UDK 62-59:669.018:669.71:621.73.043
Strokovni članek

ISSN 1580-2949
MTAEC 9, 36(6)421(2002)

ZAVORNI KOLUTI IZ Al-KOMPOZITOV

A BRAKE DISC IN Al-BASED COMPOSITE

Varužan M. Kevorkijan[1], Vuk Dragojevič[2], Tomaž Smolar[2], Davorin Lenarčič[3]

[1]Zasebni raziskovalec, Betnavska c. 6, 2000 Maribor, Slovenija
[2]Impol d.d., Partizanska 38, 2310 Slovenska Bistrica, Slovenija
[3]LP Mycron d.o.o., Puhova ul. 7, 2250 Ptuj, Slovenija
varuzan.kevorkijan@amis.net

Prejem rokopisa - received: 2001-11-07; sprejem za objavo - accepted for publication: 2001-11-30

V delu sta opisani vroče utopno kovanje in strojna obdelava zavornih kolutov iz komercialnega Al kompozita, diskontinuirano ojačanega s keramičnimi delci (Al MMC). Predstavljena je tudi ekonomska analiza, ki razkriva, da je zavorni kolut izdelan iz Al MMC lahko konkurenčen litoželeznemu.

Ključne besede: zavorni kolut, vroče utopno kovanje, strojna obdelava, ekonomska analiza

Closed-die hot forging and machining of brake discs made from commercial Al-matrix ceramic composite is described. An economic analysis of the feasibility of mass production of a fully machined hot forged Al MMC brake disc demonstrated that it could be competitive with its counterpart made from gray cast iron.

Key words: brake disc, hot forging, machining, economic feasibility

1 INTRODUCTION

Driven by the desire to reduce vehicle weight and improve fuel efficiency, the car industry has dramatically increased the use of aluminum in passenger vehicles in recent years.[1]

One area that is being examined for potential weight reduction is the brake system. The brake systems currently in use are fairly heavy and are typically made of cast and cast gray iron.

In recent years, producers have started to develop lighter and more advanced discs and drums for passenger cars. Cast aluminum and aluminum-based metal-matrix composite (MMC) discs and drums, as well as aluminum-alloy discs with aluminum-composite cladding have been reported.[2] The weight reduction can be as much as 45-60 %.[2] However, the high cost of Al MMCs relative to conventional aluminum alloys[3] has prevented widespread industrial applications. Moreover, because MMCs do not readily amend themselves to near-net-shape fabrication, the materials require extensive and, to date, costly machining[4] for the complex geometries required for automotive applications.

Machining MMC brake discs with diamond tooling has shown considerable promise[5], but more work is needed to optimize the procedure and disseminate the data to various machining plants and end-users.

In a previous report, forging trials demonstrated that on an industrial scale commercial Al MMCs could be hot forged as practiced for non-reinforced aluminum alloys, introducing some necessary adaptations only in the cutting and trimming operation.[6] Hence, the purpose of the current study was to investigate the economics of machining of hot forged Al MMC brake discs and to determine if, and under what conditions, Al MMC brake discs can be an economical alternative to the existing products made in gray cast iron.

2 EXPERIMENTAL PROCEDURES

A cast billet, 200 mm in diameter (Al composite F3S.20S; producer DURALCAN) was cut with a 550 mm diameter saw blade, tipped with polycrystalline diamond teeth. The PCD saw blade, requiring no lubricant, cut through the billet in one pass. At a cutting speed of 1-3 rev/s, the cut was completed in 25 s. The width of cut was 3 mm, corresponding to an amount of turnings of 1.5%.

The cut bars were heated at 500±10 °C for 2 h prior to forging. The temperature of the forging die was maintained at an average of 325±20 °C. The process of forging was performed on a 1000 t screw press with three consecutive hits at a deformation rate of $3s^{-1}$. Non-trimmed forgings typically had a flash consisting of 3% of the forged bar material.

Forgings were hot trimmed using a 60 t mechanical press and blades made from high-alloy steel hardened to 58 to 60 HRC. Hot trimming was accomplished in conjunction with the hot-forging process at a flash temperature of around 350-400 °C.

Forgings were machined on a vertical CNC lathe (Mori SEIKI VL-25) using a 25 µm grade polycrystalline diamond-cutting tool (GE COMPAX 1500). All machining was done under a flood of 8 % water-soluble oil. Cutting tolerances were selected to be ± 0. 015 mm. Typical machining parameters for cutting were as follows: cutting speed 7 m/s, feed rate 0.3 mm/rev and depth of cut 2.5mm. Drilling was executed at a drilling speed of 0,8 m/s and a feed rate of 0.05 mm/rev. The roughness of the machined surface was 1.5 to 2.5 µm.

Machined brake discs were finally solution annealed (2±0.5 h at 535±5 °C) and subsequently artificially aged (8±0.5 h at 175±5 °C).

3 RESULTS AND DISCUSSION

In the forging trial performed, an Al MMC brake disc was prepared by closed-die hot forging, **Figure 1**.

The measured loss of material during cutting of the extruded rods was about 2%.

Non-trimmed forgings typically had a flash consisting of a maximum of 20% of the forged Al MMC bar.

All forged brake discs were dimensionally inspected; the findings confirmed that the tolerances specified in DIN 1749 were achieved. No problems arose which could prevent the transformation of Al MMC bars by means of the forging process itself.

No failures in the microstructure of the forged Al MMC bars were observed, **Figure 2**.

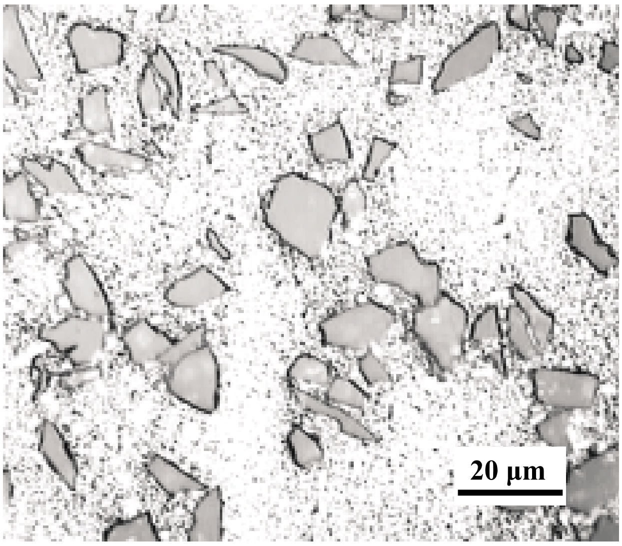

Figure 2: Microstructure of hot forged Al MMC
Slika 2: Mikrostruktura odkovka iz Al MMC

Forging and trimming die-life could not be verified due to the limited number of forged and trimmed pieces. However, since the forging behaviour of the Al MMC material was very similar to that of non-reinforced aluminum alloys, one can also propose a similar productivity.

The only necessary difference was introduced in cutting and trimming procedures. In cutting, saws using blades with PCD-tipped teeth were necessary. In trimming, instead of cold trimming, hot trimming with additionally hardened and hardfaced trimming blades must be applied.

On that account, the cost of producing an AlMMC brake disc (involving the cost of cutting, hot forging, trimming and heat treatment) was calculated to be only 25% higher in comparison with the typical cost of producing a non-reinforced aluminum forging.

However, the cost of the material is significantly higher. Currently, the cost of Duralcan's F3S.20S MMC product is approximately 5.50 USD to 6.50 USD per kg, depending on the quantity of material purchased. In any case, this is more than three times higher than the cost of a non-reinforced matrix. Because in cost-sensitive industries such as automotive industry such an expensive material cannot be used, a significantly lower cost (2.4 USD/kg) of Al MMC was proposed in our study. This estimate is based on the recently reported economy of a new rapid mixing process and the lower-cost of ceramic reinforcement.[7]

The machining trials performed demonstrated that Al MMC brake discs are routinely machinable using conventional machining centers and PCD cutting tools, **Figure 3**.

Figure 1: Hot forged Al MMC brake disc
Slika 1: Zavorni disk iz Al MMC po utopnem kovanju

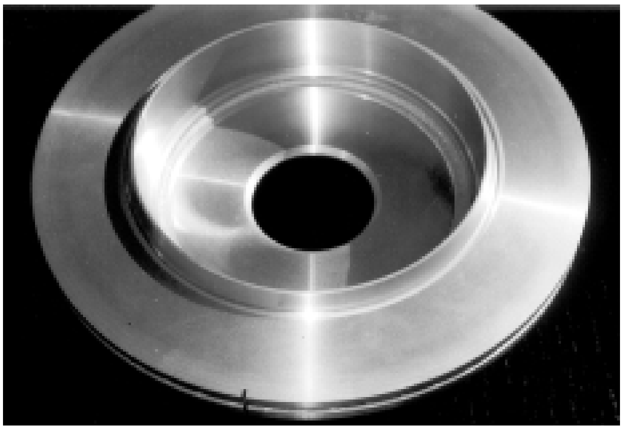

Figure 3: Fully machined Al MMC brake disc
Slika 3: Strojno obdelan zavorni disk iz Al MMC

However, establishing the optimum process parameters of speed, feed, and depth of cut is crucial for obtaining the required surface quality, prolonging tool lifetime and achieving high machining productivity.

In this study, a 25 µm grade of polycrystalline diamond was used at 5-10 m/s, 0.3-0.4 mm/rev, and up to 2.5 mm depth-of-cut. The tools were very durable, even during interrupted cuts, and typically removed over 10^{-2} m^3 of forged stock before being changed (at a maximum of 0.38 mm flank wear).

The typical roughness of the machined surface was 1.5 to 2.5 µm.

The machining cost data reported here is an estimate for the PCD inserts consumed. It does not represent a statistically valid sample size, and it does not include any estimate of capital, overhead, labour, or other associated costs that vary significantly from facility to facility. However, the relatively low cost of consumable tooling (less than 3.3 USD/brake disc) in this preliminary study indicates that machining with PCD inserts in mass production would be a cost-effective operation. Moreover, further advances in tool materials (e.g. use of Chemical Vapour Deposition Diamond-CVDD) will additionally improve their cost. For example, no longer does the CVDD crystal need to be brazed on the tip of the carbide substrate. Rather, techniques have been developed where a thicker crystal is directly deposited on the insert to cover the entire substrate,[4] thereby giving a much stronger overall tool with multiple edges. This alone will lower the cost of tooling by a multiple of the number of edges. In addition, the initial purchase price of these tools is almost half of what a typical PCD tool costs.

Any consideration of the large-scale production and usage of Al MMC brake discs demands that the issues of recycling of the fabricating scrap (and old scrap) be also addressed.[8] Due to the fact that during trimming and machining scrap generation reaches 40% of the weight of the final component, recycling significantly influences the cost of the product. We estimated in the current study that Al MMC scrap can be resold to the supplier of Al MMC billets at 80% of the price of new material.

Typical cost breakdowns of a hot forged and machined Al MMC brake disc is presented in **Table 1**. In contrast with the gray cast iron brake disc[9], the cost of the input Al MMC material constitutes a much higher percentage of the final cost. Moreover, the cost due to machining is also a significant contribution to the final part cost.

As evident from **Table 1**, machined Al MMC brake disc costs currently are typically twice as high as the cost of the Al MMC billet used to forge the component. In future, when the rapid mixing process[7] or similar cost-effective producing routes will be combined with the complete recycling of internal, new (fabricator) and old Al MMC scrap, the contribution of the input material will become lower. The cost of machining will be also reduced due to new coatings and tooling materials introduced on the market. For example, current CVDD inserts[4] are at least half or less expensive than the PCD inserts used in this study.

The proposed aluminum-based automobile brake system used about 16 kg of Al MMC, so the current cost of a single fully machined brake disc is about 53 USD, which is not competitive with the cost of the existing gray cast iron brake disc (36 USD[10]).

However, by assuming reduced costs of Al MMC and machining in the future, the cost of the same component could drop to just 25 USD and become more competitive than the current gray cast iron brake disc.

Another significant material cost reduction can be achieved by changing the design of the brake disc from a homogeneous one to the alternative aluminum-alloy disc with aluminum-composite cladding on the friction surface. Taking into account the predicted cost of the Al MMC billets (2.4 USD/kg) one can calculate that the cost of such a brake disc would be just slightly higher (2-5%) than the cost of the components made from the non-reinforced aluminum alloy.

4 CONCLUSION

Conventional hot forging and machining with polycrystalline diamond (PCD), which is a compact/ brazed product, was found to be a manufacturing approach to the Al MMC brake disc with great inherent simplicity.

Table 1: Cost breakdowns of the hot forged and machined Al MMC brake disc with an annual production volume of three million parts
Tabela 1: Struktura cene vroče kovanega in strojno obdelanega zavornega koluta, izdelanega iz Al-kompozita, diskontinuirano ojačanega s keramičnimi delci, za obseg proizvodnje 3 milijone kosov/leto

Cost element	Current contribution to the total cost		Contribution to the total cost estimated for the future	
	in %	in USD	in %	in USD
Material*	50	26.40	40*	9.60
Forming	15	7.92	33	7.92
Machining	35	18.48	27	6.48
Total		52.80		24.00

*Reduced for the value of scrap accumulated.

Al MMC brake discs were successfully closed-die hot forged as practiced for aluminum alloys, introducing some necessary adaptations only in the cutting and trimming operation.

Machining with PCD inserts was performed routinely, using a conventional machining shop.

The economic feasibility study of the mass production of fully machined hot forged Al MMC brake disc demonstrated that it could become more competitive than its counterpart made form gray cast iron, if the cost of an Al MMC billet drops from the current 6.4 USD/kg to the predicted 2.4 USD/kg.

5 REFERENCES

[1] V. Kevorkijan, Kovine zlitine tehnologije, 33 (**1999**) 6, 413.

[2] X. Huang, K. Paxton, JOM, 50 (**1998**) 8, 26.

[3] V. Kevorkijan, Adv. Mater. Process., 155 (**1999**) 5, 27.

[4] M. Gugger, J. Adv. Mater., 33 (**2001**) 1, 7.

[5] C. Lane, M. Lenox: Economics of Machining Cast MMC Brake Rotors, Proc. Of the 2nd Inter. Conf. On Cast Metal Matrix Composites, Tuscaloosa, 1993, 253-262.

[6] V. Kevorkijan, Mater. tehnol., 34 (**2000**) 5, 219.

[7] D. R. Herling, G. J. Grant, W. Hunt, Adv. Mater. Process., 159 (**2001**) 7, 37.

[8] V. Gergely, H. P. Degischer, T. W. Clyne, Comprehensive composite materials, Vol. 3, Metal matrix composites, 1st ed., Elsevier, Amsterdam 2000, p. 797.

[9] V. Kevorkijan, Am. Ceram. Soc. Bull., 77 (**1998**) 12, 53.

[10] J. E. Allison, G. S. Cole, JOM, 45 (**1993**) 1, 19.