

AN ECONOMIC EVALUATION OF ALUMINUM-BASED WEIGHT REDUCTION IN CURRENT AND FUTURE GENERATIONS OF PASSENGER CARS

EKONOMSKA EVALVACIJA PRIHRANKA NA TEŽI V AVTOMOBILIH S POUJARJENO VSEBNOSTJO ALUMINIJA

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Prejem rokopisa - received: 1999-08-31; sprejem za objavo - accepted for publication: 1999-11-02

In this work an economic evaluation of aluminum-based replacement of steel in aluminum intensive vehicles has been performed.

Key words: aluminum, vehicles, passenger cars, economic evaluation

Delo skuša odgovoriti na vprašanje, ali je avtomobil s poudarjeno vsebnostjo aluminija lahko konkurenčen jeklenemu, in kdaj.
Ključne besede: aluminij, osebni avtomobili, ekonomska evalvacija

1 INTRODUCTION

The use of aluminum in passenger cars has rapidly increased in the last 20 years. Since 1991, the use of automotive aluminum has doubled and it is expected to double again by 2005. However, it is very important to emphasize that today's vehicles are not at all aluminum intensive, consisting of, on average, 6% of aluminum alloys and, according to current predictions, vehicle producers in 2005 will still use 50% of steel as the main constituent in cars.

At a first glance, one could suggest that some very influential protagonists of aluminum just like to play games with percentages. In this respect, let me show here in numbers why aluminum will be the great winner in the car industry.

Current expectations are that the average European consumption of aluminum in cars in 2005 will be between 100 and 140 kg per vehicle, which is the present amount of aluminum in North American cars. Just as an illustration, today's average consumption of aluminum in European cars is around 65 kg per car. In contrast, the most intensive use of aluminum in a passenger car approximates to 295 kg, defining the present target for further material substitution.

The basis for these trends lies mainly in the expanding auto industry which, under market, ecological, safety and other pressures, has to maintain its development towards lighter and "aluminum intensive" vehicles. Weight reduction however does not necessarily mean "aluminum intensive", as was recently demonstrated by the ULSAB (Ultralight Steel Automobile Body) project.

It is well known that a 10% reduction in vehicle weight yields an approximately 5.5 % improvement in

fuel economy. From the economic point of view this clearly means that the real customer is going to pay for the weight reduction in his future vehicle no more than the amount of money saved through the improved fuel economy.

As will be demonstrated, aluminum, in comparison with steel, is the winner in this important economy contest.

Moreover, all ecological requirements are fully compatible with the increased usage of aluminum in cars. Comfort, safety and also other, non-economic concepts related to pure design and car-fashion all dictate a larger amount of aluminum in new models, opening the door for more than today's 6% share.

The correct question is why aluminum is not catching up faster and more aggressively in the automotive segment? As evident from the ULSAB, the world's leading steel makers are not (yet?) willing to accept a partnership with aluminum to reduced the weight of cars in the future. To demonstrate a light car body manufactured from steel, carmakers prepared an ultralight steel automotive body weighting 203 kg, about 36% less than nine midsize sedans.

The new steel initiative, Ultralight Steel Auto Body - Advanced Vehicle Concepts (ULSAB-AVC) has begun to move beyond the body-in-white to closures, suspensions, and other parts, in an effort to develop a 900 kg steel vehicle, equivalent in terms of driving and other technical performance characteristics to the 900 kg aluminum intensive cars.

The direct answer to this and other similar initiatives came immediately from the representatives of the Aluminum Association in Washington, DC.

2 ECONOMIC ANALYSIS

Contrary to what the steel industry is claiming, Mr. J. Stephen Larkin, President of the Aluminum Association, recently said that it is documented that 1 kg of aluminum, replacing 2 kg of steel to lighten a vehicle, can save 20 pounds of CO₂ over the lifetime of that vehicle. Mr. Larkin also pointed out that the auto industry is the aluminum industry's fastest growing customer. In terms of vehicle safety, pound for pound aluminum absorbs nearly twice as much crash energy as steel. With respect to recycling, in 1999 recycled aluminum made up over 60% of the total aluminum used in vehicles and these positive trends are expected to continue in the future. Moreover, nearly 90% of automotive aluminum is currently recovered and recycled.

However, all of the above superlatives can not change the fact that in today's cars, the mass ratio between aluminum and steel is 1:10 and almost the same ratio is proposed for the year 2005.

So, how do we explain the optimism of Mr. Larkin when he insists: "No matter how complicated the steel industry tries to make the materials comparison, facts about aluminum don't change"?

First of all, aluminum is roughly four to five times more expensive than steel and about three times lighter. Many of its property-to-density ratios such as the specific strength offer the potential for weight savings when replacing steel in vehicles. However, several barriers inhibit the widespread introduction of aluminum in high production volume automobiles. The major one is the high material cost. Another technical barrier is, for example, the lower modulus of elasticity of aluminum (1/3 that of steel).

Let us consider a 1100 kg passenger car, with an average fuel consumption of 9 liters per 100 km and a typical lifetime of about 5 years, driven 150 000 km.

The main question is: what mass of aluminum can completely replace the mix of properties provided by 1 kg of steel or, in another words, what mass of aluminum represents the mechanical equivalent of 1 kilogram of steel?

The answer to this basic question is, unfortunately, different for different automotive applications. Moreover, it also depends on the real design and concept of the automotive components.

Let suppose that the cross section of the component made in an aluminum alloy shall be at least 50% higher than in the equivalent made from steel. Further suppose that the length of the components will be the same. Now, by applying the above ratio to all components in an aluminum intensive vehicle with 295 kg of aluminum alloys, one can calculate that this amount of aluminum will replace 575 kg of steel, making the vehicle lighter by 280 kg. This also means that, generally speaking, one kilogram of aluminum can replace two kilograms of steel.

Consider that the price of aluminum alloy is 1.4 USD/kg. The aluminum casting cost is typically twice as high as the cost of the aluminum material used to produce the casting, which means that the cost of casting will be around 2.1 USD/kg. Assuming a medium level of machining of the final part, which again doubles its price, one can calculate the final cost of an automotive component made in aluminum. The total cost (without profit) will be 7 USD/kg. The same cost for the equivalent component made in steel will be about 1.5 USD/kg. Here, we consider the price for steel to be about 0.3 USD/kg and use the same method of pricing for casting and machining of automotive parts made in steel. Finally, let us say that the average price for fuel in Europe is about 0.8 USD/l. In this way, reducing the weight of a vehicle by 280kg (which represents 25% of the total weight of a steel intensive vehicle) costs 1202 USD or, expressed in the equivalent value of fuel: 1503 l.

In other words, a vehicle weight saving of 25% results in a 13.75% improvement in fuel economy or, equivalently, 1.24 l less fuel consumption per 100 km. In this way, after 121 000 km, which is 80% of the estimated lifetime of our vehicle, the car made in aluminum will become more cost effective than its equivalent made of steel.

However, the numbers become even better when we take into account the near 90% level of recycling of automotive aluminum. The price of raw material for recycling is about 80% of the full price for the new aluminum alloy. This means that the real price of automotive aluminum for the buyer of a new car will be just 20% of the regular market price. In this way, the price of an automotive component, made in aluminum, will drop to 5.88 USD/kg. The same lightening of the vehicle by 280 kg now costs just 872 USD or, expressed in the value of fuel: 1090 liters. In order to be competitive with the equivalent vehicle made from steel, this aluminum intensive car should now reach just 86 000 km, which is 58% of its estimated lifetime.

Suppose now that our vehicle has only 140 kg of aluminum, which is the highest predicted level of aluminum in European cars for the year 2005. Under the same circumstances proposed earlier, this amount of aluminum can replace 273 kg of steel resulting in a weight reduction of the vehicle by 133 kg (12% of the total weight). Supposing the same level of recycled automotive aluminum in the year 2005, one can calculate that the cost of this weight reduction will be 414 USD or 517 l of gasoline. Following the same procedure as before, one can determine that the weight reduction of the vehicle by 12% results in a 6.6% improvement in fuel economy or, equivalently, 0.6 liters less fuel consumption per 100 km. In this way, a car with 140 kg of aluminum will be competitive in price with its equivalent in steel after reaching 86 000 km (which is again 58% its estimated lifetime).

Generally, one can show, using simple mathematics, that every kg of aluminum in a car will become more competitive than steel after reaching 86 000 km.

Supposing that x is the mass of aluminum, the mass of steel replaced becomes $1.95x$. In this way, the weight saving for each car will be $0.95x$, or as a percentage, $0.08636x$. The decrease of fuel consumption (in accordance with the rule that a 10% lighter vehicle consumes 5.5% less fuel) is then $0.0475x\%$. Finally, the cost of "lightening" is $2.955x$ in USD, or, in liters of fuel $3.69375x$. The saving in fuel caused by the improved fuel economy is $0.004275x$, in liters per 100km. Dividing $3.6937x$ by $0.004275x$ and multiplying by 100, one can calculate the number of kilometers to be driven before the investment in x kg of aluminum will be recovered. The result is 86 000 km. Of course, this constant value is determined by the input parameters used in the model. Besides all the estimated costs and the percentage of recycled aluminum, the proposed replacement ratio stating that one kilogram of aluminum

is capable of replacing two kilograms of steel is especially important. By improving this ratio in the future through the use of "super aluminum", the aluminum-based lightening of vehicles will become more competitive. In accordance with the results obtained, recovery of an investment in vehicle weight reduction is not influenced at all by the level of "lightening". In contrast, the total improvement in fuel economy is strongly influenced by the mass of aluminum used in the vehicle. In the present model, as a result of reducing the weight of the vehicle, the total saving in fuel consumption, after recovery of investment, will be $2.736x$, in liters of fuel, or $2.1888x$ in USD.

3 CONCLUSION

In conclusion, any weight reduction of a vehicle by aluminum-based replacement of steel, as proposed in the model, will result in better economy for the customer.

There is no better news than this for aluminum!