F. Improved Automotive Suspension Components Cast with B206 Alloy

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Objective

To establish the commercial viability of B206 alloy for suspension components, by providing needed fundamental information on this alloy system and by overcoming technical issues that limit the lightweighting applications of this alloy. Once the important technical issues are solved, we should be able to provide mechanical properties equivalent to forged aluminum suspension components in net-shaped B206 alloy castings. This would allow us to lightweight automobiles and trucks in a cost-effective manner.

Approach

Four major technical focus points have been identified for this project. Accordingly, the work will be conducted in four separate phases:

1. Determine the effect of alloy composition on mechanical properties in the T4 and T7 heat-treated conditions and establish the feasibility of using less-expensive versions of the alloy.
2. Study heat treatment of B206 alloy and establish combinations of aging time and temperatures which produce desirable stress-corrosion immunity. This portion of work will also determine the feasibility of using improved T7 heat-treatment cycles to increase elongation in this temper.
3. Create cost models for automotive suspension components produced by different processes and different materials.
4. Produce control-arm castings using two different casting processes. Test components produced in the T4 and T7 tempers to provide required engineering information and establish the feasibility of using cast B206 alloy components to replaced forged aluminum parts.

Accomplishments

Kick-off meetings officially began this project early in October, 2004. Unfortunately, portions of the project were affected by delays in establishing contractual agreements and issuing of purchase orders. However, all purchase orders were in place in February, 2005.

The task 1 work is nearly complete. A study of tensile properties versus alloy composition was conducted by researchers at Alcan International. These results show that best results are obtained with two separate alloy compositions, depending on whether the T7 or the T4 temper is used. These two alloy compositions are:

1. T4 Temper

The alloy contains 4.7 to 4.9% Cu, 0.35 % Mg and 0.2 % Mn. by weight. The expected tensile properties are (yield strength (YS), ultimate tensile strength (UTS), elongation): 250-260 MPa, 430-450 MPa, and 18-22%, respectively.

2. T7 Temper

The alloy contains 4.0 to 4.2% Cu, 0.15% Mg and 0.2% Mn, and the expected tensile properties are (YS, UTS, elongation): 350-370 MPa, 430-450 MPa, and 7-10%, respectively.

The first alloy composition falls within the present composition limits specified for 206 alloy. The second is closer to 204 alloy.

In addition to the above results, a set of casting guidelines has been prepared for foundrymen who want to pour B206 alloy.

A second stage of task 1 casting trials was completed in September, 2005 by Nemak researchers at their Central Development and Technology Center near Monterrey, Mexico. Several different alloy compositions were prepared and 'wedge' castings were made. The 'wedge' castings were poured to establish the tensile properties of the alloy as the solidification rate varied from 30 seconds to 30 minutes. In addition, hot-crack test castings were poured to determine the effect of alloy composition on castability. The mechanical testing of the Nemak castings is still underway, and a technical report summarizing the results should be available in December, 2005. Once the report on the Nemak experiments is issued, this will complete phase 1 of the project.

Task 2 is being conducted at the University of Windsor under the direction of Prof. Jerry Sokolowski. Alcan International is also assisting this phase of the project by providing additional testing. A survey study of the aging of B206 alloy has been completed. Samples were aged at temperatures between 125 and 225°C for times ranging from two to forty-eight hours. The hardness and electrical conductivity were measured, and the samples were subjected to a corrosive medium to establish their vulnerability to intergranular attack. A report of these experiments was issued in October, 2005. Additional studies will establish the kinetics of the solution heat treatment process and attempt to develop an alternative T7 aging process to increase elongation in that temper.

Although preliminary discussions have taken place, no work on task 3 (the cost modeling) has been conducted.

The design work needed for task 4 has been completed at Hayes-Lemmerz, and they are ready to cut the tooling needed to produce molds for the control-arm casting. Casting trials will be conducted at their plant in Wabash, Indiana. Casting simulation and design studies are underway at Nemak. This work should be completed during the first quarter of 2006, and the tooling required to pour control-arm castings will be available two to three months later. Mercury Castings has recently come on board to this project as an additional industrial partner. They will produce test-bar castings in B206 alloy using a new semi-solid SOD (Slurry on Demand) process, which they are developing. Mercury will also produce castings from an extrusion alloy, 6061, and from two common casting alloys, 356 and 357. The mechanical properties of the SOD castings will be provided by Mercury Castings.

Future Direction

Now that the task 1 casting trials are complete, attention will be focused on the task 4 casting trials. Production of the first prototype suspension components should commence during the first half of CY 2006.

In the T7 temper, theoretical considerations suggest that it is possible to increase elongation significantly by changing the aging cycle used. This will be the primary objective of additional task 2 heat-treatment studies at the University of Windsor. We will also attempt to reduce the cost of heat-treatment by studying the kinetics of the solution heat-treatment process in B206 alloy. The cost of solution heat-treatment is on the order of 0.5

cents per pound for each hour of treatment. Reducing the solution time will also result in energy savings; about 0.03 kw-hr (330 Btu) per pound per hour.

Work on the cost models (task 3 of this project) will begin early in 2006.

Introduction

206 alloy is significantly stronger than 356 alloy and has mechanical properties approaching some grades of ductile iron. It also has excellent high-temperature tensile and low-cycle fatigue strength. Consequently, this material could be used in a number of applications to reduce vehicle weight. Cost savings may also result, because less material would be required to provide the strength needed for the application. In spite of its excellent properties, however, 206 alloy is seldom used because of its propensity for hot cracking. GKS Engineering has discovered a better method to grain refine this alloy, which reduces the tendency for hot cracking. This material has a number of potential applications, but its high strength and excellent ductility make it an ideal candidate for suspension components. Consequently, in the first stage of work (Project AMD 305 -- completed in May, 2002) control arms were produced via a tilt-pour/permanent-mold casting process to establish the viability of this material for these safety-critical components.

The work completed under AMD 305 showed that extremely high mechanical properties can be obtained. The tensile properties of permanent-mold B206 alloy control arms were nearly the same as (or slightly better than) those found with many forged aluminum components, and the low-cycle fatigue life of B206 alloy is ten times that of A356 alloy castings for an equivalent stress level. AMD 305 also showed that the permanent-mold casting process, although suitable, may not be the best manufacturing process for 206 alloy. Traditional sand casting and composite casting methods (such as Nemak´s semi-permanent-mold precision sand-casting process) are more forgiving of hot cracking. The additional work proposed in this project will examine the technical feasibility of producing B206 alloy suspension components in three other casting processes. Other important technical and commercial issues related to B206 will also be addressed. The object is to provide the technical and economic data needed to justify commercial use of this material in suspension components.

Justification

Automakers are under increased pressure to reduce CO_2 emissions and improve fuel economy through increased CAFE standards. Because of its higher strength, B206 alloy structures have the potential to reduce vehicle mass, which is directly linked to improved CAFE and vehicle performance. There is also a potential for cost savings, because less material would be required when compared to conventional aluminum castings.

Program and Deliverables

This project will take 30 months to complete and will proceed in four tasks. Below is a description of the deliverables for each of the four tasks of the project.

Phase 1

The main alloying elements in 206 alloy (Cu, Mg, Mn) will be varied in a series of statistically-designed experiments. Test bars will be cast at each composition and heat treated to the T4 and T7 tempers. Hot-crack test castings will be made to study the effect of alloy composition on castability, and 'wedge' castings will also be poured to determine the effect of solidification rate on tensile properties. These tests will determine the effect of alloy composition on mechanical properties and castibility, and will allow design and casting engineers to better tailor mechanical properties for any specific application. The minor impurity elements (Fe and Si) will also be varied to determine the effect of these elements on mechanical properties. It appears that the maximum limits for Fe and Si, presently listed in the AA specifications for the 206 alloys, are lower than necessary for most automotive applications. Increasing these limits by a modest amount would reduce the cost of the alloy. These tests will be conducted at the Research and Development Center of Alcan International and at Nemak.

Phase 2

Parts made in 206 alloy are immune to stress-corrosion in the T4 and T7 tempers; parts that have been aged, however, are susceptible. Published information on other Al-Cu-Mg alloys suggests that relatively short aging times may induce stress-corrosion, and that the susceptibility to stress-corrosion may occur before any change in hardness is found. For example, the temperatures and times used in powder coating may cause a problem. This part of the study will map out the dangerous areas which must be avoided. It will also examine alternative T7 treatments, to see if there is a way to improve material properties (especially elongation) in this temper. The use of alternative methods to test for stress-corrosion resistance will also be evaluated. The standard test is cumbersome, and takes 30 days to complete. A simpler, more rapid test is desirable. This phase of work will be carried out at the University of Windsor in Windsor, Ontario, and at Westmoreland Mechanical Testing Laboratories. Additional support will be provided by the laboratories of Alcan International.

Phase 3

A cost model will be constructed for suspension components manufactured using different processes and materials. A General Motors front-lower control arm forged in 6xxx alloy will serve as a mule for this economic study. The following component cases will be considered:

- forged 6xxx alloy
- sand-cast B206 alloy
- semi-permanent-mold cast B206 alloy
- permanent-mold cast A356 alloy

Creative Concepts will assist GKS Engineering in formulation of the cost models in this portion of the study. Sync Optima will also do finite element method (FEM) studies of the different cases, to determine changes required in the design (and weight) of the control arm as the material is changed from the base condition (forged 6xxx alloy).

Phase 4

In this final stage of work, control-arm 'Mule' castings will be manufactured by the composite precision sand-casting process at Nemak and at Hayes-Lemmerz International. Semi-solid cast parts will also be made at Mercury Castings.

In AMD 305, parts were made and heat treated to the T4 temper. In this new work, additional castings will be made and tested in both the T4 and T7 tempers. In this way, a complete set of mechanical property data will be obtained for the castings.

For this portion of the project, the compositions used to produce castings will be the optimum alloy compositions mapped out in phase 1 of the project.

Westmoreland Mechanical Testing and Research will do testing of castings made in this phase of work.

Measurable Success Indicators

The successful result desired from each of the four phases of work is outlined below:

Phase 1

Mechanical properties as a function of cast material composition will be provided, allowing automotive design engineers to optimize component properties at lowest possible cost. Information will be provided which may allow us to increase upper limits for dissolved Si and Fe and reduce costs in 206 alloy.

Phase 2

Optimum heat-treatment schedules, which avoid stress-corrosion problems, will be established and recommended. Simple and rapid tests for stress-corrosion susceptibility will also be evaluated.

Phase 3

Cost models will be provided for the production of suspension components using several manufacturing processes and different materials. This model will assist automotive design engineers to optimize component performance, and at the same time to help realize production cost savings.

Phase 4

Control-rm castings will be produced using two different casting processes, and a complete battery of material property tests of the components will provide the technical database needed to design, manufacture and use suspension components cast in B206 alloy.

Technical Results

The results of the phase 1 casting trials have been used to map out the range of mechanical properties that can be obtained from B206 alloy castings. For permanent-mold test bars, which have a relatively rapid solidification rate (20-30 seconds), the tensile properties found in the T4 temper are shown in Figure 1. The irregular polygon in this figure indicates the variation of tensile properties (UTS or ultimate tensile strength and YS or yield strength (in MPa) and % elongation) that one may expect as the composition is varied between the upper and lower limits for this alloy in the Aluminum Association specifications. The amounts of Cu, Mg, Mn, Fe and Si in the alloy were all allowed to vary.

The corresponding range of mechanical properties available in the T7 temper are indicated below in Figure 2.

In addition to the above results, two of the Alcan alloy compositions were poured into an end-chill mold. Tensile samples were cut at three distances from the chill (ranging from ½ to two inches). The tensile properties obtained from these castings are

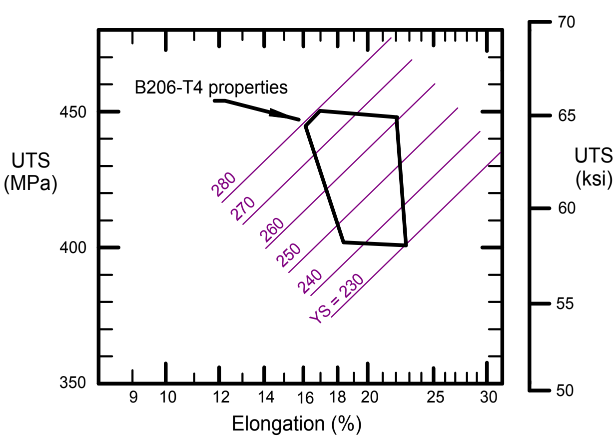

Figure 1. B206-T4 Tensile Properties

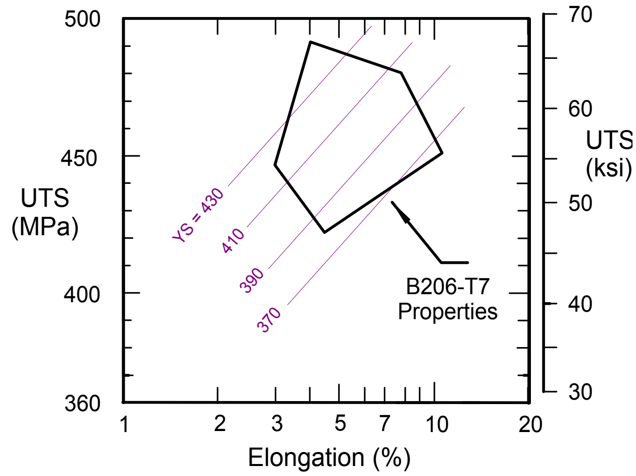

Figure 2. B206-T7 Tensile Properties

shown in Figure 3 together with data published for the more commonly used aluminum casting alloys.

The solidification time is indicated in this figure by numerical values for the secondary dendrite arm spacing (SDAS), or the cell size in the case of B206 alloy. (The data for A357 alloys are for heavily chilled sections of aerospace castings only.) It can be seen that B206 alloy exhibits mechanical properties superior to the conventional Al-Si-Mg and Al-Si-Cu casting alloys.

A number of B206 alloy samples were aged and tested for intergranular attack by corrosion. A test procedure outlined in Mil Spec MIL-H-6088 and ASTM specification G110 was used. This procedure correlated well with the results of a standard

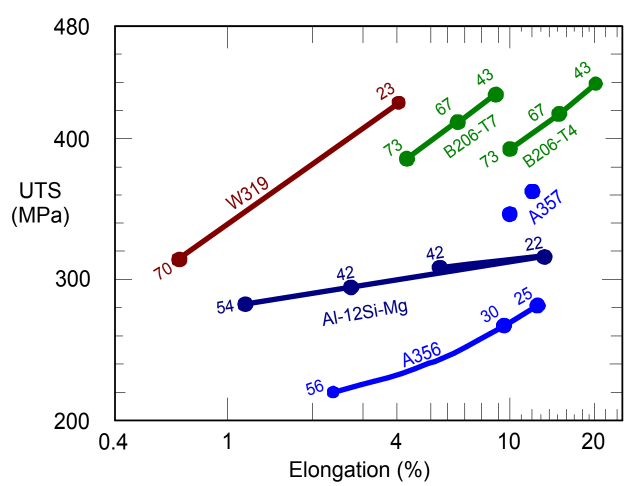

Figure 3. Range of Mechanical Properties in Five Aluminum Casting Alloys

alternate immersion test in 201 alloy,[1] and so it was adapted for use in phase 2 of this study. The average depth of the intergranular attack by corrosion (in microns) is plotted in Figure 4, as a function of aging time and aging temperature.

In this plot, the safe aging conditions are indicated by the hatched areas. (These areas indicate aged samples where the average intergranular corrosion depth was less than 20 microns deep.) The areas of worst corrosion attack are 'in between' the safe areas, at aging temperatures between 100 and 180º C. The next step in phase 2 of our program is to conduct alternate immersion stress-corrosion tests. Then, the results of the two corrosion tests will be correlated.

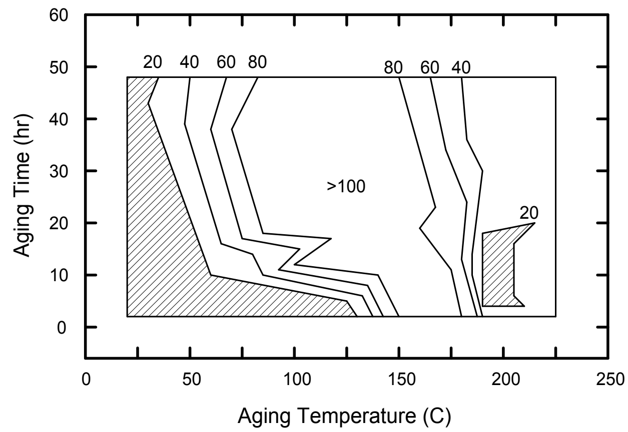

Figure 4. Average Depth of Corrosion

Presentations and Publications

No publications, presentations or patents have resulted from this project to date.

[1] M.S. Misra and K.J. Oswalt: "Corrosion Behavior of Al-Cu-Ag (201) Alloy," Metals Engineering Quarterly, Vol. 16, pp. 39-44 (1976).