

MACHINING OF A DROP FORGED BRAKE DISC IN AI BASED COMPOSITE - THE FEASIBILITY OF MASS PRODUCTION

EKONOMIČNOST KOVANJA I MAŠINSKE OBRADJE ROTORA AUTOMOBILSKE KOČNICE IZRADJENOG IZ AI KOMPOZITA

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ABSTRACT

Drop forging and machining of brake discs made from commercial Al-matrix ceramic composite was performed. An economic analysis of the feasibility of current customer design and future mass production of a drop forged Al MMC brake disc, fully machined using PC under wet and CVD diamond inserts under dry cutting conditions, demonstrated that the major cost barriers in producing Al MMC brake discs are the cost of the composite material and the cost of forging. The investigation also confirmed that the current cost of PCD and CVDD inserts consumed per machined disc does not exceed 10% of the cost of the composite material. Experiments showed that the stage of machining consuming most inserts (about 80%) is rough cutting.

The relatively low cost of tooling inserts (less than 3 USD/disc in this preliminary study and less than 1.50 USD/disc estimated for future mass production) indicates that machining with PCD and CVDD in both cases represents a cost-effective operation.

Key words: brake disc, hot forging, machining with PCD and CVDD inserts, economic feasibility

IZVOD

U radu je opisana izrada i mašinska obrada rotora automobilske kočnice. Rotor je izradjen pomoću klasičnog toplog kalupnog kovanja dok su za mašinsku obradu upotrebljeni posebni alati iz polikristalnog dijamanta (PC) –za mokru ili dijamantnog filma nanešenog hemijskom depozicijom (CVD)-za mašinsku obradu na suvo. Ekonomska analiza pojedinačnih faza proizvodnje je pokazala da bi najskuplji elementi buduće masovne proizvodnje bili kompozitni materijal i kovanje. Bez obzira na

upotrebu posebnih dijamantskih alata, ocenjeni troškovi mašinske obrade ne premašuju 10% cene kompozitnog materijala. Eksperimenti ukazuju da je trošenje dijamantskih alata najizraženije (do 80%) u fazi grube mašinske obrade otkivaka, što bi se moglo izvesti jeftinijim karbidnim alatima.

Relativno malo trošenje dijamantskih noževa (manje od 3 USD/rotor u ovoj preliminarnoj studiji i manje od 1,5 USD/rotor kako je ocenjeno za buduću masovnu proizvodnju) ukazuje, da bi mašinska obrada rotora automobilske kočnice iz Al kompozita mogla da bude cenovno ugodna za obe vrste upotrebljenih dijamantskih alata.

Ključne reči: rotor automobilske kočnice, toplo kovanje u kalupu, mašinska obrada sa PCD i CVDD alatima, ekonomska analiza

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 iron 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.

In contrast with the general opinion that to be cost-competitive with cast iron, Al MMC brake discs must be manufactured using a cost-effective casting approach [4], a recent forging trial performed at semi-industrial level demonstrated that commercial Al MMC brake discs could be drop forged as practiced for non-reinforced aluminum alloys, introducing some necessary adaptations only in the cutting and trimming operation [5]. Because drop forged MMCs do not lend themselves to near-net-shape fabrication, the materials require extensive machining [4] of the trimmed components to obtain the final functional shape of the brake disc. This in addition generates significant quantities (20-25%) of fabricator scrap, which has to be recycled in order to keep the overall production cost competitive.

On the other hand, although conventional casting techniques are able to produce composite castings with an acceptable quality level and are the most practiced fabrication route for the current production of Al MMC brake discs, several changes need to be made to metal melting and handling systems, as well as to gating system design and mold yield. Conventional filling and gating

systems have to be adapted when going from the usual foundry alloys to Al MMCs. In addition to this, the filling system has to be adjusted to avoid any macroscopic turbulence in the molten composite flow. If such precautions are not taken, most of the air bubbles trapped in the liquid composite entering the part will remain captured by the ceramic particulates and will result in large porosity [6]. Another serious problem is segregation or inhomogeneous distribution of ceramic particulate reinforcement occurring during solidification, which is caused by the density difference between the aluminum and ceramic phases [2].

A forged Al MMC disc has superior mechanical properties, a homogeneous microstructure and surface, and can be finished by low cost finishing operations such as grinding, pickling or sand blasting and is also well suited to the usual coating processes. Drop forging also offers cost advantages for tools. Whereas castings in general depend on relatively complex and costly tools, the cavities of forge dies can be made comparatively quickly and cost-effectively, particularly for small series in which the costly casting moulds cannot be amortized by virtue of the batch size.

Machining MMC brake discs with diamond tooling has shown considerable promise [7], though more work is needed to optimize the procedure and disseminate the data to various machining plants and end-users. Polycrystalline diamond (PCD) coatings for inserts became standard for machining Al MMCs [8]. However, one of the issues with PCDs is the cost. One edge of PCD is at or above the one hundred dollar range in the current market. Even if the cost of PCD inserts would be reduced to half the current price to reflect the volume purchasing discounts of an automotive segment, the machining of an Al MMC brake disc remains more expensive than the machining of its gray cast iron counterpart. As an example, some previous studies indicated that the total cost of PCD inserts per brake disc in mass production would be about 1.3 USD [7].

One class of tool material that has shown promise in machining of Al MMCs is CVDD (Chemical Vapor Deposition Diamond) [8]. Past studies generally indicated PCD as the better choice because CVDD inserts often failed catastrophically due to the failure of braze holding the CVDD to the tungsten carbide substrate [8].

Recently, novel techniques have been developed to create a CVDD insert that gives a number of significant advantages [8]. 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, 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 [8].

Hence, the purpose of the current study was to investigate the economics of machining of drop forged Al MMC brake discs by using commercially available PCD and CVDD inserts and to determine under what conditions machining of Al MMC brake discs becomes cost-effective.

2 EXPERIMENTAL PROCEDURES

A cast billet, 200 mm in diameter (Al composite F3S.20S; producer DURALCAN) was cut with a 375 mm diameter saw blade, tipped with 54 polycrystalline diamond teeth (supplier: KINK Company, Taipei, Taiwan). 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 4 mm.

The cut bars were heated at $500\pm 10^\circ\text{C}$ for 2 h prior to forging. The temperature of the forging die was maintained at an average of $325\pm 20^\circ\text{C}$. 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 $350\text{-}400^\circ\text{C}$.

Forgings were machined on a vertical CNC lathe (Mori SEIKI VL-25) using SPG-422T square CVDD coated insert for rough cuts and TPG-322T CVDD coated inserts for the finish cut. Both types of insert (supplier: sp^3 , Inc., Mountain View, CA, USA) were with complete CVDD coverage on one side providing four cutting edges. All machining was made dry. Typical machining parameters for rough cutting were as follows: cutting speed 7.7 m/s, feed rate 0.5 mm/rev and depth of cut (DOC) 2.5mm. The cutting parameters for finish cutting were: cutting speed 7.7 m/s, feed rate 0.125 mm/rev and depth of cut 1.3 mm. The run size of 24 ventilated brake discs were fully machined with CVDD inserts.

In a separate set of machining tests, PCD inserts (CPG-422; supplier: Gilmore Diamond Tools, Inc., E. Providence, RI, USA) were used in order to compare the cost of both machining routes. For rough cutting, the machining parameters were: cutting speed 4.5 m/s, feed rate 0.3 mm/rev and depth of cut 2.5 mm. The finish cut was performed at a cutting speed of 6.7 m/s, a feed rate of 0.15 mm/rev and a depth of cut of 1.3 mm. All machining with PCD inserts was done under a flood of 8% water-soluble oil. The total number of fully machined ventilated brake discs using PCD inserts was 12.

In order to estimate the insert cost per brake disc machined, it was assumed that the PCD insert should be changed at a maximum of 0.35 mm flank wear while CVDD inserts should be replaced when flank wear exceeds 0.20 mm. The

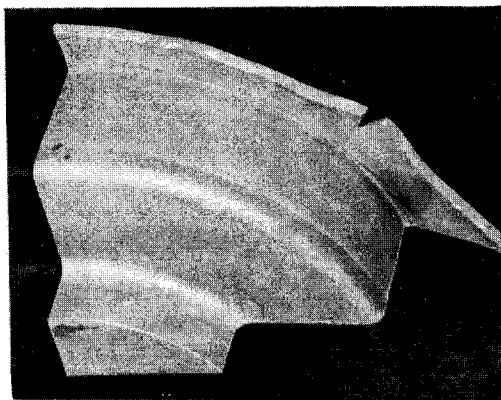
flank wear of the inserts was determined by optical microscopy after each cutting trial. The volume of the material removed was calculated from the mass of chips collected during the machining trials.

Machined brake discs were finally solution annealed (2 ± 0.5 h at $535\pm 5^\circ\text{C}$) and subsequently artificially aged (8 ± 0.5 h at $175\pm 5^\circ\text{C}$).

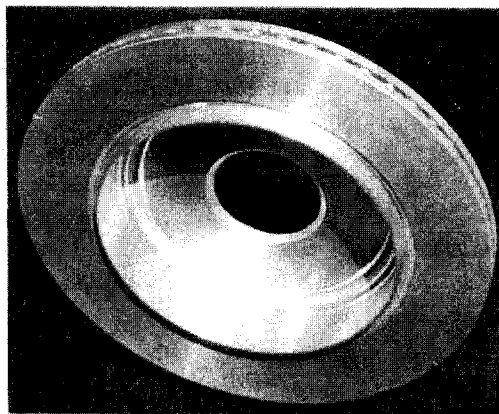
3 RESULTS AND DISCUSSION

In the forging trial performed, Al MMC brake discs were prepared by drop forging, Fig. 1.

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



*Figure 1 - Hot forged Al
MMC brake disc
Slika 1 Toplo kalupno
otkovan rotor
automobilske kočnice iz
Al kompozita.*



*Figure 3 - Fully
machined Al MMC
brake disc
Slika 3 - Mašinsko
obradjen rotor*

