New Applications of Forged Aluminum Suspension Arms

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Demand for vehicle weight reduction continues to rise as a result of recent trends in safety enhancement, driving performance improvement and better fuel economy. With the progress in such development, auto manufacturers have become more aware of the advantages provided by forged aluminum suspension arms, which reduce automobile weight and offer excellent safety advantages. This paper introduces Kobe Steel's activities in the applications of aluminum suspension arms. Also described are Kobe Steel's approach to product design, development and improvements in manufacturing technology.

Introduction

Automobiles are required to be even lighter for further achieving environmental protection through fuel economy improvement, as well as safety feature enhancement and drivability improvement1). Automotive suspensions are also required to reduce their weight and thus more aluminum is being adopted. Aluminum forgings, in particular, are often applied because of their significant weight reduction effect along with their high reliability. Kobe Steel develops and manufactures aluminum suspension arms under the ISO/TS16949 management system, including PPAP which involves design analyses, prototype manufacturing and design verification through strength evaluation. This paper introduces Kobe Steel's activities in the development of forged aluminum suspension parts.

1. Use of aluminum in automotive suspension

Various processes are used in the manufacture of aluminum suspension arms. **Fig. 1** summarizes the processes including forging, casting, cast / forging and semi-solid forming (SSF). Of all the processes, aluminum forging provides the highest weight reduction effect, as much as 35 to 40% reduction compared to cast iron, since the forging process offers higher strengths compared to the other processes. Aluminum forging is regarded as the optimum process for producing lighter suspension parts with assured internal qualities and high reliabilities. As shown in **Fig. 2**, the production volume of aluminum forgings has been increasing since 2000. This increase reflects the growing applications of aluminum forgings to automotive weight reduction.

Fig. 3 shows a typical construction of automotive

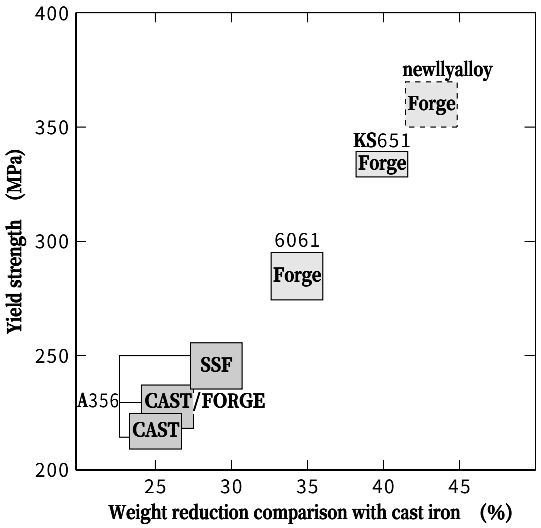

Fig. 1 Weight reduction effect of aluminum forgings (Comparison with cast iron)

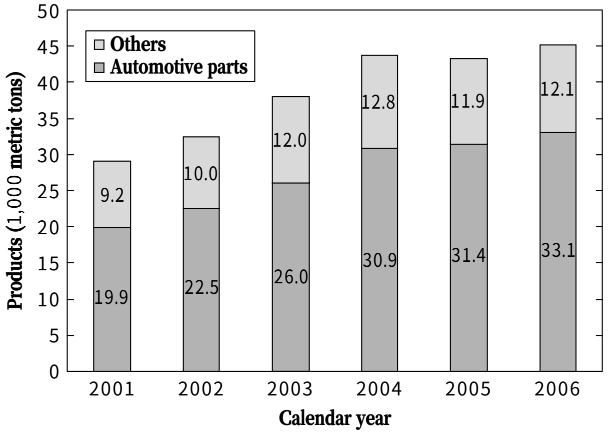

Fig. 2 Annual production of aluminum hot forgings2)

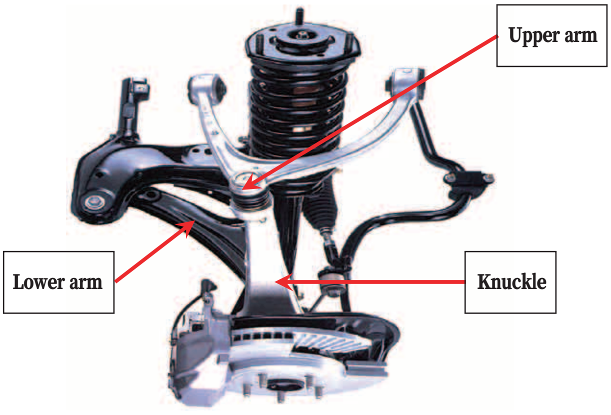

Fig. 3 Automotive suspension system3)

suspensions. The structure, called a "double-wishbone", consists of several parts including a lower arm, upper arm and knuckle. Because these parts constitute an unsprung mass, decreasing their weights contributes not only to the overall weight reduction, but also to stable driving performance and high riding quality.

2. Analytical design of suspensions

Kobe Steel, certified to TS16949, has established a comprehensive product development flow as shown in **Fig. 4**. The flow covers the whole process from analytical designing based on load conditions and layout conditions of suspensions through to the strength evaluation of prototype forging. The analytical design assures accuracy by incorporating various material data, such as static strength, fatigue characteristics & elevated temperature properties, and boundary conditions derived from various factors including bench test data. A suspension arm comprises parts, such as cushion-rubber bushings and ball joints, in their joint portions. Thus, to analytically design an arm, an elasto-plastic strength analysis has to be conducted with these parts assembled together. Incorporating bench-test data works very effectively in setting the boundary conditions for, for example, bushings and ball joints. **Fig. 5** shows typical data comparing designed values against experimental values for the deformation and fracture of a lower arm subjected to a static rupture test under backward load. Other design factors, such as fatigue strength and stiffness, are also incorporated in the designs and verified. Concurrently, clearances among parts are checked to avoid any interference.

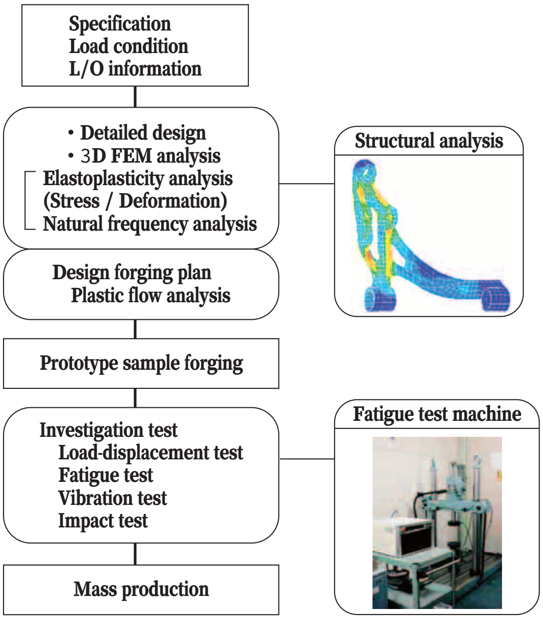

Fig. 4 Flow chart of product development[4)]

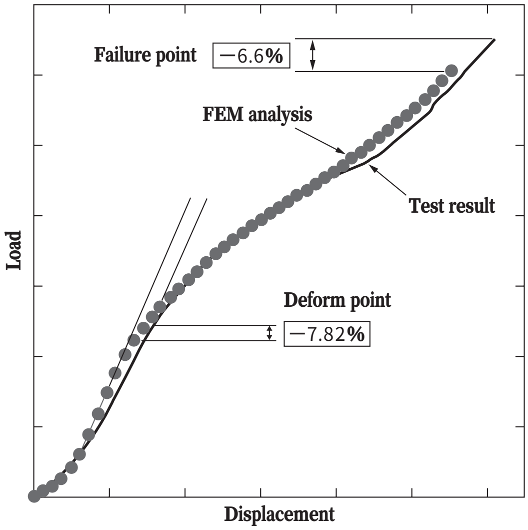

Fig. 5 Comparison between FEM analysis and test result of suspension load test

3. Plastic flow analyses of aluminum forging

Progress has been made in recent years in the application of plastic flow analysis methods of forgings having three dimensional shapes. Kobe Steel is putting the methods into practice for the forging of aluminum suspension parts.

A typical forging process for producing suspension parts employs several dies, e.g., bent pre-form, buster, blocker and finisher. In order to analyze the plastic flow at each of the process steps, three dimensional models of the dies are prepared as shown in **Fig. 6**. FEM analyses are repeated sequentially for the process steps to finally obtain the plastic flow in the finisher. The data used for the analysis include the forging temperature, flow stress of the material at the temperature, shear-friction coefficient and sliding-friction coefficient.

The output obtained from an FEM analysis includes time-dependent deformation behavior, strain distribution (**Fig. 7**) and temperature distribution (**Fig. 8**). The results are useful in predicting the filling in a forging die, generation of defects and stress

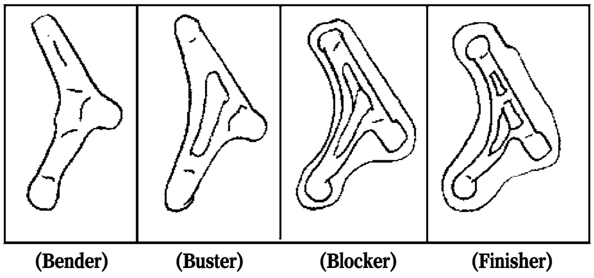

Fig. 6 Typical sequence of forging process

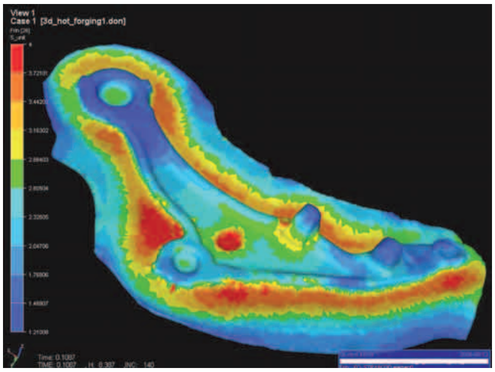

Fig. 7 Equivalent strain distribution obtained by FEM analysis

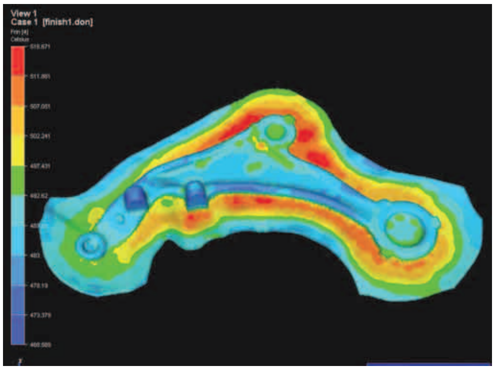

Fig. 8 Temperature distribution obtained by FEM analysis

exerted on dies. Simulating the time-dependent deformation behavior clarifies the states of the materials in the dies and the mechanism of defect generation. This allows the fine-tuning of buster and blocker dies to prevent defect generation.

Optimized pre-form shapes serve to minimize the amount of material charged, homogenize the deformation strains within buster dies and to prevent incomplete filling of the dies. In order to achieve these, analyses are conducted on pre-forms having several different dimensions and also on buster dies having different structures and cavity shapes. A wide variety of factors, such as bending of pre-forms, are involved in such analyses, however, the analyses are important since they affect manufacturing costs directly.

Forging defects are affected in many cases by the balance in volume distributions for buster and blocker dies and the radii of corners and fillets5). An excessive mass of buster or blocker, or an insufficient fillet radius, for example, may cause flow-through defects in H-shaped cross sections. Lap defects may be caused by an undersized fillet radius compared with the corresponding radius in the finisher cavity. The plastic flow analyses can simulate those defects and assist the process optimization. Such optimization has traditionally been carried out by trial-and-error based on prototype production, which took an enormous amount of time and cost. The die design based on plastic flow analyses significantly decreases the amount of time and cost spent in the prototype production.

Forging temperature affects the flow stress and mechanical properties of forged materials6). Thus, estimating the temperature during the forging process is effective in stabilizing the quality of forging. Forging temperature is determined by several parameters including billet temperature, die temperature, deformation strain rate and friction coefficients. The estimation of forging temperature allows appropriate selection of these parameters and stabilizes the inner quality of forgings (**Fig. 9**).

In the case of aluminum forging, die failure occurs mostly from cracking at die corners or stress concentration portions. Thus, predicting stress in a die is highly effective in preventing damage of the die7). The stress generated in a die may be calculated from the stress distribution determined by the plastic flow analysis for the forging produced from the die. The strain in the die is calculated from the stress distribution, assuming the die being an elastic body. The stress is calculated from the die strain. The die life may also be prolonged by controlling the cavity pressure during forging8). The cavity pressure is affected by flow stress of forged material, product shape, flash shape, flash amount and forging temperature. The flash amount and shape are controlled by die design (**Fig. 10**).

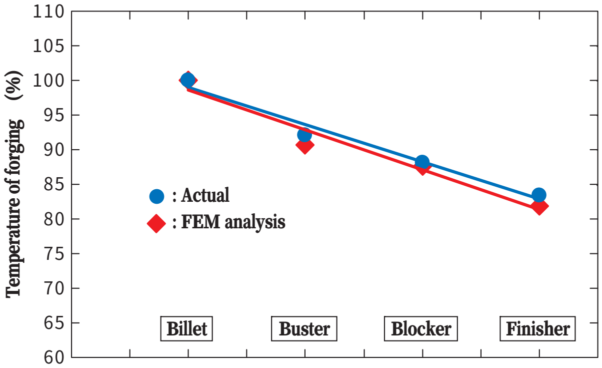

Fig. 9 Material temperature change in forging process

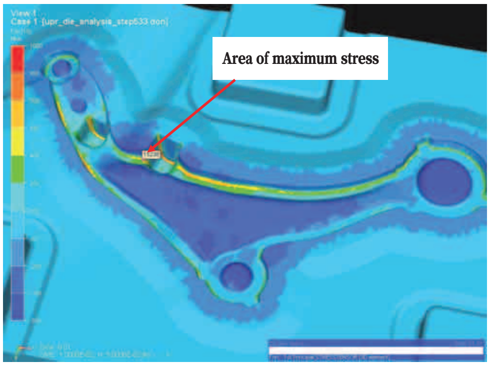

Fig.10 Stress distribution of forging dies obtained by FEM analysis

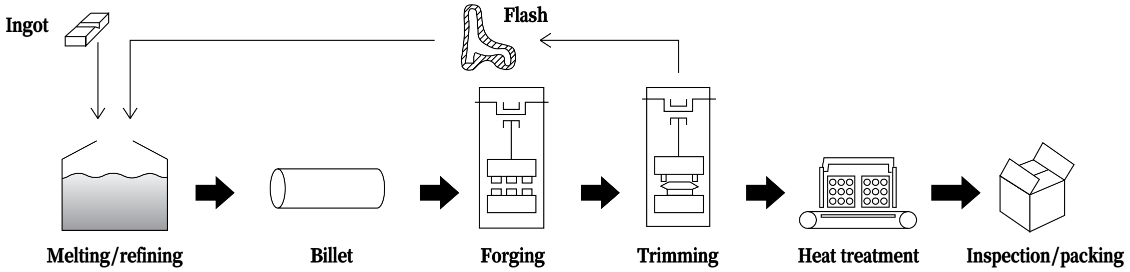

Fig.11 Consecutive production and recycling system

4. Production system

Kobe Steel has established an integrated production system covering the whole process form billet making to forged product finishing. The company has a billet casting foundry built adjacent to a forging factory.

This integrated production system is shown schematically in **Fig. 11**. The system allows a complete recycling of forging burrs, reducing manufacturing cost.

The forging factory is equipped with four 61.740 MN mechanical press machines, the largest of the kind in Japan. The machines allows the simultaneous use of several large dies and enables continuous forging of large parts, such as lower arms. Meanwhile, multi-cavity dies can be used for mid-sized suspension parts such as upper arms. Thus, the capacities of the large forging machines are fully utilized.

Dies are all standardized so that they can be used in any one of the four press machines. The standardization not only assures interchangeability, but also lowers the manufacturing costs of the dies. Forging dies are machined based on the CAM data derived from the three dimensional solid-model data obtained by the analytical designing, which considerably shortens the lead-times of the dies. High-speed machining centers are used for the fabrication of the high-precision dies in short lead times. Improved machining technologies are adapted for the machining of hard materials.

5. Oversea development

Automobile manufacturers are increasing their overseas production volume as their business globalizes. In response to this trend, Kobe Steel started operation of Kobe Aluminum Automotive Products (KAAP) at Kentucky, USA (**Fig. 12**) in 2005. KAAP runs three 61.740 MN press machines, as of today. KAAP follows the manufacturing system and technologies of Kobe Steel and operates an integrated production line covering from billet making to finish forging of arms. The company makes its own billets using an apparatus equivalent to the one used in Japan. The company's forging machines and dies are also equivalent to those used in Japan so that the same level of quality is achieved by both Kobe Steel and KAAP. KAAP's forging dies, in particular, applies the same standard as in Japan so that they can be interchangeably used between the two companies. The two companies can also share CAM data.

Fig.12 Kobe Aluminum Automotive Products, LLC

Conclusions

Further automotive weight reduction is required for improved fuel economy, environmental protection, comfort driving, enhanced safety features, etc. In response to such needs, Kobe Steel will strive to develop and produce suspension parts, utilizing CAE to shorten development periods for further automotive weight reduction.

References

1) WWW site of Aluminum Alloy refiners Association: *Aluminum & Automobiles*, http://www.aluminum.or.jp/jidosya/japanese/index.htm
2) WWW site of Aluminum Alloy refiners Association: *Aluminum Statistics*, http://www.aluminum.or.jp/toukei/index.htm
3) WWW site of Aluminum Alloy refiners Association: *Aluminum & Automobiles*, http://www.aluminum.or.jp/jidosya/japanese/index.htm
4) A. Fukuda et al.: *R&D Kobe Steel Engineering Report*, Vol.52, No.3 (2002), p.88.
5) Forging Technology Laboratry Foundation: *Forging Technology* (Die Design), (1982), p.263, Toshindo.
6) Y. Inagaki et al.: *R&D Kobe Steel Engineering Report*, Vol.55, No.3 (2005), p.83.
7) ASTM INTERNATIONL Handbook Committee: *Metals Handbook Ninth Edition*, (1988), p.247.
8) Forging Technology Laboratry Foundation: *Forging Technology* (Die Design), (1982), p.52, Toshindo.