UDK 669.715:621.73.043:629.113
Strokovni članek

ISSN 1580-2949
MATER. TEHNOL. 35(3-4)191(2001)

PRODUCTION TECHNOLOGY AND USE OF ALUMINUM DROP FORGING COMPONENTS

PROIZVODNJA IN UPORABA IZKOVKOV IZ Al-ZLITIN

Varužan M. Kevorkijan

zasebni raziskovalec, Lackova 139, 2341 Limbuš, Slovenija
kevorkijan.varuzan@amis.net

Prejem rokopisa - received: 2000-08-02; sprejem za objavo - accepted for publication: 2000-09-09

In this report the production and use of forged aluminum parts are described and the automotive and other principal markets for forged aluminum components are outlined.

Key words: drop forging, lightening, aluminum alloys, forged automotive components

V delu opisujemo proizvodnjo in področja uporabe aluminijastih odkovkov s poudarkom na njihovi uporabi v avtomobilski industriji.

Ključne besede: vroče utopno kovanje, avtomobilske komponente, aluminijeve zlitine, izkovki iz aluminija, avtomobilska industrija

1 INTRODUCTION

In attempting to achieve the "three-litre" fuel-consumption target some leading European car makers recently introduced the "think light" concept based on all-aluminum body and the replacement of steel in many suspension parts by aluminum.

Global market demands and the growing number of car makers who are recognizing aluminum's potential as a realistic and cost effective alternative to steel forgings, have signaled the start to this kind of business in Slovenia- an associate member of the European Union.

According to the Forging Industry Association "forging is a manufacturing process where metal is pressed, pounded or squeezed under great pressure into high-strength parts known as forgings. The process is normally (but not always) performed hot by preheating the metal to a desired temperature before it is worked. It is important to note that the forging process is entirely different from the casting (or foundry) process, as the metal used to make forged parts is never melted and poured (as in the casting process). The forging process can create parts that are stronger than those manufactured by any other metalworking process. This is why forgings are almost always used where reliability and human safety are critical".

The combination of lightness, strength and formability make aluminum the ideal material for any transport application. The initial investment in energy is repaid many times over in fuel savings and environmental improvements during the life of most vehicles.

Customers of forged aluminum parts operate in numerous sectors. From the automotive and motorcycle industries to the hydraulic-pneumatic industry and others. However, they all have one thing in common: to remain competitive they strive for ever improving performance.

These customers are very demanding and they are selective in their choice of suppliers. After all, these suppliers have to make a clear contribution to their ultimate performance and must have the will to constantly improve their performance.

Today the opportunities for aluminum in the car are centered around the body, the wheels, the suspension and items of equipment. The suspension components represent the most important market segment for aluminum forgings in modern cars. The automotive industry is one of the main users of forged components, closely followed by the machine tool and apparatus industry, as indicated in **Table 1**, which indicates the consumption of aluminum forgings in Germany's automotive sector - one of the most important consumers of aluminum forgings in the European automobile industry.

Table 1: Market for forged aluminum components in Germany (excluding wheels) [1]

Tabela 1: Povpraševanje po izkovkih iz aluminija v Nemčiji (brez platišč) [1]

Year	1994	1995	1996	1997	1998
Tonnage	8884	9166	9902	11603	14283
Transport industry (%)	47	45	55	64	67
Mechanical and equipment engineering (%)	22	24	18	13	13

The automobile industry forecasts an increase of over 300% in forged-aluminum components in cars[2]. In comparison with steel, however, forged-aluminum components represent a niche market which, even after achieving all growth forecasts, will retain a niche character. The increasing demands for aluminum in cars are mostly initiated by the necessity to make modern cars lighter and more environmentally friendly. But there are also safety, technical, commercial and other reasons which are all very influential on increasing the proportion of aluminum forgings in current and future generations of passenger cars and other vehicles.

2 HOT FORGING OF ALUMINUM

The technology applied is a conventional drop-forging process with a closed die (hot forging) performed on both screw and mechanical presses. The selected aluminum alloy is plastically deformed in the hot but solid condition in a shaped die until it takes on the shape of the die cavity. The starting material is most often extruded aluminum bars, but in some cases cast billets are also used for production. During the manufacturing process a work-piece is produced which is characterized by a homogeneous structure completely free of pores and blowholes.

The production process is organized into the following production areas: raw material inspection and storage; cutting; forging; trimming; heat treatment; chemical and/or mechanical surface cleaning and final control and delivery. The raw material area consists of metal containers piled up in bundles. The main aluminum alloys used in production are: 6080, 6060, 2014, 2017 and 7075.

For cutting the raw material and preparation of the forging stock, different band- and disk- sawing machines are used. According to [3], using a circular or band saw with carbide-tipped blades is the fastest and generally the most satisfactory method. Sawing, however, produces sharp edges or burrs that may initiate effects when the stock is forged in closed dies. Burrs and sharp edges are usually removed by a radiusing machine. State-of-the-art saws for cutting aluminum alloys are highly automated and frequently have an automatic radiusing capability and control systems that permit very precise control of either stock length or stock volume and therefore stock weight.

Forging is performed on different forging lines consisting of screw and mechanical presses all equipped with tunnel furnaces for material preheating. The metal temperature is a critical element in the aluminum forging process and careful control of temperature during preheating is important. The heating equipment has pyrometric controls that can maintain the temperature to within ±5 °C. The tunnel furnaces have three zones: preheat, high heat, and discharge. All furnaces are equipped with recording/controlling instruments and are frequently surveyed for temperature uniformity in a manner similar to that used for solution- treatment and aging furnaces.

Heated aluminum-alloy billets are temperature checked using contact pyrometry. The typical capacity for preheating of aluminum billets is 200-400 kg/h.

The heating time for aluminum alloys varies depending on the section thickness of the stock and the furnace capabilities. Generally, 4 to 8 min per 10^{-2}m of section thickness is sufficient to ensure that the aluminum alloys have reached the desired temperature of preheating.

The heating of dies is the second critical element in the aluminum-forging process. The die temperature used for the closed-die forging of aluminum alloys varies from 150 to 260 °C depending on the alloy being forged. On-press die-heating systems are based on gas-fired burners.

Die lubricant is the third critical element in the aluminum forging process [3]. The lubricants used in aluminum alloy forging are subject to severe service demands. They must be capable of modifying the surface of the die to achieve the desired reduction in friction, withstand the high die and metal temperatures and pressures employed, and yet leave the forging surfaces and forging geometry unaffected. Lubricant formulations are typically highly proprietary and are developed either by the lubricant manufacturers or by the forgers themselves. Lubricant composition varies with the demands of the forging process and the forging type. The major active element in aluminum-alloy forging lubricants is graphite; however, other organic and inorganic compounds are added to colloidal suspensions in order to achieve the desired results. Carriers for aluminum-alloy forging lubricants vary from mineral spirits to mineral oils and water.

Lubricant application is typically achieved by spraying the lubricant onto the dies while the latter are assembled in the press and just prior to forging. A pressurized-air or airless spraying system is usually employed.

Trimming presses are used for cold and exceptionally hot trimming operations.

The heat-treatment equipment comprises of the main electrical furnace for solution annealing and electrical furnaces for aging. All aluminum-alloy forgings, except 1xxx, 3xxx, and 5xxx series alloys, are heat treated with solution treatment, quench, and artificial aging processes in order to achieve the final mechanical properties. Because of the shape complexity of aluminum forgings, quench-racking procedures are particularly critical for obtaining the the uniform quench necessary to achieve the required mechanical properties and to minimize distortion. Furthermore, quenching techniques for aluminum-alloy forging are also critical because of their configuration and often widely varying cross-sectional thicknesses within the same forging. Depending on the specific aluminum alloy being processed, quench techniques for forgings include controlled-temperature water from 20 to 100 °C and synthetic quenchants, such as polyalkylene glycol and others, designed to achieve the required quench rate in order to obtain the required mechanical properties without excessive distortion. State-of-the-art aluminum-forging solution-treatment and aging furnaces have multiple control/recording systems, microprocessor furnace control and operation systems, and quench monitoring and recording systems, that provide very precise control and repeatability of the heat treatment process.

A pickling line with several reaction vats in a protective cabin is used for chemical etching of the surface of forged parts. After chemical etching with caustic soda and nitric acid the surface recovers its shiny silver aluminum appearance. Purely technical parts can then routinely be made to look decorative. Any damaged parts can be separated out after etching by using a dye penetrant or better by visual inspection in the final control area.

Aluminum-alloy forgings are usually cleaned as soon as possible after being forged. The following treatment is a standard cleaning process that removes lubricant residue and leaves a good surface with a natural aluminum color:

- Etch in a 4 to 8% (by weight) aqueous solution of caustic soda at 70 °C for 0.5 to 5 min;
- Rinse immediately in hot water at 75 °C or higher for 0.5 to 5 min;
- Desmut by immersion in a 10% (by volume) aqueous solution of nitric acid at 88 °C minimum;
- Rinse in hot water.

With this procedure the values specified in DIN 1749 can be achieved by drop-forging and subsequent heat treatment with absolute certainty. Moreover, qualified manufacturers declare that the strength values in DIN can be consistently exceeded by 30% and the manufacturing tolerances can be up to 100% less [4].

3 FROM AN IDEA TO THE FINAL FORGED PRODUCT

Starting with the customer request, specialists working hand-in-hand with the customer prepare the best technical and commercial offer.

The technical offer is based on well-known forgeability facts valid for aluminum alloys [3]; the experience accumulated in the technical office; 3-D modelling (CAD/CAM); simulation calculations of the filling and solidifying processes in the dies and innovative technology that results in high quality at a competitive cost.

The main purpose of all of the above-listed efforts is to define the *optimal* forgeable design of a future forged part which is closely matched to the customer's needs at the minimum requested cost. This is the art of aluminum forging.

For the closed-die forging of aluminum alloys, die material selection, die design, and manufacturing are critical elements in the overall aluminum forging process. Dies are a major element in the final cost of such forgings but less than the cost of the aluminum alloy which is the dominant cost in the breakdown of the total cost of production.

A key element in the cost control of dies for aluminum forging and in the successful fabrication of aluminum-alloy forgings is die design and die system engineering. Moreover, the design of aluminum forging dies is highly intensive in engineering skills and is based upon extensive empirical knowledge and experience. Because of this, the advent of computer-aided design (CAD) hardware and software has had an extensive impact on aluminum-alloy die design.

Most aluminum-alloy forging dies for current industrial needs are produced by CAM-driven CNC direct sinking with very close tolerances (e.g. ±0.07 mm or less).

Once the offered forgeable design is fully confirmed by the customer, the rest is the routine production of forging.

4 QUALITY CONTROL

The inspection of aluminum-alloy forgings takes two forms: in-process inspection and final inspection. In-process inspection, using such techniques as statistical process control and/or statistical quality control, is used to determine if the product being manufactured meets critical characteristics and that the forging process is under control. Final inspection, including mechanical property testing, is used to verify that the completed forging product conforms with all drawings and specification criteria. Typical final inspection procedures used for aluminum-alloy forgings include dimensional and heat-treatment verification and non-destructive evaluation.

All final forgings are subject to dimensional verification. For closed-die forgings, conformance of the die cavities to the drawing requirements, a critical element in dimensional control, is accomplished prior to placing the dies in service by using layout inspection of plaster or plastic casts of the cavities. With the availability of a CAD data base on forgings, such layout inspections can be accomplished more expediently with CAM-driven equipment, such as coordinate-measuring machines or other automated inspection techniques. With verification of the die-cavity dimensions prior to use, the final part of the dimensional inspection may be limited to verifying the critical dimensions controlled by the process (such as die closure) and monitoring the changes in the die cavity.

Proper heat treatment of aluminum alloy forgings is verified by hardness measurements. In addition to these inspections, mechanical property tests are conducted on forgings to verify conformance to specifications. Mechanical property tests vary from destruction of forgings to testing of extensions and/or prolongations forged integrally with the parts.

Finally, aluminum alloy forgings are frequently subject to non-destructive evaluation to verify surface or internal quality.

To arrive at a perfect finished product engineers need to take care during the process from the very beginning. The functional requirements and, above all, the dynamic stresses to which the product is exposed are the starting point for well-conceived design and a choice of alloy which guarantees the required structural and mechanical characteristics.

5 THE FUTURE PROSPECTS OF ALUMINUM DROP FORGED COMPONENTS PRODUCED IN SLOVENIA

All around the world, automotive producers will continue to "think more and more light" demanding highly competitive light metal forgings for future generations of passenger cars. To be capable to "think light and competitive" in automotive forgings for the global satisfaction of customers, one needs at least three things - knowledge for thinking, aluminum for forging and technology for running. And in Slovenia we alreadyhave all of them in-house!

6 REFERENCES

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