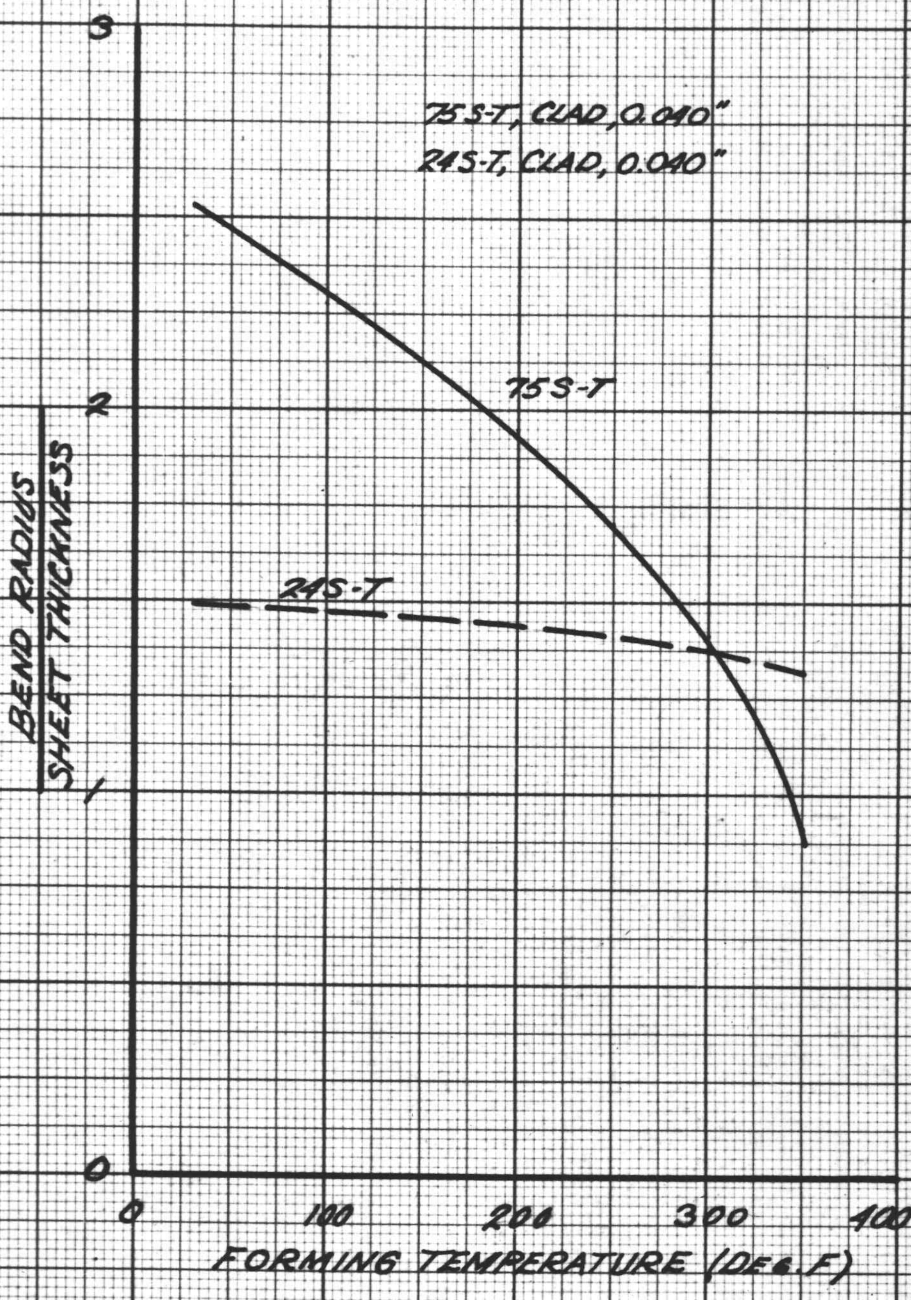

Fig. 5 - Effect of forming temperature on the experimental minimum bend radius in roll forming (12, p.482).

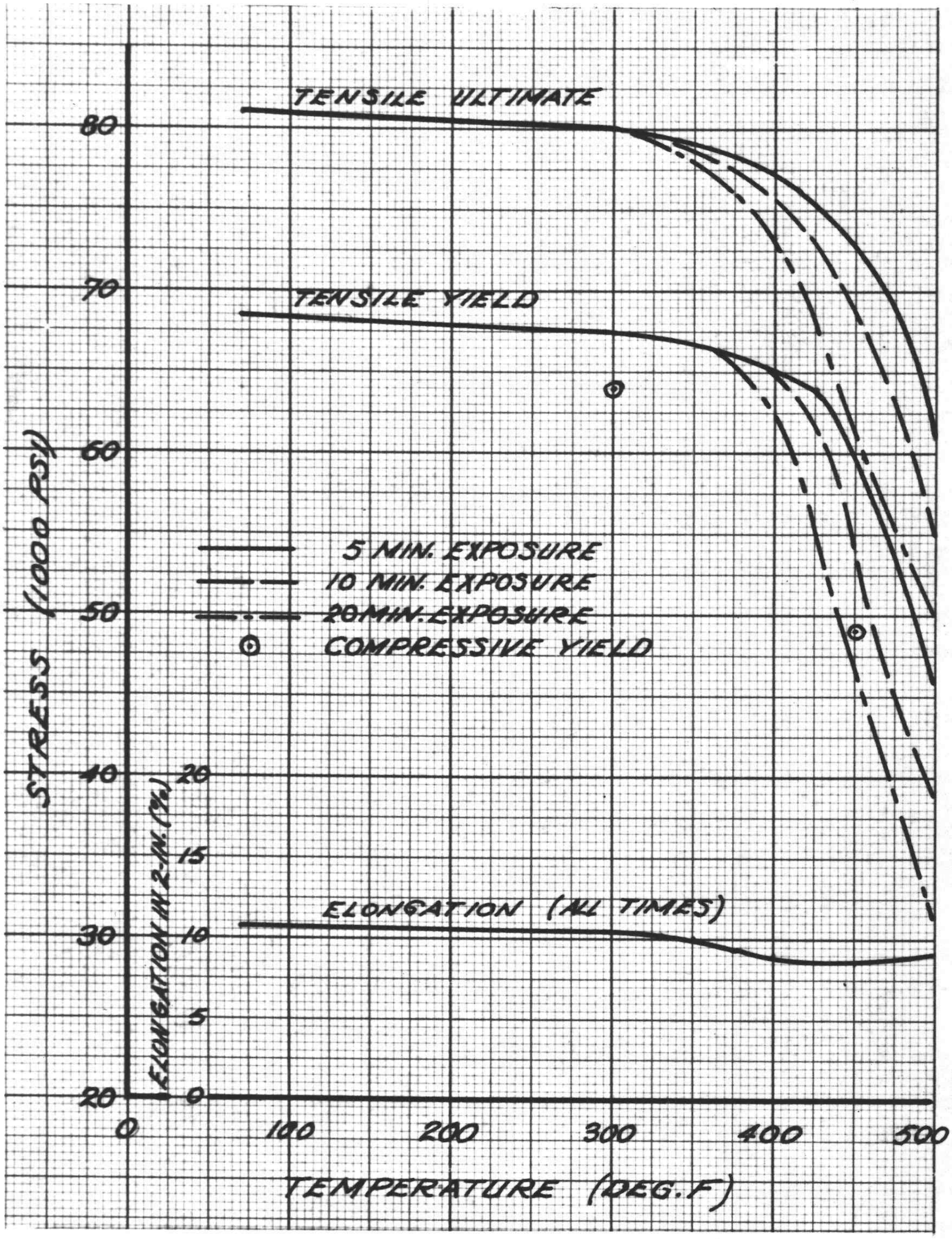

Fig. 6 - Room temperature properties following elevated temperature exposure of 75S-T. Sheet thickness 0.064 inch, crossgrain (6, p.19).

curves show that the mechanical properties of 75S-T after returning to room temperature from temperatures up to 300 degrees Fahrenheit are not seriously affected. The curves of time at temperature against temperature, Figure 7, give another means of examining the results of reheating 75S-T to form it. By correlating these data with the times necessary to perform certain forming operations and the desired final metal properties, the aircraft manufacturer can determine some important points about heated tool design. The results of the study would also have an effect on the design of the parts themselves.

Data from another source concerning the effect of heating on tensile properties have been plotted in Figure 8. These curves show the effects over a great range of time, but for only two temperatures.

Many experimental forming operations have been carried out on 75S-T at temperatures up to 500 degrees F. However, it has been found through experience that most types of forming can be done with this metal at 250 degrees F, and done with less forming pressure, less springback and smaller bend radii than can be accomplished with 24S-T at atmospheric temperature. Not only is that true, but reheating of 75S-T has no adverse effect on its resistance to corrosion (9, p. 924).

FORMING AIRCRAFT PARTS

The following is a classified list into which the great bulk of formed aircraft parts will fit (11, p. 7):

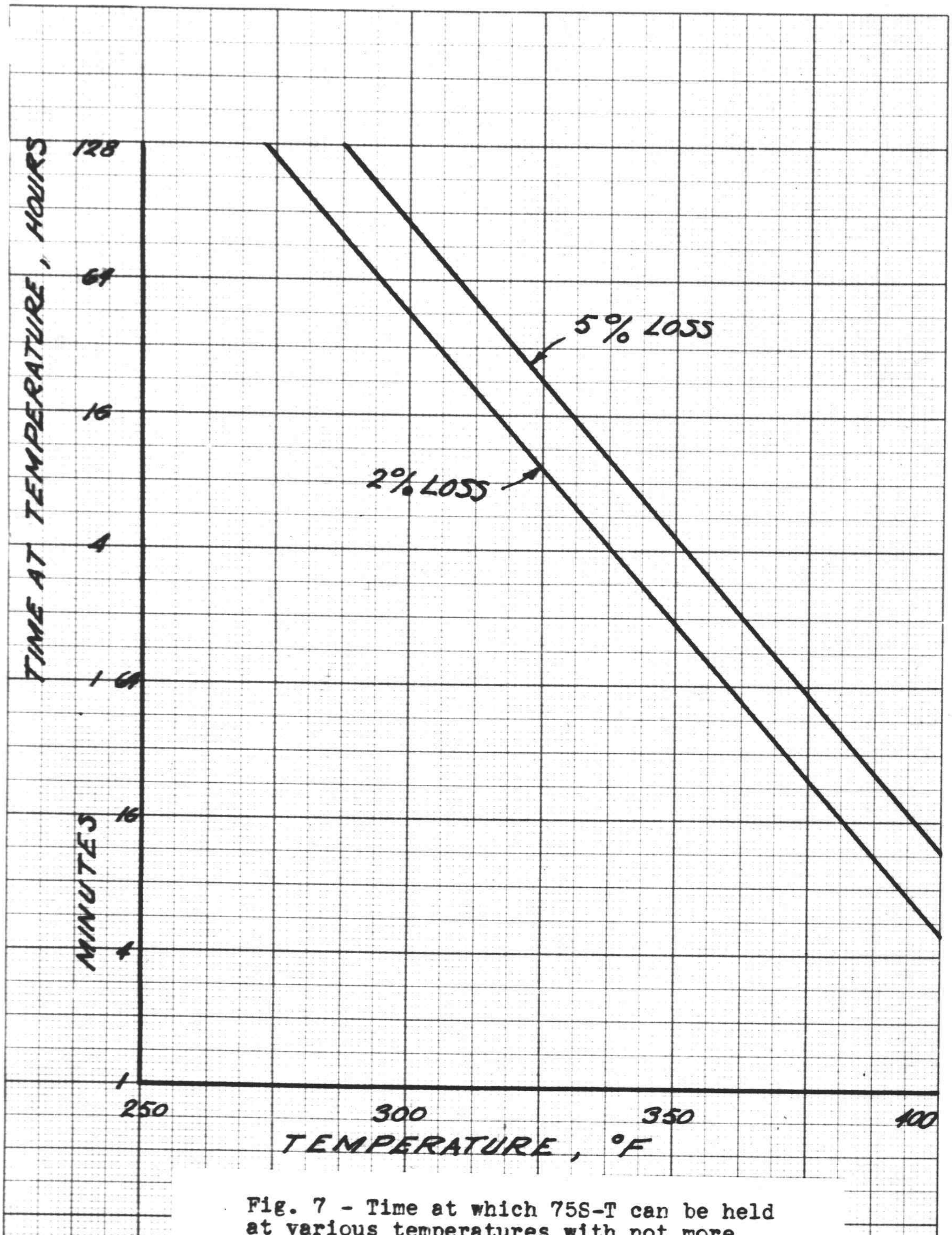

Fig. 7 - Time at which 75S-T can be held at various temperatures with not more than 2 or 5 per cent loss in yield or tensile strength (12, p.473).

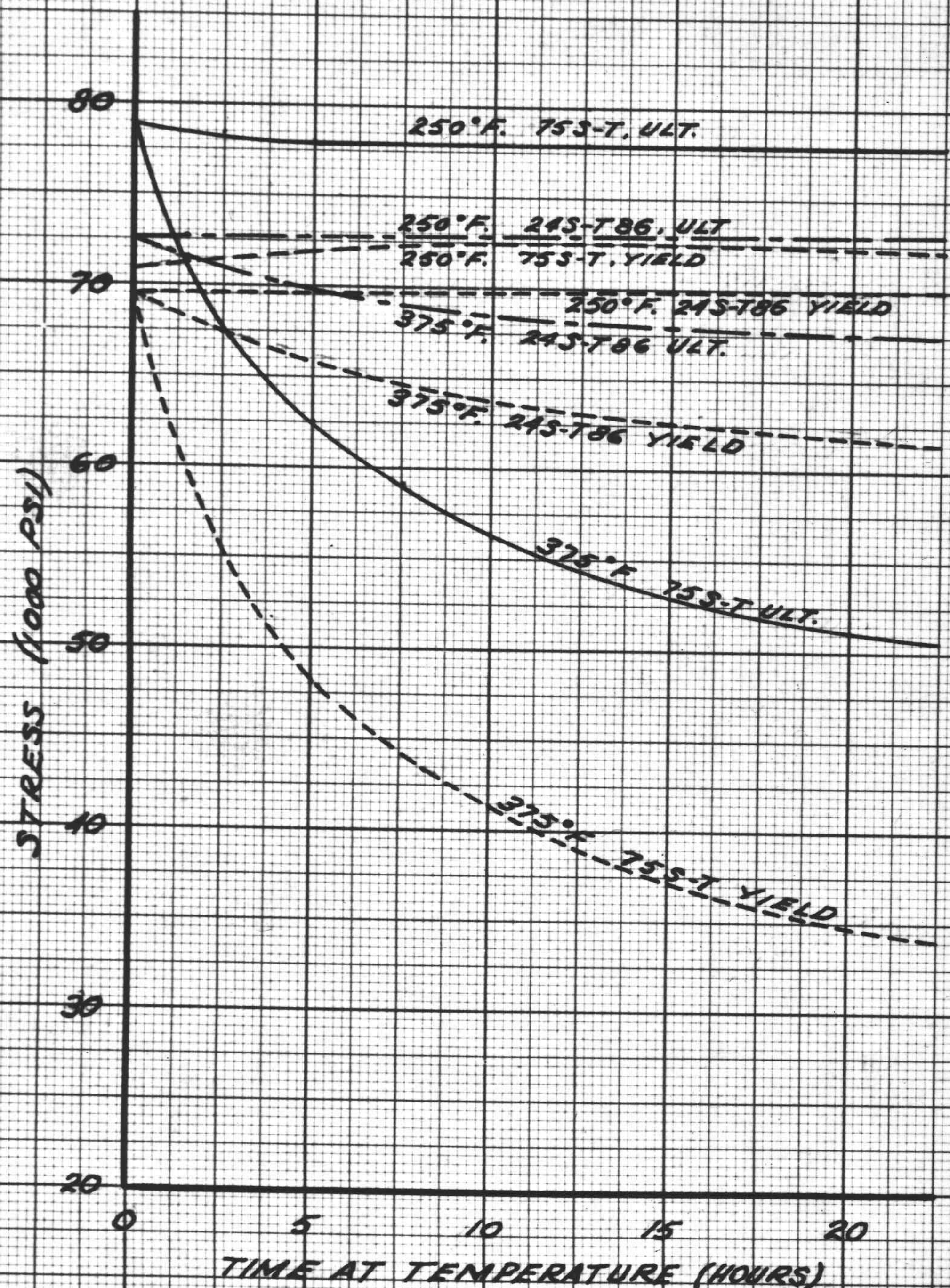

Fig. 8 - The effects of heating for various lengths of time at two temperatures on tensile properties of properly aged 75S-T and 24S-T86 aluminum alloys (16, p.10).

1. Singly curved parts
    (a) Straight flanged parts
    (b) Straight channels
    (c) Smoothly contoured parts
2. Curved channels
    (a) Symmetrical shapes
    (b) Nonsymmetrical shapes
    (c) Varying sections
3. Contoured flanged parts
    (a) Stretch flanges
    (b) Shrink flanges
    (c) Combination of stretch and shrink flanges
4. Double curvature smoothly contoured parts
    (a) Large radii in one direction
    (b) Large radii in both directions
    (c) Saddle-back parts
    (d) Small radii at edge
5. Deeply recessed parts
    (a) Regular cups
    (b) Cups and tubes of varying shapes
    (c) Regular boxes
    (d) Closed parts with sloping walls
    (e) Open parts
    (f) Parts with re-entrant contour
    (g) Parts with saddle-back bottom
    (h) Parts with undercuts

6. Shallow recessed parts
   (a) Dish-shaped parts
   (b) Embossed, beaded and corrugated parts
7. Minor forming features
   (a) Beads and bosses
   (b) Flanged lightening holes
   (c) Joggles
8. Tubing

The fundamental properties that determine the forming characteristics of a metal must be examined along with each type of part before it can be decided whether a particular metal is suitable for that kind of fabrication. When starting out to design a part, the engineer may have in mind the idea of making it as light in weight as possible with a maximum amount of strength. It is a generality to say that 75S-T will be the material to select. Parts having sheet in compression often cannot be made appreciably lighter by using 75S-T, because here the limiting factor may be the stability of the sheet in compression, a property depending on thickness rather than compressive strength. The necessity of forming 75S-T at an elevated temperature would eliminate it in this case, since 24S-T in the same thickness would do as well and would be easier to form. On the other hand, a sheet part intended to carry tension loads would be better made from 75S-T due to the chance of using thinner metal. The greater difficulty of forming caused by choice of this material would be offset by the advantage of decreased weight plus higher strength.

These are some of the factors that must be considered when examining the foregoing list of typical parts. These along with others will be discussed for each of the headings. In order to be brief, the discussion will follow this outline:

1. Part classification
2. Examples of typical parts
3. Advantage of using 75S-T
4. Tools used in forming
5. Forming operation
6. Fundamental properties of metal affected by forming operation
7. Forming from 75S-T at elevated temperature
8. Condition of part after being formed (springback)

1. Part 1(a). Straight flanged parts.
2. Doors, brackets, any part with wide web compared to flange depth.
3. It is advisable to use 75S-T if the part is to carry large loads, especially compressive when there is no danger of buckling failure. Reinforcements can sometimes be eliminated.
4. Rubber hydro-press.
5. Straight bending.
6. Ductility. In cold bending wide sheet, surface condition is important. If narrow sheet, edge condition is important. Sheet thickness is the determining factor for bend radius when hot forming is used.
7. Well adapted to this method. This saves correcting warpage after heat treating a part cold-formed in a softer metal. Tool change-over is not too difficult (10, p. 20).

8. Springback can be taken care of by overforming the flange as controlled by design of the die.

1. Part 1(b). Straight channels.
2. Hat sections made from sheet. Stiffeners, stringers.
3. 24S-T86 is recommended over 75S-T if the shape is such that it can be formed in the "SRT" state, this being 24S-T86 prior to artificial aging. This alloy has the highest modulus of elasticity of any sheet produced, but only a limited amount of forming is permissible at room temperature, and this must be done before aging (2, p. 17; 8, p. 66). It is very difficult to straighten such parts as these after heat treating. 75S-T is second choice here.
4. Press brakes with very long beds, power rolls, draw bench with stationary rolls or dies.
5. Bending.
6. Ductility.
7. There is questionable advantage in using 75S-T in roll forming operations, since 24ST-86 also shows increased formability at higher temperatures, according to tests of this type of forming method (13, p. 455). The decision as to alloy would be made with respect to bend radius desired in the finished product. Commercial minimum bend radii at 300 degrees F are: 24S-T86, five times sheet thickness; 75S-T, two and five-tenths times sheet thickness.

As for heated tool design, changeover does not seem to be difficult. An example is the installation of infra-red lamps between stands for heating the rolls, and the addition of an oven for preheating the aluminum strip. This was done on a Yoder commercial roll forming machine (13, p. 452).

8\. Springback is much lower after hot forming than after cold forming. Also, it was found that the roll forming operation caused less springback than that in common die bending (13,p.465).

1\. Part 1(c). Smoothly contoured parts.

2\. Curved skin sections.

3\. Thin skin panels should be 75S-T if dimpling for rivets is contemplated (8, p. 66). A great deal of weight can be eliminated throughout the airplane by using 75S-T.

4\. Stretch press, power brake, roll bender.

5\. Stretching and bending.

6\. Ductility, elongation, capacity to strain uniformly.

7\. Singly curved skin sections are usually formed in a contouring roll bender. There is not much opportunity for hot forming here, nor is it needed. The sheet is guided into the rolls by hand and since bend radii are large, the contours are usually checked by templates (3, p. 39).

The stretch press is often used for sheet curved in one direction. There is no advantage to the use of elevated temperatures here because the maximum strain available from 75S-T sheet is not improved (12, p. 487).

8\. Considering the forming operation alone, it is more advisable to use 24S-T than 75S-T in stretch forming of skins. The 75S-T will give about two-thirds the stretch that 24S-T will, since the elongations are eleven percent and eighteen percent respectively (12, p. 470). Also, 75S-T has more springback than 24S-T.

1. Part 2(a)(b)(c). Curved channels.
2. Wing-rib chords (extrusions), curved stringers and stiffeners, channels with varying leg angles.
3. Curved channels are usually formed from straight channels. The same remarks under Part 1(b) apply here.

   Straight channels are often extrusions. Extrusions in 75S-T are best because of high modulus of elasticity, giving good resistance to the instability type of failure under compressive loads. This material offers the opportunity to make the structure lighter than with other alloys.
4. Wrap former, roll bender, stretch press.
5. Bending, stretching.
6. Capacity to strain uniformly, ductility, springback as influenced by yield strength.
7. The advantages of high tensile strengths and high compressive yield strength and high modulus of elasticity make the disadvantage of hot forming 75S-T extrusions by wrap former and roll bender comparatively unimportant.

   Temperatures between 250 and 350 degrees F cause better conformance to tool contour than obtainable with 24S-T extrusions (12, p. 494). This is applicable to the wrap former.

Heating 75S-T has no effective value in the stretching operation because of lack of improvement of the permissible maximum stretch.

In bending a curved channel, the inner fibers shrink, and the outer fibers stretch. At the neutral surface the fibers retain their original length. In stretching devices an attempt is made to curve without shrinking. Then the neutral surface is at, or slightly outside, the inner surface. Hence, the inner fibers are stretched slightly and the amount of curvature is limited by the stretch at the outer surface (11, p. 50). Thus, as much difficulty should be experienced in stretch bending 75S-T sheet channels at elevated temperature as at room temperature.

8. If the part is made from material other than 75S-T extrusion, springback is eliminated by over-stretching and over-bending, heat treating, then stretching to the final contours.

   Parts made of 75S-T extrusions in the wrap former or roll bender are over-formed to take care of springback. It is necessary to have temperature uniform throughout the metal in order that the finished part will not be warped.

1. Part 3(a). Stretch flanges.
2. Lightening holes, sheet metal parts having a flat web and concave flange.
3. The advantage of using 75S-T lies with the purpose of the part itself. If the part is designed to carry heavy loads, it may be advisable to use this material.

4. Rubber hydro-press (Guerin), single action mechanical or hydraulic presses.
5. Bending with simultaneous stretching of the outer fibers of the flange.
6. Ductility (1, p. 3).
7. In tests 75S-T had the poorest formability of any material tried at temperatures of 70 degrees and 450 degrees F (1, p. 31). However, temperatures of 275 degrees or higher increase the formability to above that of 24S-T at room temperature (12, p.485). This suggests an advantage in selecting 75S-T as the material for this type of part when the elevated temperature forming method is available.
8. Springback of stretch flanges after forming is slightly less than for straight bends for the same condition of forming temperatures, sheet thickness, and die bend radius (1, p. 31).

The condition of the finished part will depend on the relation: $\frac{D_c - D_b}{D_b}$, where D_c is the finished contour diameter and D_b is the original hole diameter. The alloy 75S-T shows best formability (fewer fractures) in the temperature range of 250 degrees F to 400 degrees F. The above relation has values in this temperature range of 0.36 to 0.45. For the same range, 24S-T has values of 0.35 to 0.41, the first figure being unchanged from that at room temperature (12, p. 484).

1. Part 3(b). Shrink flanges.
2. Nose section of a rib, miscellaneous parts having a flat web with a convex flange.
3. Same as for Part 3(a).
4. Rubber hydro-press, single action mechanical or hydraulic presses.
5. Bending, shrinking.
6. Yield strength, determining the tendency to wrinkle (12, p. 470).
7. There is no advantage gained by forming 75S-T at elevated temperatures, except that 300 degrees F decreases springback by thirty percent (12, p. 486).
8. The harder aluminum alloy materials all have poor formability when forced into shapes depending on the ability of the metal to shrink, whether at low temperatures or high. The tendency is for the metal to wrinkle around the contour of the flange. This is subdued somewhat by cutting segments from the metal at the edge of the flange. Some of the machine-formed parts that have buckled can be made usable by handwork (17, p. 18).

1. Part 3(c). Combination of stretch and shrink flanges.
2. Wing ribs, other combinations of flat sheet with lightening holes having concave flanges and convex flanges.

3,4,5,6,7,8. Same as for parts 3(a) and 3(b).

1. Part 4(a). Large radii in one direction.
2. Section of skin near nose or tail of airplane, leading edge of wing section containing a gun nacelle.
3. Where the part is designed to undergo considerable load, use of

75S-T will be of advantage.

4. Stretch press, double and triple acting hydraulic press, rubber hydro-press.
5. Bending and stretching. The stretching machines that form these shapes grip the edges of the sheet and hold it while a die, having the proper contours, is forced against the sheet, causing the sheet to stretch so as to conform to the shape of the die. The die surface is usually lubricated to decrease restraining action and consequent localized deformation.

   The hydraulic-type presses utilize the hydraulic action of rubber pads to force the sheet by bending and stretching to conform to the shape of the die.
6. Ductility and ability to strain uniformly under biaxial tension.
7. There is no advantage in forming this type of part from 75S-T at elevated temperature. Recommendation is made that no alloys in the "T" condition be formed by this method at elevated temperature (7, p. 151).

Hot stretch forming of alloys in the annealed or "O" temper is valuable in some individual cases. As an example, it has been the usual practice to form wing leading edges with gun nacelles in the drop hammer, with a final stretch forming operation to complete the part. This is time consuming and expensive. This particular part, and others similar to it, may well be formed in a single operation from annealed 75S sheet by using the best forming method (7, p. 149). The advantages of this method depend upon close control of die contour, friction and temperature distribution (12, p. 488).

Heating the formblocks for both the stretch press and the hydraulic press is accomplished by imbedding electrical heating elements in the individual dies.

8. The condition of a part after this type of forming depends on the individual shape, the alloy and its temper, the temperature of forming, and the effect of friction (7, p. 1-3). Actual failure of the sheet during the forming operation usually precludes the possibility of the part ever being used. A small amount of wrinkling may be acceptable if the material is 24S-O, 75S-O, or the equivalent, as this can be ironed out by hand work.

1. Part 4(b). Large radii in both directions.
2. Skin for fuselage center section.
3. Use 75S-T where hot dimpling method is available for riveting.
4. Forming is often done on a pneumatic hammer.
5. Stretching.
6. Ductility.
7. Not advisable to use elevated temperatures.
8. Accuracy of parts formed in this manner depends on the skill of the operator. (Remarks under 4(a) also apply to this type of part).

1. Part 4(c). Saddle-back parts.
2. Miscellaneous.
3. The use of 75S-T is of advantage only if the part is expected

to carry large loads.

4. Stretch press.

5,6,7,8. Same as for Part 4(a).

1. Part 4(d). Small radii at edge.
2. Skin adjacent to a door. Parts of this kind may have large radii in two directions and a flange along one or more edges. (For further discussion see Part 4(a).

1. Part 5(a)(b)(c)(d)(e)(f)(g)(h). Deeply recessed parts.
2. A multitude of parts of various sizes and shapes come under this classification. Inasmuch as the tools, forming operations, effects on the metal, et cetera, that apply to one part, apply equally as well to all of the others, the discussion will cover this group as a whole.

   Typical parts include hydraulic oil tanks, ducting, wing tips, nose caps, nacelles, and other similar shapes.
3. As usual, the advantage of using 75S-T lies in the purpose of the part. Most of these parts are not under stress, due to their not being a part of the structure carrying loads. They are often constructed of 3S alloy because of its greater ease of forming.
4. Hydro-press, mechanical press, drop hammer.
5. Stretching, bending and shrinking.
6. Ductility and capacity to strain uniformly.
7. Forming in 75S-T in a single operation can be carried out at 200 degrees F on parts having generous radii. More violent

forming, such as for boxes with sharp corners, necessitates higher temperatures, 350 degrees or more (12, p. 490).

8. Parts formed in this class of shapes when finished are satisfactory or unsatisfactory. The violent forming action that takes place causes wrinkling and tearing of the metal. In the case of tearing, the piece is usually discarded. Wrinkling depends to a great extent on the punch and die design in the case of drop hammer forming, but small amounts can be removed by planishing hammer.

It is concluded that satisfactory parts can be formed in 75S-T at elevated temperatures, but less difficulty will be encountered by forming in the annealed temper with subsequent heat treatment to gain full hardness.

1. Part 6(a). Dish-shaped parts. Part 6(b). Embossed, beaded, and corrugated parts.
2. This classification includes all recesses formed in parts for purposes of making clearance for other parts and supplying stiffness to flat sheets such as are in the web of a wing rib or fuselage bulkhead.
3. The part may be designed to carry loads. If so, the use of 75S-T will be of advantage due to the possibility of obtaining greater strength with less weight by reducing sheet thickness.
4. Hydro-press, mechanical press.
5. Stretching.
6. Ductility and capacity to strain uniformly.

7. There are no advantages to forming 75S-T at elevated temperatures. The metal 75S-O can be formed at high temperatures to better advantage than can 24S-O under the same condition (12, p. 490). This leads to the conclusion that such parts intended to be made of 75S-T must first be formed in the annealed condition at high temperature, then artificially hardened to obtain full strength of the metal.
8. The condition of the part after being formed will depend upon its shape and the effect of heat treating in regard to warping. Re-pressing over the die after the heat treatment is sufficient to straighten most parts.

1. Parts 6(a) and 6(b) have been covered in the previous discussions.

1. Part 6(c). Joggles.
2. Offset in sheet metal or extrusion to provide clearance for the assembly of mating parts (4, p. 27-35).
3. The advantage of using 75S-T depends on the design of the individual part.
4. Press brake.
5. Bending.
6. Ductility.
7. 75S-T is well-suited to this operation at elevated temperature. Heating may be applied by resistance or conduction (12, p. 491).
8. The condition of the part after being formed should be unaffected as to strength. Springback will be slight when forming is carried out at elevated temperature.

1. Part 8. Tubing.

No reference to using 75S-T for tubing has been found.

CONCLUSIONS

The extensive amount of data gathered during the last few years on elevated temperature forming of high strength aluminum alloys, shows conclusive proof that forming of this type is practical and desirable in many cases. This applies particularly to 75S, an alloy that is very difficult to form at atmospheric temperature. The effect of the process is not overwhelming. Some detailed design changes of individual parts must be made to adapt 75S. Some tool changeover must be done. The latter is expensive and difficult in some cases. However, the advantages in being able to make greater use of the new ultra-strength alloys overshadow the disadvantages encountered in adapting the manufacturing processes.

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