How Deformation Affects the Mechanical Properties of Aluminum Forgings

Abstract:
Distortion of heat-treated aluminum forgings during machining has always been a problem. The obvious economic and engineering advantages of large aluminum forgings resulted in the US Air Force heavy press program at the end of World War II. Though they proved cost competitive, these larger forgings introduced increasingly severe machining problems due to distortion. Acceptable finished parts could be produced by competent machine shops, but often only with elaborate machining sequences and slow removal of metal.

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About 25 years ago, stress relief by cold deformation between quenching and aging began to be applied to a significant number of forgings. While the process has been applied primarily to forgings expected to give distortion problems, some aerospace manufacturers require all heat-treated aluminum forgings to be stress relieved by cold deformation.

Effect on Tensile Properties

Before getting into the detail of stress relief by cold deformation, it might be well to review the effect of this type of stress relief on final tensile properties.

For many years, the process was applied to 7000 and 2000 series alloys that were to be aged to the T652 condition. In the routine tensile testing of these forgings, no significant differences between the old T6 and the new T652 treatments was noted. At least, no unusual problems in meeting specification minimums were apparent.

About 1964, 7075-T73, an overaged temper, was introduced to help solve the stress-corrosion-cracking (SCC) problem prevalent in the high strength alloys with the T6 temper. Though 7075-T73 has served well for this purpose, it was quickly discovered that, when forgings were cold compressed between quenching and aging to produce a stress relieved 7075-T7352 temper, yield and tensile strengths seemed to drop in all test directions as the percentage of reduction increased. In die forgings, it was found that more than about 2% cold reduction in compression could result in below-specification strengths, probably because of the more rapid overaging resulting from residual cold work. On the other hand, it was known that some of the 2000 series alloys (2024 and 2219, for example) are cold worked after quenching to raise yield and tensile strengths.

To check the effect of cold deformation by compression, as well as the effects of various natural and artificial aging relationships on properties controlled tests have been run using hand forged slabs. Aging temperatures and times involved are those normally used to produce the conventional tempers. Routine testing of production die and hand forgings indicates that properties in the other test directions are similarly affected in each alloy.

Alloy 7075. A section of 11 in. (≈280 mm) square cast 7075 ingot was used to produce a hand forging, 30 by 12 by 3 in. thick. This forging was cut into 5 by 5 by 3 in. blocks, which were solution treated at 880°F, quenched in 140°F water, and cold reduced on flat dies to various percentages. One block was retained with no cold reduction.

Two short transverse test bars were taken from each block, and aged for 24 h at 250°F. Two others from each block were aged at 225°F for 7 h followed by 350°F for 10 h. (These treatments produce the T652 and T7352 tempers, respectively.)

The results confirmed previous observations on routine testing of die forgings. In the T6 temper, increasing cold
reduction produces a slight drop in yield strength, but values remain above the specification minimums. However, in the overaged, or T73 condition, yield and tensile strengths drop with increasing cold deformation, and can drop below specification minimums at higher levels of deformation.

**Alloy 7049.** Relatively new, 7049 was developed specifically for use in the T73 or T7352 temper, where it has higher strengths than 7075-T73 with comparable stress corrosion resistance.

For the tests, a hand forging (110 by 8 by 3 in.) was made from 19 in. diameter ingot. This was cut into 6 by 4 by 3 in. blocks, which were solution treated at 875°F, quenched in 70°F water, and cold reduced various percentages on flat dies. Two short transverse test bars were cut from each block, and aged at 250°F for 24 h followed by 330°F for 10 h.

**Alloy 2618.** The 2618 and other 2000 series alloys, though not as strong at room temperature as the 7000 alloys, are frequently used because of their higher elevated temperature properties, and better welding and forming characteristics.

For the tests, an 11 in. square cast ingot was forged to a 4 in. thick slab. Sections of this slab were solution treated at 980°F, quenched in boiling water, and given varying cold reductions on flat dies. The sections were then aged at 390°F for 20 h, producing the T61 and T6152 tempers. Results, determined on three short transverse specimens cut from each section, revealed a drop in yield and tensile strengths with 1% cold reduction, but values increased beyond that point.

**Alloy 2219.** The 2219 alloy, and 2024 which follows, has long been worked between solution treating and aging treatments to raise strength. Stress relief is provided at the same time, and we attempt to use procedures that will provide the best combination of these two effects.

An ingot of 2219, 13 in. diameter, was worked into a 40 by 8 by 3 in. thick slab, which was then cut into 4 by 3 by 3 in. blocks. All material was solution treated at 1000°F, and quenched in cold water. Some blocks were then aged without cold reduction for 18 h at 375°F, producing the T6 temper. Three blocks were also cold reduced 2, 4, and 6%, and aged for 10 h at 350°F, producing the T852 (stress relieved) temper. Three other blocks were cold reduced 8, 10, and 12 pct, and aged for 24 h at 325°F, producing the T87 (maximum property) temper.

Note the abrupt increase in yield and tensile strengths with 2% cold deformation, but strengths then stay almost unchanged with up to 12% reduction. Aging conditions also change as required by the various temper definitions.

**Alloy 2024.** A hand forged slab, 28 by 8.5 by 3 in. thick, was made from a piece of 8 in. rolled round. The slab was cut into 4 by 3.5 by 3 in. blocks, which were solution treated at 920°F, quenched in 70°F water, cold reduced to various percentages on flat dies, and aged for 12 h at 375°F.

**Better Stress Relief Possible**

Knowing the effect of mechanical deformation on properties, more efficient stress relieving procedures can be developed. Stress relief of hand forgings by cold deformation is, of course, quite straightforward. After being solution treated and quenched, the cold forging is placed between cold flat dies, and reduced in thickness by the desired amount. It is then aged, which results in the TXX52 temper.

With hand forgings, it is relatively easy to control the extent of reduction, thus protecting the final properties in the 7000 series alloys. One practice would be to aim for 1 to 2% deformation in alloys like 7075 or 7049. A true 0.5% reduction is probably just as effective as some greater percentage in minimizing distortion. In alloys like 2024, where the cold deformation is also needed to achieve desired strengths, higher percentages of reduction are naturally used.

In die forgings, because of widely varying section sizes and the more precise requirements for final forging dimensions, stress relief by cold deformation becomes more complicated. The steps are the same, but the possible variations multiply. Fixed practice, once the process is established for a given part, becomes very important, and requires tight control.

The following procedure typically applies when a mechanically stress relieved (T52) temper is specified for a large aluminum forging:

- All necessary preliminary operations to get the part ready for finish forging.
• Final hot closed-die operation.
• Solution treat.
• Quench.
• Cold reduce. This may be in finish dies, or in a separate set of specially designed dies.
• Age.

For a TXX52 temper, specifications typically call out 1 to 5% deformation by cold compression. To accomplish 1 to 5% cold reduction in all zones of a die forging of any degree of complexity requires a separate set of carefully designed dies. Even with the special dies, a large forging with widely varying thickness is very difficult to control to these limits. To complicate matters further, reductions of more than about 2% will significantly lower tensile properties in certain alloys, as described previously.

The 7075-T7352 temper is now being used extensively and its properties drop rapidly with cold reduction. This drop can be counteracted by decreasing the degree of overage. Fortunately, there is a wealth of practical experience proving that substantial stress relief, as measured by less machining distortion, can be accomplished without a literal 1 to 5% all over reduction by cold compression.

In many instances, separately designed cold reduction dies can be used, and the regular finish dies in many others. It is impossible to make a general statement that one approach is better than the other from the standpoint of distortion control. In alloys, such as 2024, where cold deformation is required for properties (and particularly if section sizes vary widely), a set of specially designed cold reduction dies may be mandatory.

**Conclusion**

While most large aluminum forgings can be processed to produce a machined part relatively free of distortion, this can only be accomplished by close cooperation between the forger and the machine shop. About 95% of the time, the forgings will machine satisfactorily. Occasionally, there will be distortion problems, and accurate feedback from the machine shop becomes vital. Sometimes a slight change in machining practice or sequence will solve the problem; there have been many instances where one shop machined a forging with no problem, while another shop had severe distortion problems on the same forging.

If the problem cannot be solved at the machine shop (or would require increased costs to solve), the best is to go back and look at the entire process. Knowing the problem, it is possible to make intelligent alterations to the process, like calling for more or less deformation in specific areas. It is possible to recommend redesign of the part to provide more uniform metal removal during the machining. With relatively few exceptions, it is achievable to provide forgings that could be machined with acceptable levels of distortion.

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