IBC Advanced Alloys

Advanced Alloys
Alloy Selection for the Aerospace Industry

Abstract

The aerospace industry is a forward looking one. Driving the development of new materials and fabrication techniques, the aerospace industry is one where short term costs can yield significant savings throughout the lifespan of the product. Herein, the use of copper beryllium alloys by the aerospace industry is examined in order to determine what material properties make them so attractive and how these properties can be leveraged into further long term savings.

1 Introduction

More than any other major industry, the aerospace industry is one where a relatively small change in design can have enormous economic impact on the product over its lifespan. The upfront cost of an aircraft is significant of course, but it is eminently possible for optimizations at the time of manufacture to pay back their development costs many times over. A prime example of this of course is the aircraft recently introduced by the likes of EADS Airbus A380 or the Boeing 787.

The Boeing 787 in particular has capitalized on the possibilities presented by the incorporation of new, advanced materials and features a structure made largely of composite materials. The costs associated with developing not only an entirely new aircraft such as the 787, but in fact, an entirely new method of building them, are astronomical. What makes these upfront costs bearable to the industry is the increases in efficiency these upfront costs can garner. While the initial cost of the Boeing 787 is projected to be higher than for other similarly sized aircraft, it is also projected to have a significantly longer range on a similar volume of fuel which is projected to result in a lower lifetime costs.

Table 1: Breakdown of operating cost (in cents) per ASM for three sample airlines in 2005 [1].

Cost	American Airlines	JetBlue	Southwest Airlines
Fuel	2.84	2.05	1.71
Maintenance	1.17	0.58	0.79
Crew	1.13	0.58	1.11
Other Operating	0.81	0.77	0.68
Total Operating	5.96	3.98	4.30
Total Operating and Non Operating	12.3	7.27	7.86

A commonly used metric for comparing costs in the airline industry is the Cost per Available Seat Mile (cost per ASM). This metric looks at the cost of each seat on a route, whether it is filled or not. In order to determine if the flight is profitable, one simply totals up the revenue for the flight and subtracts the total cost per ASM for all seats. Example data for three major American airlines is given in Table 1. In 2005, the fuel and maintenance costs per ASM represented between one half and two thirds of the total operating costs per ASM as shown in Figure 1. The implication of this of course is that anything that can be done to decrease maintenance or fuel costs can have very significant long term savings. To this end, a number of cases where beryllium copper alloys are already

IBC Advanced Alloys Corp Suite 900, 595 Howe Street, Vancouver, BC V6C 2T5, Canada
T +1 604 685 6263 F +1 604 687 8678

being used to decrease these costs will be examined.

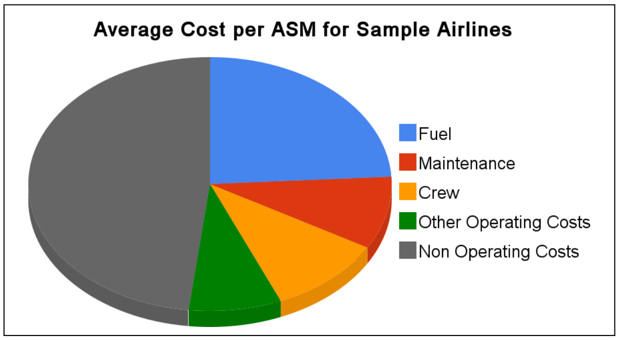

Figure 1: Average cost (in cents) per available seat mile for American Airlines, JetBlue and Southwest Airlines. Fuel and maintenance, costs associated with the efficiency of the aircraft design represent a third of the total operating and non-operating costs.

2 Bushings and Wear Surfaces

The aerospace industry makes ample use of costly, high specific strength materials (that is, materials with large strength to weight ratios) as well as costly manufacturing processes in order to minimize mass. Aircraft landing gear and control surfaces are prime examples of assemblies that involve both exotic materials such as titanium as well as expensive, complex castings [2]. Inherent in the complex linkages involved, landing gear and stabilizer assemblies make use of dynamic joints. These dynamic joints, such as pivots and sliders mean the assembly will wear over time and will require maintenance. If the wearing surface is made of an exotic, expensive material, or requires an expensive casting operation to make, then the periodic refurbishment or replacement of these parts can result in significant costs. In order to reduce these costs, wear surfaces such as beryllium copper bushings can be introduced in to the structural design [3].

Beryllium copper is an ideal material for making these wear surfaces for a number of reasons. First of all, beryllium copper alloys, such as C17200 and C82500 have higher strength, hardness, wear properties and bearing load capabilities than any other copper alloy [4]. These alloys form a thin, tenacious oxide on their surface which acts much like a self healing lubricant.

Bushings, which experience repetitive surface to surface sliding contact, necessitate the use of materials which are non-galling in order to maintain a smooth surface. The excellent non-galling characteristics of beryllium copper alloys adeptly fulfill this requirement. Furthermore, beryllium copper alloys exhibit excellent thermal properties, with low coefficients of thermal expansion and excellent thermal stability. These are crucial properties for materials being used in aerospace applications, which can be exposed to extreme ranges of temperatures.

This thermal stability means that the material being protected can be cooled to below zero to induce shrinkage and the beryllium copper bushing can then be press-fit. When the temperatures stabilizes, a shrink fit is achieved, holding the bushing in place. Once the bushing is sufficiently worn to necessitate removal, it can either be removed via thermal contraction of the protected part, or simply machined or cut off. In this manner, maintenance costs of the aircraft can be significantly reduced. Wear is moved from expensive parts and assemblies to easily replaceable, lower cost beryllium copper parts with optimal wear and galling properties as well as excellent load capacity and corrosion resistance. Maintenance is required less frequently, and is less expensive to perform as a result.

3 Structural Components

It has been demonstrated that not only can beryllium copper alloys be used for wear applications, but their excellent hardness and strength means they are also eminently capable of assuming structural roles within the airframe. Sometimes it is simply not feasible to introduce a special wear surface, in these cases, beryllium copper alloys, with their excellent wear properties, can simply be used in place of steel or other materials that don't wear as well. As indicated in Table 2, the specific strength of beryllium copper alloys is

Table 2: Yield strength, density and specific strength of various alloys.

Alloy	Yield Strength MPa	Density kg/m^3	Specific Strength $MPa{*}m^3/kg$
Steel (1020)	300	7800	0.038
Steel (1080 Tempered)	900	7800	0.115
Steel (H14 Tool)	1100	7900	0.139
Aluminum (7075)	400	2800	0.143
Aluminum (6061)	220	2800	0.079
Titanium (6Al-4V)	900	4430	0.203
BeCu (C17200)	1000	8250	0.121

on par with that of high strength steel and aluminum alloys and vastly better than low carbon steel, meaning that these substitutions can be performed, often without incurring any weight penalties.

While beryllium copper alloy parts can be more expensive than their steel or aluminum counterparts, their excellent wear and fatigue properties mean that replacement or refurbishment intervals can potentially be lengthened dramatically, once again reducing maintenance costs.

An added advantage of beryllium copper alloys which increases their attractiveness in certain applications is the excellent fluidity of the melt material. The fluidity of higher beryllium content alloys such as C82800 is particularly good. This fluidity makes them ideal for complex castings. Structures such as pitot tube housings involve very fine cast structures and can only be cast if the melt material has excellent fluidity. For this reason pitot tube housings for high speed aircraft are generally made from these beryllium copper alloys (C82500 or C82800). Another example of this type of application that currently sees extensive implementation of beryllium copper alloys is the inlet guide vanes of helicopter turbines, which once again require the combination of good specific strength, thermal stability and excellent casting fluidity that only beryllium copper alloys provide [5].

4 Instrumentation Cages

Another area of aerospace design where beryllium copper alloys have proved themselves useful is instrumentation cages. Aircraft designs are optimized for aerodynamics so as to minimize fuel costs. This means that portions of the aircraft can face severe packaging restrictions. Instrumentation cages are one such space critical application, so very high strength is required in order to minimize volumes, this generally eliminates aluminum alloys as a possibility and leaves only high strength steels, titanium alloys and beryllium copper alloys as possibilities. The remaining steel alloys must in turn be eliminated due to their ferrous nature which causes magnetic interference in sensitive instruments such as gyroscopes. Finally, titanium alloys are expensive, can be difficult to work with and traditionally do not cast well. Beryllium copper alloys on the other hand are much easier to work with, featuring very good machinability and weldability and excellent castability, which makes them the easy choice for these types of applications.

5 Conclusion

The aforementioned applications of beryllium copper alloys are only a few of the possible applications. This is a material which is non-magnetic, yet has a strength approaching that of tool steels. It possesses excellent fluidity, facilitating delicate and precise castings, it has a low coefficient of thermal expansion and is stable across a broad range of temperatures. All of these are properties that are required for aerospace applications.

The aerospace industry is one of maximizing efficiency. Margins are low, and small differences in part design can lead to significant lifetime costs or savings. Upfront added manufacturing costs, such as adding wear surfaces or substituting more expensive materials with better properties can result in real and significant cost per ASM reductions, which add up quickly over the lifespan of the aircraft. Likewise, in order to meet the stringent packaging requirements necessitated by fuel efficient aerodynamic designs, high strength at low volumes are crucial in certain applications. Beryllium copper alloys have demonstrated their ability to fulfill these demanding requirements.

References

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