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High-speed laser melt injection for wear protection of skin-pass rolls

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Abstract

Laser melt injection (LMI) is a technology for producing metal matrix composite (MMC) layers on tools such as skin-pass rolls by injecting hard particles into a laser-induced weld pool. However, low process speeds prevent the application of laser melt injection on a large scale. To overcome this drawback, a new approach is presented: High-speed laser melt injection (HSLMI) is a promising method for generating highly wear-resistant MMC-layers on tools with high productivity.

For the first time, high process speeds of up to 100 m/min were reached with HSLMI of spherical fused tungsten carbide (SFTC) particles into the steel 1.2362 that is used for skin-pass rolls. It was found that both the crack susceptibility and the SFTC dissolution can be reduced significantly by increasing the process speed.

The wear behavior of the MMC layers was studied in a pin-on-plate test. It was found that the SFTC reinforcement leads to a significant improvement in wear resistance over the non-reinforced steel substrate. The wear volume was reduced from 3.6 mm³ to 0.1 mm³ to 0.3 mm³ by an SFTC particle-reinforcement.

Keywords: laser melt injection, metal matrix composite, wear protection

1 Introduction

Skin-pass rolling is the last process in a rolling line. In this process, the final sheet thickness and the surface properties are set. For improving the formability and the paint adhesion of rolled sheets, specific textures are formed into the sheets by textured skin-pass rolls [1]. Until now, there are at least six different technologies for texturing skin-pass rolls that can be divided into stochastic and deterministic technologies according to the resulting texture. Stochastic textures can be generated by shot blast texturing, electro discharge texturing and precision texturing [2]. Shot blast texturing and electro discharge texturing roughen the roll surface. In precision texturing, a chromium-based coating with spherical nubs is applied. Deterministic textures can be generated by laser texturing or electron beam texturing. With these technologies, usually, small craters are created by local melting of the roll surface. Another way of laser texturing is the generation of implants with titanium diboride [3]. Each implant is generated by laser melt injection (LMI) using titanium diboride powder with an average powder diameter of 4 µm as hard material. This two-step process consists of pre-depositing the titanium diboride powder with an organic binder and the laser-induced implantation. However, the deterministic generation of implants with LMI is a time-consuming process.

Therefore, high-speed laser melt injection (HSLMI) for generating near-net shape metal matrix composite (MMC) layers on rolls with high productivity has been developed. In this one-step process, wear-resistant MMC layers featuring a stochastic texture can be generated. Spherical fused tungsten carbide (SFTC) particles are injected into a 1.2362 substrate. In previous research, it was shown that an SFTC reinforcement reduces the wear of copper pistons by 69 % to 75 % [4]. Fig. 1 shows a schematic diagram of HSLMI. Experiments showed that a high SFTC particle velocity, which can be adjusted via the volume flow rate of the

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powder feeding gas, is a key factor for enabling high process speeds. For HSLMI, laser powers of up to 10 kW and a volume flow rate of the powder feeding gas of 15 l/min are used.

2 Methods

Characteristics of the MMC layer such as the layer thickness, the SFTC particle content and defects such as the porosity and the cumulated crack length were investigated as a function of the process speed. For this, a series of LMI experiments was carried out with a constant laser power of 6.7 kW and a constant powder feed rate of 90 g/min. The only varied parameter was the process speed. The MMC layer thickness, the SFTC particle content, the porosity and the cumulated crack length were measured on light microscope images of cross sections of the MMC layers. The cumulated crack length is the sum of all individual crack lengths within a region of interest (ROI) of 2 mm². Only cracks within the 1.2362 matrix were considered. For determining the wear resistance, sliding wear tests with MMC samples featuring a cylindrical surface were carried out. Pins made of 1.3505 with a spherical cap were used as counter bodies. For each test, a test force of 30 N was applied for four hours.

3 Results and Discussion

The process speed of LMI could be increased up to 70 m/min with a laser power of 6.7 kW. For reaching higher process speeds of up to 100 m/min, the laser power needed to be increased to 10 kW. A process speed of 100 m/min corresponds to a processed area per unit time of 1000 cm²/min. With HSLMI, near-net shape MMC layers featuring a small layer thickness and a small waviness can be generated, see Fig. 2. This reduces the effort for final machining of SFTC reinforced parts significantly. Due to a high difference in hardness between the SFTC particles and the 1.2362 matrix, the final machining is challenging and expensive. The interface between the SFTC particles and the 1.2362 matrix shows a good metallurgical bonding. Only a few particle deformations were detected. Furthermore, cracks within the 1.2362 matrix were detected that also run through SFTC particles. The cracks are mainly oriented vertically to the surface of the MMC layer.

The layer thickness and the SFTC particle content depending on the process speed are shown in Fig. 3. The layer thickness decreases degressively with increasing process speed from 1 mm at a process speed of 10 m/min to 0.1 mm at a process speed of 70 m/min. The SFTC particle content scatters between 14 vol% and 30 vol% with no clear correlation to the process speed. For explaining the degressive decrease of the layer thickness, two opposite influences need to be considered. On the one hand, the energy per unit length decreases with the process speed which has a reducing effect on the layer thickness. On the other hand, the process efficiency increases with the process speed since the thermal losses are reduced which has an increasing effect on the layer thickness [5].

Another advantage of HSLMI is the significant reduction of the cumulated crack length and the porosity. At high process speeds, a low energy per unit length leads to a reduction of the heat input and accordingly to temperature-related defects. Cracks and pores were detected at all investigated process speeds. However, both the porosity and the cumulated crack length decrease degressively with increasing process speed, see Fig. 4. The porosity can be reduced from 6 vol% to 1 vol% and the cumulated crack length from 6 mm to

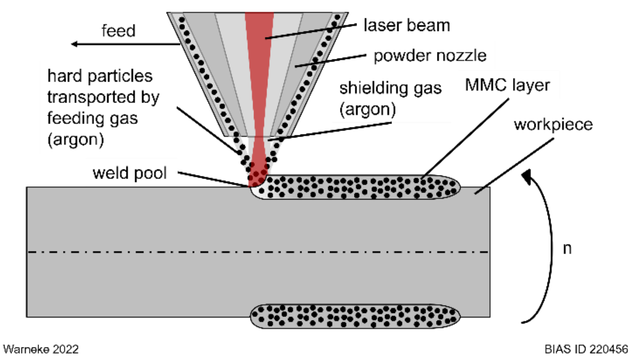

Fig. 1: Schematic diagram of HSLMI.

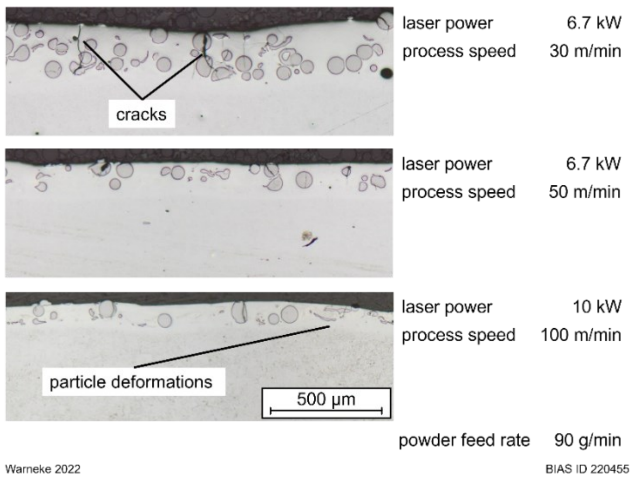

Fig. 2: Cross sections of SFTC particle reinforced 1.2362 obtained by HSLMI.

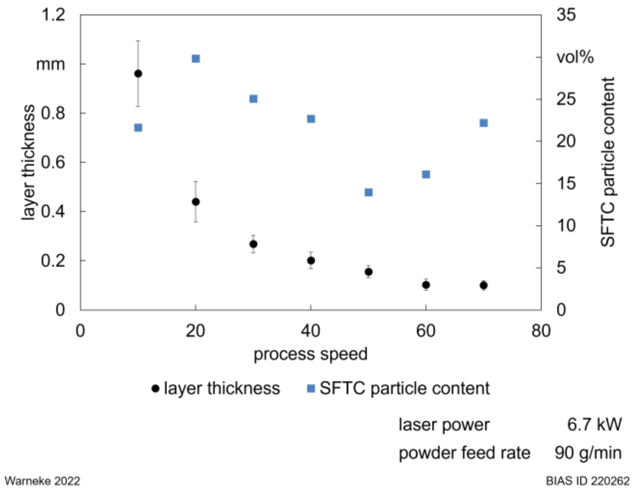

Fig. 3: MMC layer thickness and SFTC particle content as a function of the process speed.

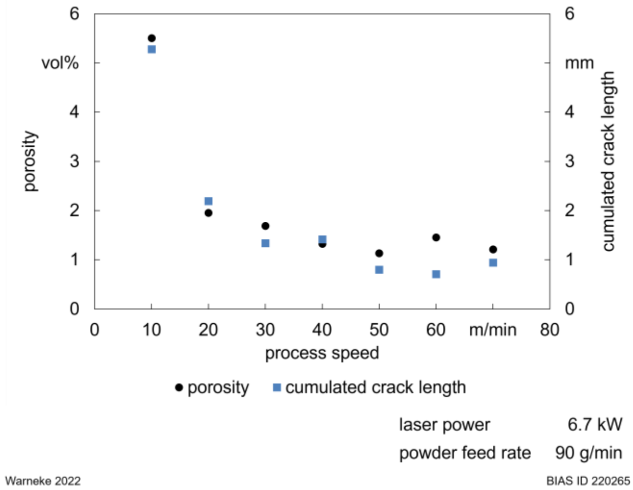

Fig. 4: Porosity and cumulated crack length as a function of the process speed.

1 mm by increasing the process speed from 10 m/min to 70 m/min. At a process speed of 10 m/min, the porosity and the cumulated crack length are significantly higher than at higher process speeds.

For determining the wear resistance of the MMC layers, sliding wear tests were carried out. Fig. 5 shows the wear volume of non-reinforced and SFTC particle reinforced samples generated at different process speeds and the wear volume of the corresponding pins. The SFTC reinforcement of the samples lead to a reduction in wear volume from 3.6 mm³ to 0.1 mm³ to 0.3 mm³. The pins wore out stronger than the samples in all four configurations.

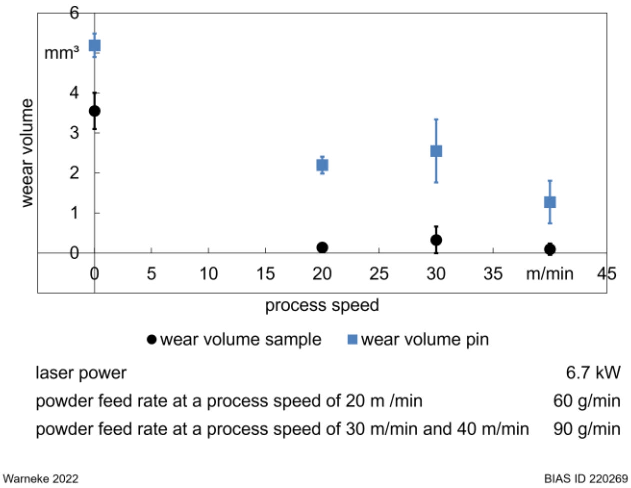

Fig. 5: Wear volume of non-reinforced 1.2362 (process speed = 0 m/min) and wear volume of SFTC reinforced 1.2362 as a function of the process speed.

4 Conclusions

HSLMI has been introduced. With HSLMI, process speeds of up to 100 m/min can be reached.

The process speed has a major influence on the MMC microstructure. The cumulated crack length and the porosity within the 1.2362 matrix decrease when increasing the process speed.

By reinforcing the steel 1.2362 with SFTC particles by HSLMI, the wear resistance is improved significantly. However, the influence of the process speed on the MMC microstructure has no decisive impact on the wear resistance.

Acknowledgements

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