BRONZE CLADDING FOR BIMETAL PARTS PRODUCED BY LASER DEPOSITION BRAZING

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ABSTRACT

Bronze has emerged as a highly functional material for various tribological applications, owing to its diverse alloys that offer adaptable material properties for a wide range of loads. Bronze can be used as a solid material or applied as a functional layer in bi-metal components, offering a combination of the superior mechanical properties of the steel base body with the excellent tribological properties of the bronze alloy. Conventionally, bi-metal bearings are casted, a labour-intensive and material-inefficient process. Laser deposition brazing offers a potential solution to these disadvantages. However, it faces the challenge of ensuring sufficiently high layer bonding strength between the steel base body and the bronze alloy layer. This paper presents the production of bi-metal bearings through laser deposition brazing and material analysis, focusing on the development of a reliable process that ensures high-quality bonding between the steel and bronze layers.

Keywords: Laser Cladding, Bronze

1. STATE OF THE ART

There are seven different Laser Surface Processing (LSP) techniques, divided into three primary categories depending on the intensity (the quantity of energy per unit area applied to the metal surface by the laser beam) and the modification of the metal's aggregate state: heating, melting, and vaporization (refer to **Figure 1**). Low intensity leads to surface heating, exemplified by heat treatment for hardening purposes. With increasing intensity, metal melting occurs, as seen in welding, while higher intensity can directly vaporize metal, as evidenced in the cutting of metals [1].

Further categorization is based on whether the goal is to influence the micro-geometry of the surface or alter the material properties. These procedures are carried out by the addition of material, with distinctions drawn regarding whether the added material and/or substrate are melted. The added material can take various forms, such as wire, tape, paste, or powder. The following section specifically elaborates on processes involving powdered added material.

When aiming to alter material properties without introducing additional substances, two distinct procedures come into play: laser hardening and laser remelting. Laser hardening involves heating the surface to a temperature below the melting point [2], whereas laser remelting elevates the surface temperature beyond the melting point [3].

The micro-geometry of the surface can undergo modification through processes such as melting the roughness peaks, referred to as laser polishing [4], or by vaporizing and removing material through a technique known as laser ablation [5]. Both laser polishing and laser remelting are material-free processes involving surface melting. However, they differ in that laser polishing selectively melts only the roughness peaks to alter micro-geometry, whereas laser remelting profoundly remelts the substrate surface, aiming to fundamentally influence material properties.

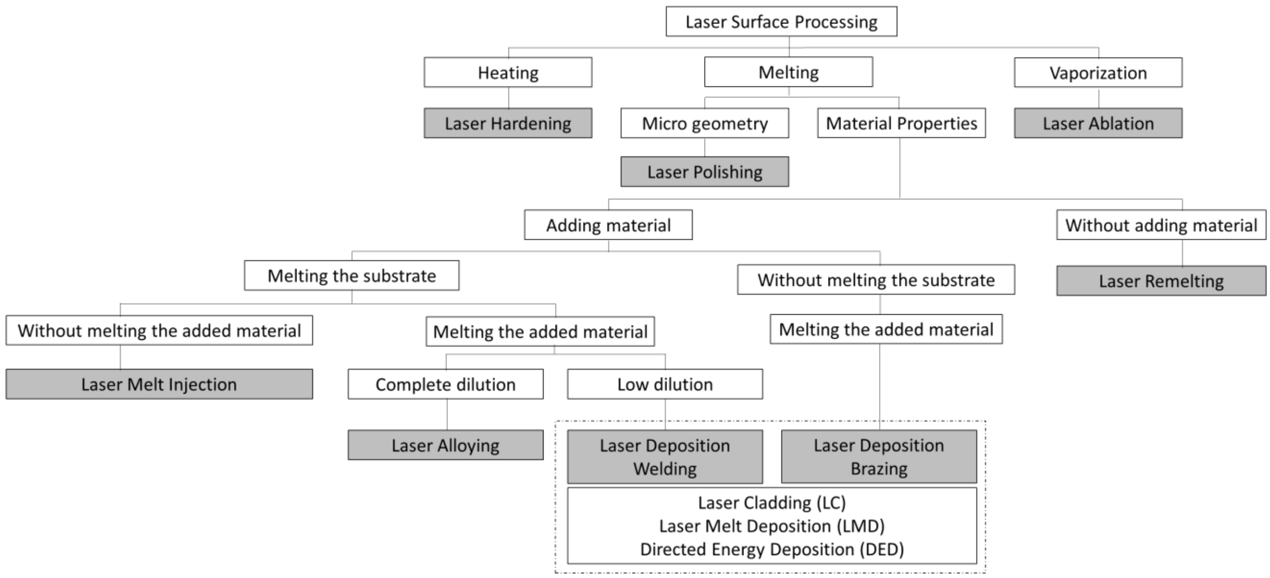


Figure 1: Overview and classification of Laser Surface Processes

In LSP involving the addition of material, four distinct procedures are identified: Laser Melt Injection (LMI), Laser Alloying (LA), Laser Deposition Welding (LDW), and Laser Deposition Brazing (LDB). LMI entails melting the surface without affecting the added material. Typically, ceramic particles are injected into the molten surface to create a wear-resistant metal-matrix-composite (MMC) [6]. LA takes place when metallic powder is used, completely melting, and blending with the molten substrate, resulting in the formation of a new alloy at the part surface with specific properties [7] (refer to **Figure 2**). In LDW, more energy is directed into the powder and less into the substrate compared to the LA process [8]. In LDW, both the powder and substrate have comparable melting temperatures, causing the substrate to melt along with the powder. If the powder material has a significantly lower melting temperature, more laser power is directed into the powder material and less into the substrate material, known as LDB [9]. There is no dilution zone anymore, as seen in LDW.

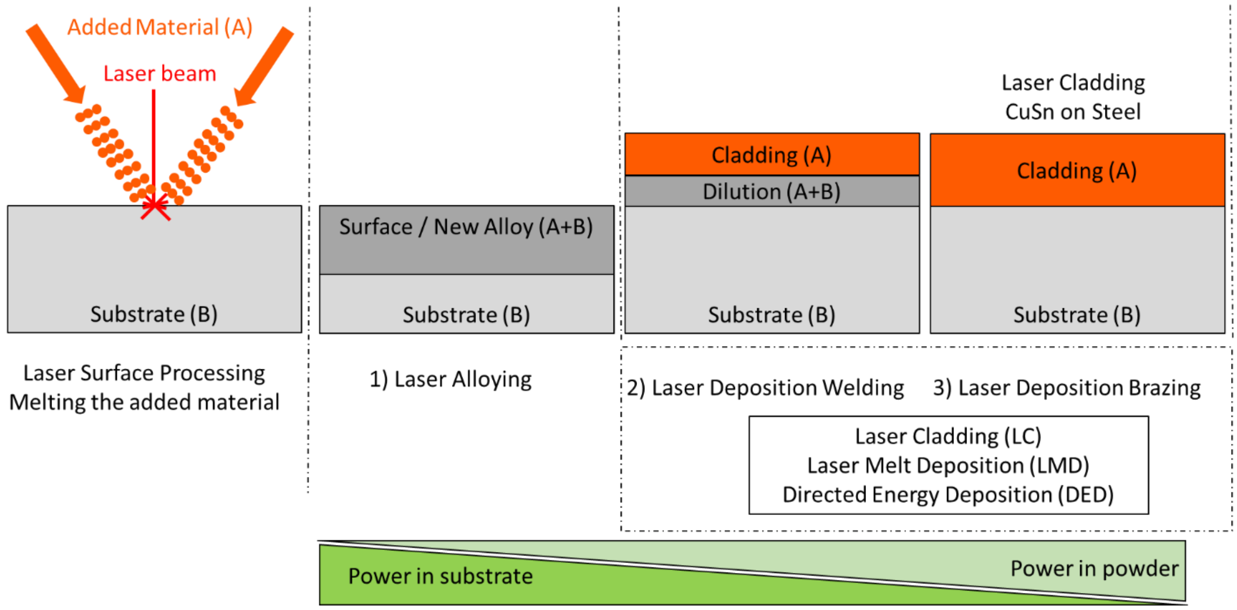


Figure 2: Difference between Laser Alloying, Laser Deposition Welding and Laser Deposition Brazing

The distinction between cladding by welding (LDW) and cladding by brazing (LDB) is highlighted in the established German standard for the classification of industrial production technologies [10]. Despite these differences, both LDW and LDB are commonly associated with terms like Laser Cladding (LC), Laser Metal Deposition (LMD), or Directed Energy Deposition (DED) [11]. All four processes - LMI, LA, LDW, and LDB - can be executed using the same technical setup for delivering powder material into the process zone and injecting it into the laser beam and/or melt pool generated by the laser beam. This paper focuses on LDB, and the subsequent chapter offers a more detailed explanation based on this specific process.

LDB processes can be classified into soft and hard brazing categories [12]. When the melting temperature is below 450°C, the process is referred to as soft brazing. This also includes cladding with white metal, a term denoting tin-based alloys with additions of antimony and lead, commonly employed for various tribological applications [13]. On the contrary, if the brazing alloy has a melting temperature above 450°C, the processes are labelled as hard brazing. Instances of hard brazing include coatings with alloys like copper-tin (CuSn).

Tin bronze typically contains tin (Sn) within the range of 5% to 12%, and a higher tin content is associated with increased hardness. This allows for the customization of material properties to meet specific requirements [14]. CuSn alloys are utilized as a functional surface in tribology applications such as turbochargers, hydraulic pumps, and plain bearings (e.g., in gearbox systems) [15].

The sliding wear behaviour of a material is closely dependent on its microstructural properties. To enhance tribological properties, it is vital for a bearing material to possess three key microstructural constituents: a ductile phase, a load-bearing constituent, and a lubricating element. Bronze with lead (Pb) satisfies these essential conditions for being an effective bearing material. The presence of a ductile phase, specifically in the form of the α-phase (a copper-rich solid solution of tin), provides support to the load-bearing constituent, represented by the Cu-Sn intermetallic phase. Additionally, the effective inclusion of solid lubricant, dispersed as insoluble lead (Pb) particles in the microstructure, contributes to reduced wear and friction coefficients, particularly in dry sliding conditions [16].

However, given that lead is identified as a heavy toxic metal, several regulations, including directives like REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) by the European Union, have been enforced to limit its usage in various mechanical components. These measures aim to prevent the exposure of Pb-containing components to both human and ecological environments [17]. Consequently, there is an urgent requirement to develop and evaluate new Pb-free alternatives, such as bismuth bronze alloys, for bearing applications [18].

2. EXPERIMENTAL PROCEDURE

The study employed an industrial multifunctional machine with multiple axes, allowing for the cladding of both smaller components and larger parts with dimensions of up to 1000mm in diameter, 1100mm in length, and a weight of up to 1000kg. A Yaskawa robot guided the laser head. The multifunctional machine featured two distinct laser heads: one for externally cladding parts and another for internally cladding tubes with a diameter >68 mm. A Laserline GmbH diode laser of the LDM 8000-100 model, boasting a maximum power of 8kW, was utilized. The laser beam's wavelength ranged from 900nm to 1080nm, and it exhibited a laser beam quality of 100mm*mrad.

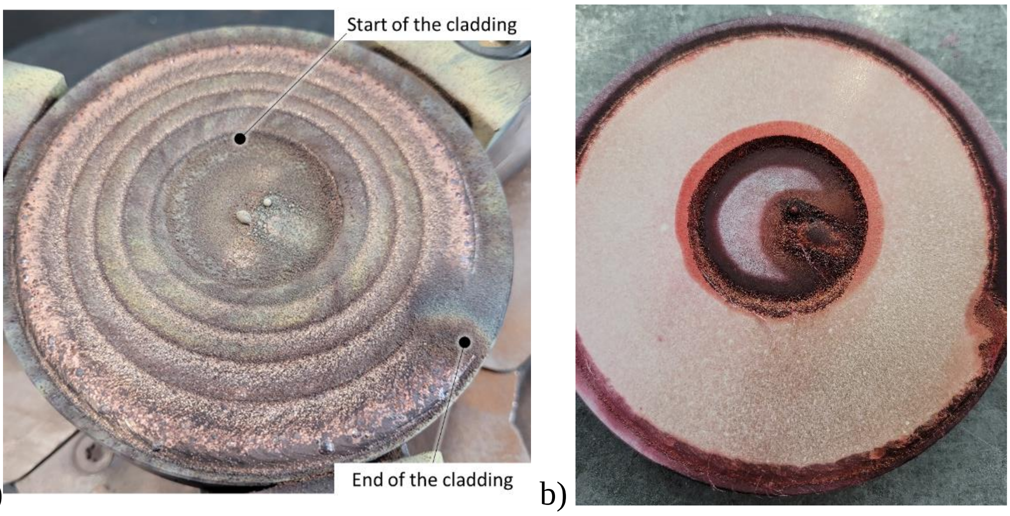
Two copper-tin alloys, namely CuSn11Bi3 (Tokat300) and CuSn12Ni2 (Tokat325), were employed in powder form, with particle diameters smaller than 150µm. A powder feeding machine of the

PF22H type from GTV Verschleissschutz GmbH delivered the powder to the laser head. Substrate materials included the steel alloys C45 and 42CrMo4. The investigations focused on disk-shaped specimens measuring 114mm in diameter and 18mm in thickness. Each test was repeated three times for both materials and substrate materials, using identical parameters to facilitate statistical analysis of values and standard deviations. Deposition onto the substrates occurred in a spiral pattern, moving from the inside to the outside. Subsequently, specimens were machined to a thickness of 1.3mm using a turning machine.

On the planar machined surface, a penetration test was conducted following ISO 4386-3. The visible inspection penetrant, type VP-30 from Met-L-Chek, was applied, followed by removal after a 10-minute waiting period. Subsequently, a penetrant inspection developer, D-70 from Met-L-Chek, was applied, and after a 2-minute waiting period, the parts were subjected to visual inspection. To examine the bonding between the coating and the substrate across the entire coating area, an ultrasonic test was carried out following ISO 4386-1. The ultrasonic test utilized the AMS 2145E device from Olympus.

3. RESULTS AND DISCUSSION

Figure 3a) depicts a C45 steel sample laser cladded with Tokat300 bronze (CuSn11Bi3), emphasizing the spiral coating path. After laser processing, the bronze displays slight oxidation, leading to a matte appearance on the surface. Subsequently, the surface underwent machining to remove the oxidized layer, resulting in a smooth functional surface. In **Figure 3b**), a representation of the dye penetrant test result is provided. The test reveals no indications, confirming the absence of any open surface imperfections.



a) b)

Figure 3: Top view of the specimen a) after the laser cladding and b) after machining and penetration test

The results obtained from the repetition of all four material combinations three times demonstrated consistently high quality and repeatability. All ultrasonic tests consistently revealed no indications, providing conclusive evidence of a defect-free bonding between the bronze cladding and the steel. Dye penetration tests further affirmed the absence of surface open imperfections, underscoring the overall high quality of the cladding. This quality was further validated through metallographic analysis, as shown in **Figure 4**.

The metallographic image illustrates a remarkably straight interface between the Tokat300 bronze coating and the C45 steel substrate, indicating minimal impact on the substrate during the LDB process. Only a few imperfections in the form of small pores are observed in the bronze cladding. An assessment of the pore diameters across all detected pores in all twelve specimens revealed a mean value of 30µm ± 22 µm with standard deviation, further emphasizing the precision and quality of the cladding.

Figure 4: Metallographic cross-section of laser cladded CuSn11Bi3 (Tokat300) on C45 steel

Porosity analysis values for all four material combinations are provided in Table 1, including mean values and standard deviations. Notably, all mean values are below 1%. It's important to note that there isn't a specific standard for recommended porosity values in cladding. As an alternative, standards for joint welding (excluding beam welding) can be considered. According to such standards, porosity values between 1% and 5% are recommended, depending on the intended applications [19]. Alternatively, for comparison, the standard for electron and laser beam welded joints provides requirements and recommendations for evaluation groups concerning irregularities, suggesting higher values ranging from 2% to 6% [20].

Table 1: Parameters of the cylinder

	Tokat300 (CuSn11Bi3)	**Tokat325 (CnSn12Ni2)**
Steel 42CrMo4	0.2% ± 0.3%	0.6% ± 0.5%
Steel C45	0.8% ± 0.6%	0.2% ± 0.08%

Figure 5 displays the mean and standard deviations of hardness values measured in the bronze cladding of CuSn11Bi3 (Tokat300) and CuSn12Ni2 (Tokat325) on the C45 steel substrate. The standard deviations are minimal, accounting for less than 5% of the absolute values. The elevated hardness values observed in the steel indicate the thermal influence of the LDB process to a depth of 1mm, identified as the heat-affected zone (HAZ). Notably, the hardness values of CuSn11Bi3 are slightly lower than those of CuSn12Ni2, attributed to the lower tin content in CuSn11Bi3.

When C45 steel undergoes a standard hardening process, it is anticipated to achieve a hardness level of around 600HV. Nevertheless, in the Heat Affected Zone (HAZ) of the steel coated with CuSn, the hardness values remain under 400HV. Comparing this to existing literature on steel clad with a different bronze (CuAl - aluminium bronze), it consistently shows a 1mm deep HAZ. In contrast, CuAl laser cladding results in a more substantial hardening of the steel, reaching HAZ hardness values of 650HV [8]. This dissimilarity is attributed to the higher melting temperature of aluminium bronze CuAl in comparison to tin bronze CuSn, leading to a more pronounced thermal impact on the steel.

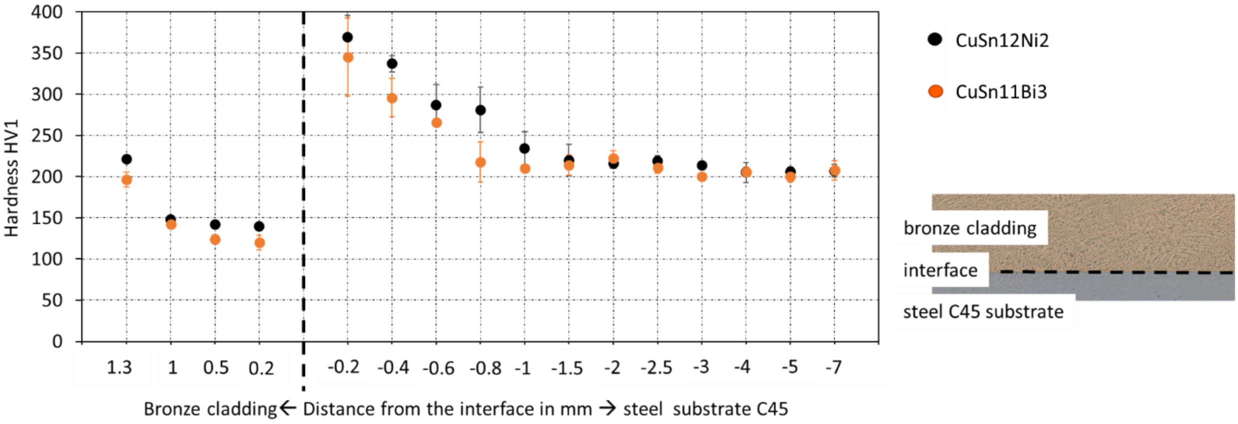


Figure 5: Hardness curve of laser cladded CuSn11Bi3 (Tokat300) on C45 steel

Figure 6 depicts two finalized industrial components ready for use after the machining process. **Figure 6a** depicts a component specifically designed for a planetary gearbox application. This component is made of 42CrMo4 steel and is coated with CuSn11Bi3 (Tokat300). It has dimensions of 220mm in diameter and 260mm in length. **Figure 6b** showcases a component tailored for a power generation application, with a diameter of 345mm and a length of 156mm. The inner surface of this power generation component has undergone coating. To achieve this, the laser head was slightly tilted, enabling the deposition of bronze onto the inner surface. The resulting bronze layer demonstrates a consistent thickness across the entire width of the plain bearing.

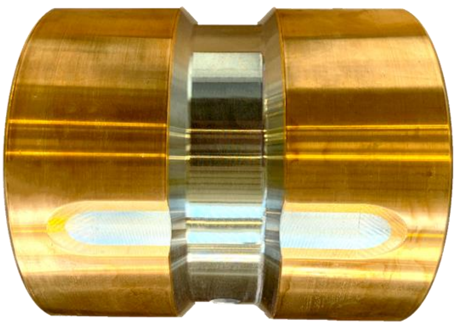

a)

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Figure 6: a) Gear box application; b) power generation application

4. SUMMARY

The article delves into the production technology of Laser Deposition Brazing (LDB), as flexible, resource efficient and versatile in alternative to casting for bimetal part production. The process qualification involved testing two distinct bronze alloys on small samples to evaluate and confirm their quality by penetration testing according to ISO 4386-3, a low porosity as well as the absence of cracks in the micrographs. The process was transferred from small samples to production of larger industrial components, confirming the technological suitability of LDB for bimetal components intended for tribological application like in gear boxes or hydraulic pumps. The hardness curves show a typical increase in hardness in the HAZ of the steel substrate. The study shows that Laser Deposition Brazing is a suitable production technology for manufacturing high-quality bimetal components.

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