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METAL POWDER PRODUCTION BY ROTATING ELECTRODE USING LASER

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Abstract. *The demand for advanced materials has continued to increase, resulting in an urgent need for high-quality metal powders. To meet this demand, various conventional powder production techniques, such as chemical, mechanical, electrolytic, and atomization processes, have been developed and extensively used to produce metallic powders. However, these techniques have limitations in producing fine powders with a spherical morphology and are not well-suited for low-volume production of specialized alloy powders for research and development. Furthermore, there has been a lack of research on equipment development for the produced powders, which limits their widespread applications. To address these issues, this study proposes the use of a laser source to produce metal powder. The rotating electrode process involves irradiating a plasma on a rotating sample of the material to be transformed into powder. In this study, a high-power continuous-wave laser is directed onto a rotating consumable metallic substrate driven by a high-speed motor. To this end, the work proposes the development of a device capable of producing metal powder integrated into a laser bench, which consists of a powder processing and collection chamber and a high-speed pneumatic motor. The laser irradiation on the rotating substrate results in surface melting and the expulsion of fine droplets, offering potential cost-effective and efficient alternatives to conventional powder production techniques. To validate powder production, experiments were conducted to atomize samples of different steels using a fiber laser with a power of 10 kW and a rotating speed of 70,000 RPM, with variations in motor speed and laser power to determine the optimal processing window. The preliminary results are presented in this study. Overall, this work showcases the potential of laser-based rotating electrode processes for producing high-quality metal powders with desirable properties. However, further research is needed to optimize the process parameters and develop suitable equipment for larger-scale production of metal powders using this method.*

Keywords: Powder, production, laser applications, electrode.

1. INTRODUCTION

Powder metallurgy processes, such as laser cladding and additive manufacturing (am), have shown great potential for industrial applications (Lawrence, 2018). These techniques offer the ability to produce intricate coatings and near-net-shaped parts with superior mechanical properties compared to traditional methods (Tuominen *et al.*, 2013).

However, the quality of the final parts heavily relies on the quality of the powder utilized. Various factors, including particle size, sphericity, and chemical composition (including purity), directly influence the microstructure of the end product (Formanoir *et al.*, 2016). Therefore, it is crucial to produce high-quality powders to ensure optimal properties in the final components.

Gas and water atomizers have been extensively developed due to their high productivity and efficiency in generating micron-sized particles (Attia and Alcock, 2011). Nevertheless, these particles may suffer from issues such as hollowness, non-uniform chemical composition, and a broad particle size distribution caused by collisions during non-solidification (Chastand *et al.*, 2018).

To address these challenges, the rotating electrode process (REP) offers several advantages. It enables a high cooling rate, minimizes segregation, and provides a narrow particle size distribution (Ravry *et al.*, 2023). Consequently, REP effectively mitigates problems associated with hollowness, non-homogeneity, and a wide particle size distribution caused by non-solidified particle collisions (Ravry *et al.*, 2022). The powders produced exhibit a spherical shape, ensuring high purity. Moreover, these particles are ejected at or near their melting temperature (Attar *et al.*, 2015).

The objective of this study is to demonstrate the feasibility of using a laser beam as a heat source instead of an electrical arc in the rotating electrode process (REP). REP is prone to electrical arc instability caused by a vortex

generated by a high-speed rotating electrode in a gas environment. Controlling the electrode-to-piece distance, which affects the arc voltage, is complex and leads to variations in deposited energy.

The implementation of a laser solution offers several advantages. It eliminates the need for electrical current to pass through the spindle, enabling higher ejection speeds and reduced particle size. This technique will allow us to identify the atomization regime and monitor the production of irregular particles, which have a negative impact on the overall yield of spherical powder.

2. MATERIALS AND METHODS

Experiments were conducted on a prototype developed at the Precision Engineering Laboratory - LMP UFSC. The schematic diagram of the prototype is presented in Figure 1. The IPG Photonics® YLS 10000 laser model was used as the energy source for the experiments.

The YLS 10000 laser is a fiber laser source (Yb-Ytterbium) with a wavelength range of 1070 nm to 1080 nm. It has a maximum nominal power of 10 kW and features multi-module output beam generation. To focus the laser beam, the welding head YW52 from Precitec® is integrated into the system.

The collimating lens in the setup has a focal length of 150 mm, while the focusing lens has a focal length of 300 mm. The focal point, or spot size, has a diameter of 800 μm at the focal region. A high-speed spindle and a carbon steel collection chamber surrounding the spindle are utilized to collect the powder.

For conducting the tests, an experimental setup equipped with a numerically controlled movement system (CNC) was utilized, which was integrated into the laser control panel. This integration enables the adjustment of input parameters using the Siemens Sinumerik 840D SL control.

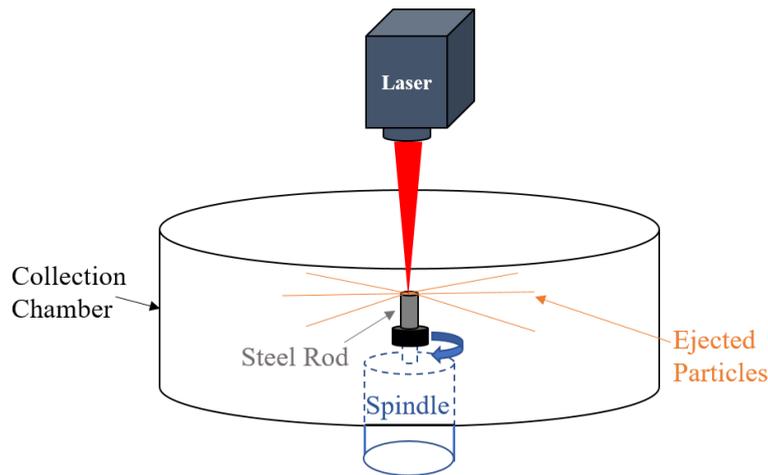


Figure 1. Schematic illustration of the REP installation using a laser beam as a heating source.

The collection chamber's internal surface is coated with a galvanized steel metal plate. This configuration enhances the collision between high-temperature ejected particles and the room temperature plate. Consequently, the atomization process and fragmentation regimes occur, resulting in the formation of metal powder.

Two sets of experiments were conducted using 12 mm diameter steel rods. The rods were rotated at the speed: 40,000 rpm. Laser powers of 2000 W and 3000 W were applied to melt the steel rods. Scanning electron microscopy (SEM) was utilized to observe the particles and assess their surface appearance and shape. Table 1 shows the motor speed and laser power parameters used.

Table 1. Experimental parameters for powder production.

Laser Power (W)	2000	3000
Spindle Speed (RPM)	40000	40000

As part of the laser scanning strategy, the head movement involved forward and backward motion along the X-axis, as illustrated in Figure 2. This strategy is beneficial for achieving uniform energy density applied to the rotating electrode, thus promoting homogeneity in the process.

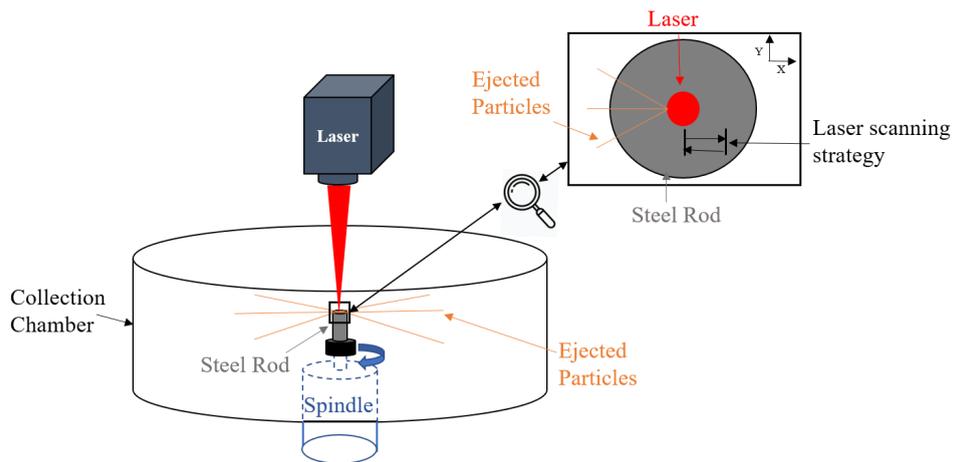


Figure 2. Laser scanning strategy.

In the production of metal powder, carbon steel rods were utilized as rotating electrodes. These shafts were specifically machined and prepared to serve as substrates for the powder production process. The rotating rod, represented in Figure 3, plays a crucial role in the atomization and fragmentation of the metal material.

For the initial phase of the experiments, a standard 1020 carbon steel alloy was utilized as the primary material. The objective of this stage was to assess the viability of producing powder using laser technology. As the project progresses, it is anticipated that a variety of engineering materials will be employed to manufacture powder using laser-based methods.

The carbon steel shafts are designed to rotate at a controlled speed, allowing for the controlled melting and ejection of molten metal particles. The high-speed rotation creates centrifugal forces that propel the molten metal outward, leading to the formation of fine metal powder particles.

The rotating rod's design and construction are crucial in achieving optimal powder production. Factors such as the shaft's diameter, surface finish, and material composition are carefully considered to ensure efficient atomization and the desired powder characteristics.

Figure 3 provides a visual representation of the rotating rod, showcasing its structure and configuration. This component is a key element in the overall process of metal powder production, enabling precise control and manipulation of the atomization process to yield high-quality metal powder.



Figure 3. Steel Rod.

3. RESULTS AND DISCUSSION

The figure 4 displays the carbon steel metal powder produced using laser energy in conjunction with the rotating rod. This metal powder is the result of a specific manufacturing process that involves the utilization of carbon steel as the primary material.

The production process entails directing laser energy onto the carbon steel rod, causing it to heat up and eventually melt. As the carbon steel melts, it transforms into tiny molten droplets that are propelled away from the rotating rod surface. These molten droplets rapidly solidify in-flight, forming fine particles of carbon steel metal powder.

The figure provides a visual representation of the resulting metal powder, showcasing its characteristics such as particle size, shape, and surface appearance. The specific properties of the carbon steel metal powder are crucial for various applications, including additive manufacturing, metallurgy, and powder metallurgy.

By employing laser energy in conjunction with the carbon steel rod, it is possible to precisely control the process parameters and optimize the quality and properties of the resulting metal powder. Figure 4 serves as a visual demonstration of the successful production of carbon steel metal powder using this particular technique.



Figure 4. The carbon steel metallic powder produced with laser.

The SEM images presented in Figure 5 showcase the steel particles under observation. The particles have been classified into two main types, primarily based on their size after undergoing a sieving process. Specifically, particles exceeding 80 μm in size exhibit irregular or flat shapes, accompanied by either a rough or smooth surface texture.

These larger steel particles display variations in their morphology, with some particles appearing irregularly shaped, while others exhibit a flatter geometry. Additionally, the surfaces of these particles can be characterized by either a rough or smooth texture, indicating differences in surface roughness or smoothness.

The SEM images provide a visual representation of these distinct particle types, allowing for a detailed examination of their size, shape, and surface characteristics. Analyzing and classifying steel particles based on their size and surface features is essential for understanding their properties and potential applications in various fields such as metallurgy, materials science, and engineering.

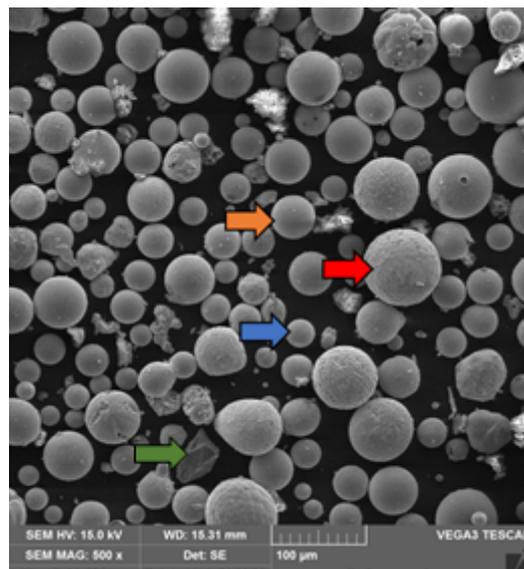


Figure 5. SEM images in electron imaging mode of atomized steel powder at 2000 W and 40,000 rpm. Red Arrow depicts a particle size larger than 80 μm , Orange Arrow depicts a particle size between 30 μm and 40 μm , Blue Arrow depicts a particle size smaller than 30 μm and Green Arrow depicts the flat particle.

On average, the flat particles represent little in relation to the total powder produced and have not been observed in large quantities in the powder produced at the chosen parameters. Within the size range of 25–80 μm , a mixture of flat and spherical particles was observed.

In a previous study that utilized a centrifugal disk atomizer in an ambient atmosphere (Ravry *et al.*, 2023), zinc particle shapes were produced. However, in that particular research, all particles within the 0–200 μm range were elongated and irregular. In contrast, our study revealed that particles around 80 μm were entirely spherical.

Further examination of these spherical particles led to the discovery of regular facets on their surfaces, as shown in Figure 6.

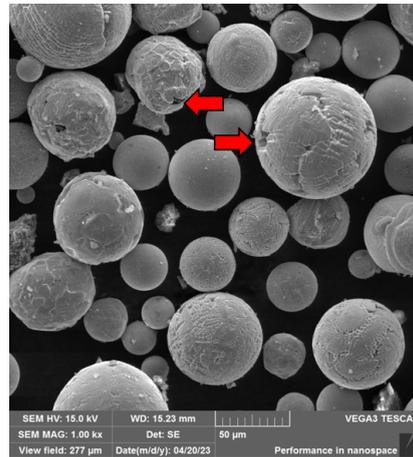


Figure 6. Further examination of spherical particles at 2000 W and 40,000 rpm.

Interestingly, when the rotational speed reached 40,000 rpm and 3000 W laser power was used, each particle exhibited visible holes within the spherical structure, resembling a shell composed of blocks surrounding a core. Notably, these blocks could either be flat or protruding, as depicted in Figure 7, with no apparent correlation to particle size.

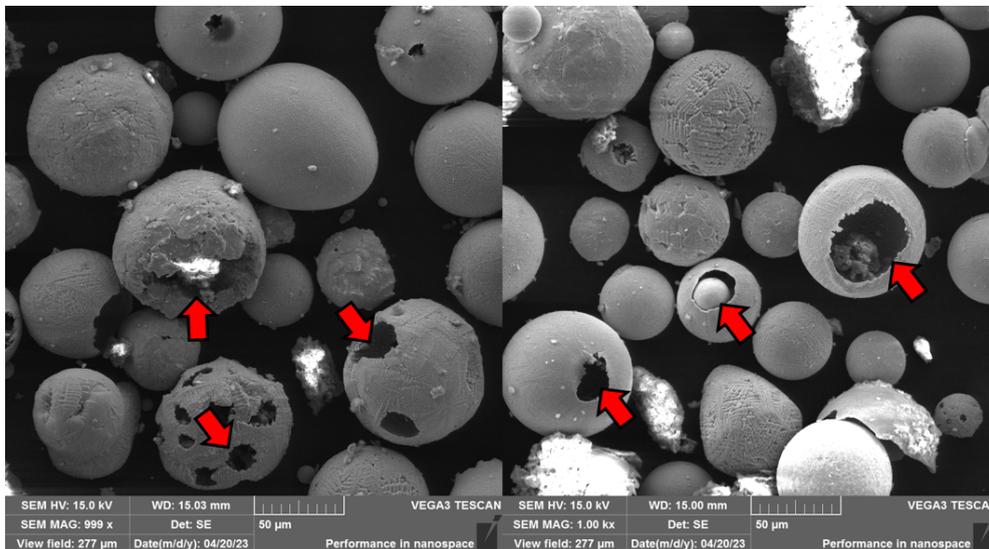


Figure 7. Further examination of spherical particles at 3000 W and 40,000 rpm.

This characteristic is directly linked to the tangential velocity achieved by the particles upon exiting the laser-generated melt pool and the higher energy density caused by the higher power of the laser that generates a more aggressive expulsion dynamic of the molten particles. Upon collision with the collection chamber, they experience a more sudden and forceful impact. The laser power significantly affects the speed at which the molten puddle forms, consequently influencing the ejection velocity of the particles from it.

4. CONCLUSIONS

The utilization of a laser source as a replacement for electrical arc in the Rotating Electrode Process (REP) has demonstrated successful atomization of carbon steel powder. Notably, analysis of the resulting particle sizes revealed a significant degree of heterogeneity.

One critical characteristic that profoundly influences the behavior of particles is the tangential velocity upon their exit from the laser-generated melt pool. Upon collision with the collection chamber, particles experience a forceful impact, with the intensity directly related to their tangential velocity. This relationship underscores the importance of understanding and controlling the exit velocity of particles to optimize the atomization process.

Additionally, the laser power employed in the REP exerts a substantial influence on the dynamics of the molten puddle formation. The rate at which the puddle forms directly affects the subsequent ejection velocity of particles. Consequently, careful modulation of laser power is crucial in controlling the atomization process and achieving desired particle characteristics.

These research findings highlight the intricate interplay between laser power, particle ejection dynamics, and particle behavior within the melt pool. By gaining a deeper understanding of these factors, significant advancements can be made in various applications such as additive manufacturing, surface modification, and material processing.

Further investigations in this domain will contribute to the refinement of laser-based processes and enable the development of optimized strategies for atomization. This, in turn, will drive advancements in the aforementioned applications, facilitating the production of tailored materials with improved properties and functionalities.

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6. RESPONSIBILITY NOTICE

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