F. Improved Automotive Suspension Components Cast with B206 Alloy (AMD 405[i])

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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 light weighting 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, 2005. All purchase orders were in place in February, 2005. Dr. Geoffrey Sigworth handed over the administration of the project to Dr. Murat Tiryakioğlu in March 2006. Phases 1, 2 and 3 are completed. Casting production is about to start at Nemak as of December 9, 2006. Phase 4 is expected to be finished by March 2007.

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[1] Dr. Tiryakioğlu took over administrative responsibilities of this project from Dr. Geoffrey Sigworth in March 2006.

The **phase 1** work is 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 (in wt.%):

1. T4 Temper

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

2. T7 Temper

For a ductile T7 version, the alloy contains 4.2 to 4.4% Cu, 0.15% Mg, 0.2% Mn, 0.10%Fe, 0.10%Si. The expected average tensile properties would be (YS, UTS, elongation): 370-390 MPa, 445-455 MPa, and ~9% elongation.

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 phase 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.

Phase 2 was conducted at the University of Windsor under the direction of Prof. Jerry Sokolowski. Alcan International also assisted this phase of the project by providing additional testing. A survey study of the aging of B206 alloy was 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 were conducted to establish the kinetics of the solution-heat-treatment process. Attempts to develop an alternative T7 aging process to increase elongation in that temper were mostly unsuccessful. More work is needed.

Phase 3 has been completed. A cost model was developed by Edmund A. Herman, P.E. of Creative Concepts Company, Inc. in March 2006. A Microsoft Excel spreadsheet was developed which can be used to compare costs of producing castings using A356-T6, B206-T4 and B206-T7 alloys.

Phase 4 is in progress. The design work needed for this phase was initially completed at Hayes Lemmerz. In April 2006, there were intense discussions on how the filling system should be designed to minimize the entrainment of surface oxide films and therefore maximize mechanical properties. Dr. Tiryakioğlu and Prof. John Campbell provided Mr. Greg Woycik at Hayes Lemmerz with a conceptual design of a filling system that was expected to minimize the damage to liquid metal during mold filling. However, Mr. Woycik was unexpectedly released of his job at Hayes Lemmerz. Hayes Lemmerz is no longer involved with this project. The gating system design concepts proposed by Tiryakioğlu and Campbell were adopted by Nemak and final gating system design was developed with the assistance of Prof. Campbell. Mold-filling simulations using Magma software showed significant improvement over previous designs.

Future Directions

Castings to be produced at Nemak will be tested at Westmoreland Mechanical Testing and Research and General Motors Corporation. These tests include component fatigue, tensile, fracture toughness, compressive testing and corrosion. In addition, deformation characteristics will be evaluated to determine whether any outliers in tensile tests are due to structural defects that can be avoided with better melt quality and modifications to mold filling system design. A full project report will be available in April 2007.

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[ii] -- 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 stages. Below is a description of the deliverables for each of the four phases 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 castability, 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 to peak strength (T6), 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 FLCA 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 the project group in formulation of the cost models in this portion of the study. Sync Optima will also do 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. 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 results desired from each of the four phases of work are 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 that 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-arm 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, 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 is indicated in Figure 2.

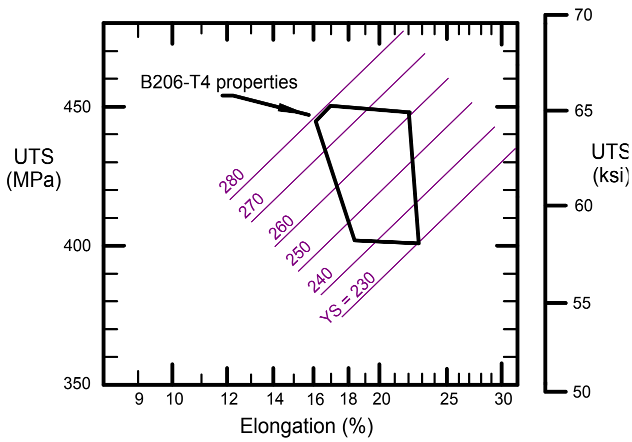


Figure 1. B206-T4 tensile properties.

In addition to these 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 12.5 to 50 mm (½ to 2 inches). The tensile properties obtained from these castings are shown below, 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 is 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.

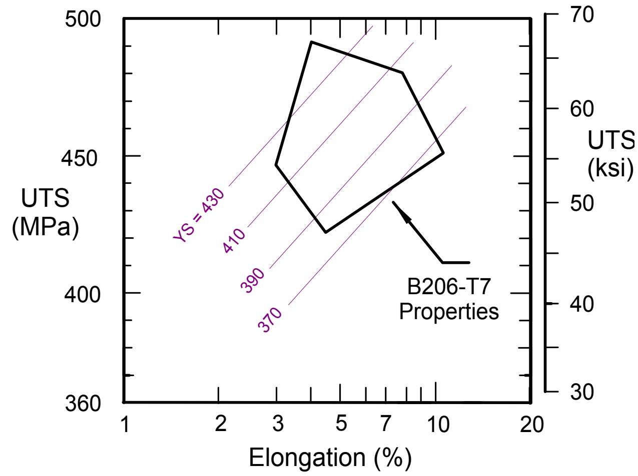


Figure 2. B206-T7 tensile properties.

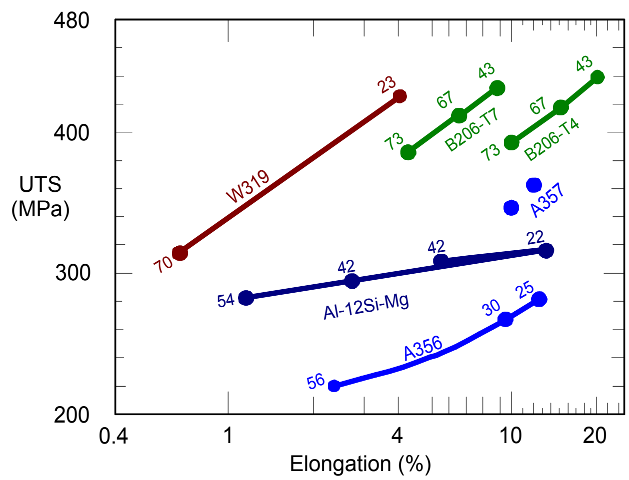


Figure 3. Range of mechanical properties in five aluminum casting alloys.

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 alternate immersion test in 201 alloy,[2] 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

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

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 180°C.

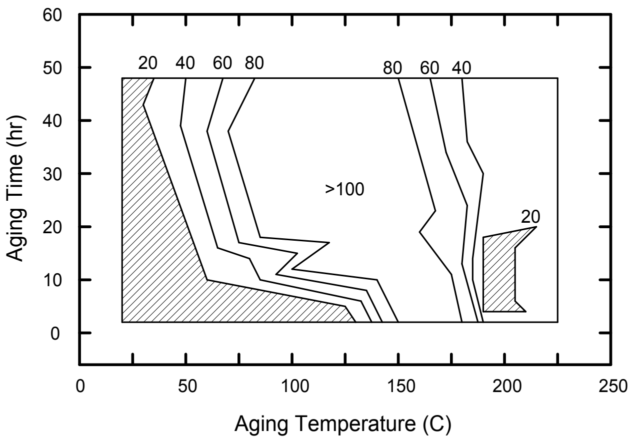


Figure 4. Average depth of corrosion.

In Phase 2 of our program, immersion stress-corrosion tests were conducted in accordance with ASTM G47-98 standard. Specimens were all naturally aged for 3 days and artificially aged for different durations at temperatures between 100 and 225°C. The stress-corrosion-cracking (SCC) life contour plot is provided in Figure 5 as a function of artificial aging temperature (T) and time. The worst stress corrosion life occurred between 100 and 175°C, which is consistent with intergranular corrosion results outlined in Figure 4. More analysis will be conducted for possible correlation between the results from the two test methods.

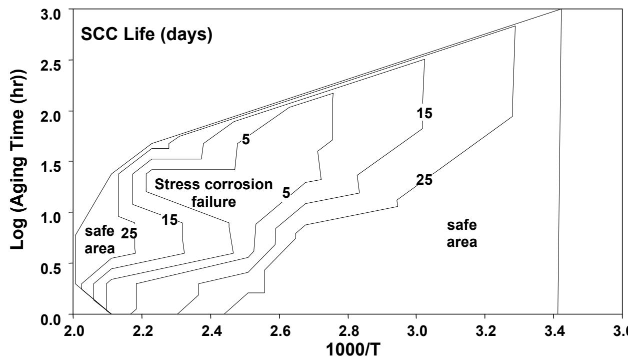


Figure 5. Stress corrosion cracking life contours as a function of artificial aging time and temperature.

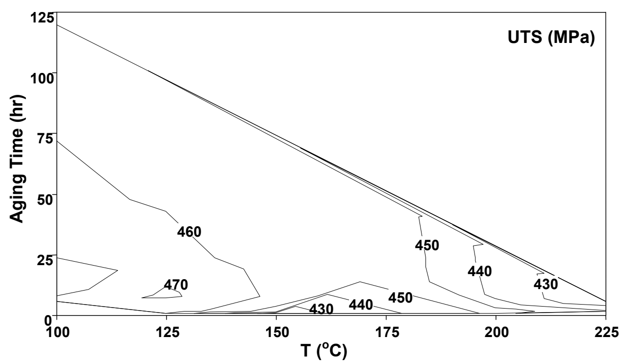
Contour plots of tensile properties after artificial aging at temperatures between 100 and 225°C for various durations are presented in Figure 6. Highest UTS and elongation are obtained at an artificial aging for 12-24 hours at 125°C. A small set of experiments are planned at Alcan Laboratories to obtain more detailed results.

Presentations and Publications

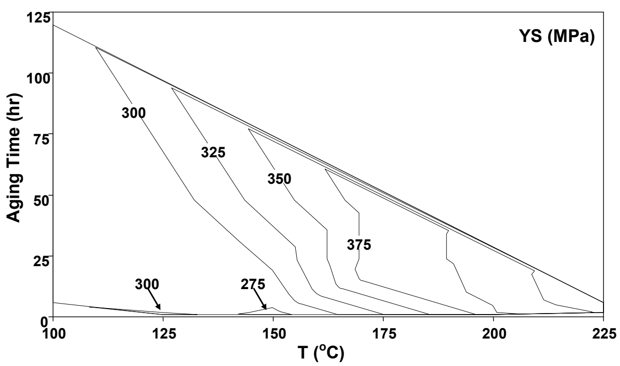
The results from this project so far have generated two presentations and papers:

1. G.K. Sigworth, J.F. Major: "Factors Influencing the Mechanical Properties of B206 Alloy Castings," **Light Metals 2006**, pp. 795-799, 2006 (presented at 2006 TMS Annual Meeting).

2. J.F. Major, & G.K. Sigworth, "Chemistry / Property Relationships in AA 206 Alloys," paper 06-029, **AFS Transactions** (presented at 2006 AFS Congress).



(a)



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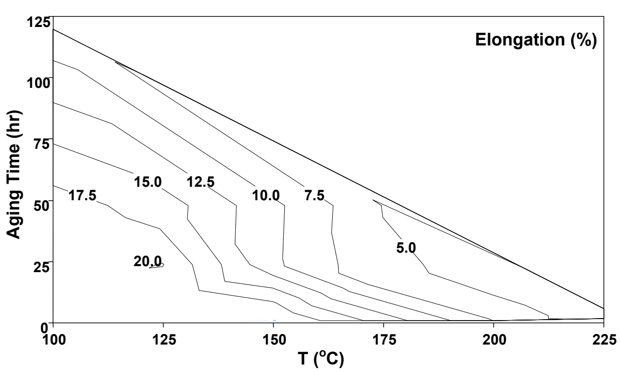

(c)

Figure 6. Contour plots for (a) ultimate tensile strength, (b) yield strength and (c) elongation as a function of artificial aging time and temperature.

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[i] Denotes project 405 of the Automotive Materials Division (AMD) of the United States Automotive Materials Partnership (USAMP), one of the formal consortia of the United States Council for Automotive Research set up by the "Big Three" traditionally U.S.-based automakers to conduct joint pre-competitive research and development.

[ii] Denotes project 302 of the Automotive Materials Division (AMD) of the United States Automotive Materials Partnership (USAMP), one of the formal consortia of the United States Council for Automotive Research set up by the "Big Three" traditionally U.S.-based automakers to conduct joint pre-competitive research and development.