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Surface Analysis of Railway Buffers Heads Covered with Bronze Using Laser Cladding

M. Sitarz, A. Kurc-Lisiecka, W. Gamon *
Rail Transport Department, University of Dabrowa Gornicza,
1C Cieplaka Str., 41-300 Dabrowa Gornicza, Poland
* Corresponding author. E-mail address: wgamon@wsb.edu.pl

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Abstract

Railway buffers during the operation are staying in almost permanent contact with each other, creating friction node in the point of contact of two railway buffer heads. In consequence of overcoming track curves, turnouts and unevenness of track, the railway buffer heads moves relative to each other causing friction, which results in its wear. When the wear is excessive, it might be a reason to withdrawn vehicle from service, it causes flattening of buffer head, and in consequence its abnormal cooperation. To avoid this phenomenon the buffer heads should be covered with graphitized grease, but this method has many disadvantages. Accordingly, it was found that it would be beneficial to cover the buffer head with bronze using laser cladding. In this article the metallographic and mechanical analysis of the newly created top layer of railway buffer head are presented. In article the results from tribological tests conducted on Amsler test bench are also presented. Based on test results described in article concluded that the layer of bronze coat on working surface of railway buffer head can be beneficial from operational point of view.

Keywords: Wear resistant alloys, Railway buffer heads, Laser cladding, Clads of aluminum bronze CuAl9Fe3, Properties of clads

1. Introduction

During the operation of railway vehicles, the railway undertakings are obliged to conduct specialized maintenance operation comply with the approved technical documentation [1]. These procedures are carried out on the vehicles depending on the distance or period from last service. The scope of the maintenance operations (reviewing or repairing) is very differential and depending on the type of vehicle, type of mounted equipment, operation conditions etc. Operations conducted as part of the carried out services on railway vehicles usually are divided into few levels, depending on their frequency and amount of conducted works [2-4]. Some of the maintenance processes are carrying out frequently, which can be “inconvenient” for railway undertakings due to the necessity of appropriate planning the operation in such a way that it will be possible to submit it to required reviewing and repairing operations in appropriate time. One of those is periodically covering the railway buffer heads with lubricant to minimalize their wearing [5-7].

The railway vehicles equipped in standard screw coupler usually have two buffers on each headstock (Fig.1). They are devices which amortize vibrations and impacts due to buffing of vehicles during operation or due to trackway unevenness. All of them have convex buffer head with normalized shape. During the ride it stays in contact with the railway buffer head of the next railway vehicle (another railway wagon or locomotive). Consequently, in a result of train movement the cooperation of buffer heads is unavoidable and it allow to gently overcoming track curves, turnouts and vertical unevennesses of trackway [2]. The railway buffer heads which are staying in contact are subjected to persistent wearing. It reduce its normative convex, which has negative influence on safety, and in extreme cases it can provide to derailment of vehicles on track curves. To prevent wearing, the users of railway vehicles (generally railway undertakings) have to periodically apply lubricant (graphite grease) on external, working surface of buffer head. Frequency of doing this service is very high and depends on maintenance documentation of each vehicle. However, this solution has a lot of disadvantages. Therefore, it was claimed that it will be beneficial to choose and apply the method which will increase durability of railway buffer heads with simultaneously possibility to resign from currently solution – greasing the buffer heads. On the basis of the provided literature analysis [2-12] and preliminary test of different types of bronzes (e.g. manganise bronze) was claimed that due to high corrosion resistance and positive tribological parameters, it will be indicated to use aluminum bronze to cover the working surface of buffer head. The purpose of this article was to find out the possibility of getting on the steel surface of railway buffer heads from steel S355J2, the weld claddings from aluminum bronze CuA19Fe3 with high quality and usable properties which increase wearing resistance of railway buffer heads.

Fig. 1. Railway buffers mounted on headstock of freight car

2. Materials and experimental procedure

The trials of laser cladding were performed by means of a robotic stand equipped with ABB industrial robots and a high power diode laser HPDL LDF 4000-30 LaserLine with maximum output power of 4.0 kW (Fig.2). The laser beam was transmitted from the HPDL laser generator to the focusing head CoaxPowerline, produced by the Fraunhofer Institute (Germany), by an optical fiber core having a diameter of 1000 µm. The test of laser cladding (Fig. 3) were carried out on the side surface of the steel rod made of mild steel S355J2 having a nominal diameter of 38.0 mm, in such a way to enable the subsequent tests of mechanical properties and tribological characteristics of the clad layers. The additive material was powder with chemical composition of aluminum bronze CuAl9Fe3. The powder of CuAl9Fe3 was delivered directly to the melt pool by coaxial nozzles integrated with the focusing laser head. The powder was transported from the powder feeder and injected into the liquid of a melt pool in argon atmosphere at the pressure slightly higher than the pressure of the ambient, approx. 1.0 atm. High purity argon (Ar 5.0) was used to ensure full protection of the heated area. During the laser cladding tests, the laser head was positioned vertically and transversely to the axis of the steel rod. The rod was rotated at the chosen rotational speed, determined in such a way to ensure constant linear speed of the laser beam relative to the surface, and thus constant energy input of the cladding process. Under such conditions overlapped clad layers were produced on the whole side surface of the steel rod. The detailed processing parameters and technological conditions are given in Table 1. When the laser cladding tests were completed, the rod with overlapped clad layers was cut into specimens by means of precision cutting machine with a diamond disc. Next, the specimens in the form of discs have been prepared for subsequent metallographic and tribological examinations, as well as for hardness measurements. The test specimens for further investigations were used to verify the procedure of laser cladding and elaboartion of detailed cladding procedure specifications of real railway buffers heads.

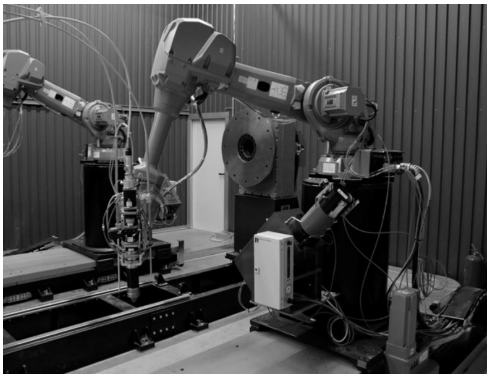

Fig. 2. A view of the robotic stand equipped with a high power diode laser HPDL LDF 4000-30 LaserLine

Table 1.
The parameters of laser cladding of steel rod by aluminum powder CuAl9Fe3

Parameters	Value
Laser power [W]	2100
Cladding speed [mm/s]	15
Powder feeding rate [g/min]	15
Energy input of cladding [J/mm]	140
Gas feed [l/min]	15
Gass shielding [l/min]	10
Over lapp shift [mm]	1.6

The microstructure examinations were performed by means of light and scanning microscopy on samples of the steel S355J2 at delivery conditions and after laser cladding by aluminum bronze CuAl9Fe3. Observations with a scanning electron microscope (SEM) were conducted on the metallographic cross-sections of steel after laser cladding with powder of bronze CuAl9Fe3. The microstructure investigations were performed by using a scanning electron microscope Evo MA10 manufactured by Zeiss (Germany). Additionally, the microanalysis of chemical composition of steel S355J2 after laser cladding with aluminum bronze were carried out using a Bruker spectrometer EDS coupled computer XFlash® 5010 electron microscope.

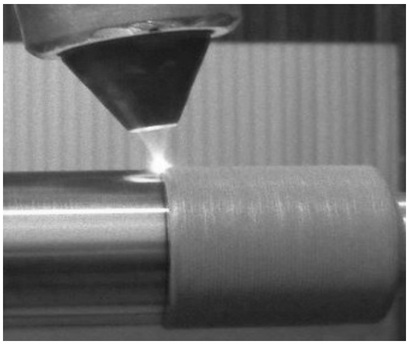

Fig. 3. A view of laser powder cladding process of the rod made of steel S355J2 by aluminum bronze using a high power diode laser HPDL

The carbon equivalent (Ce) of steel S355J2 was determined according to the following relation (EN 10025-2):

$$\%Ce = \%C + \frac{\%Mn}{6} + \frac{\%Cr+\%Mo+\%V}{5} + \frac{\%Ni+\%Cu}{15} \tag{1}$$

where: %C, %Mn, %Cr, %V, %Ni, %Cu – concentrations of the individual elements in mass percent.

The hardness measurements were carried out by Vicker's method (PN-EN ISO 6507-1), on samples of steel S355J2 in delivery conditions and also after laser cladding by aluminum bronze CuAl9Fe3 using the microhardness tester FM 700 produced by Future-Tech (Japan), equipped with an automatic measurement system.

The investigations of abrasive wear of steel samples with lubricated and non-lubricated surfaces, and also samples covered by bronze CuAl9Fe3 during laser cladding were performed by means of the Amsler tribometr, with a combined roll-roll (counterspecimen was static), according to PN-84/H-04332.

3. Results and discussion

The spectrometric examinations of chemical composition of the steel samples confirmed that the investigated steel is a low-carbon (mild) steel grade S355J2 (according to EN 10025-2: 2004). Carbon equivalent Ce determined from the relation (1) on the basis of chemical composition is 0.40%. Such value of carbon equivalent shows good weldability of S355J2 steel. The investigated material in delivery condition exhibited the ferritic-pearlitic microstructure with hardness of about 153HV0.5 (Fig. 4). Based on the metallographic examinations small nonmetallic inclusions, mainly aluminum oxides were identified on the cross-section of single layer clad of bronze CuAl9Fe3 (Fig. 5a – detail „A"). Below the fusion line in the heat affected zone, numerous cracks having a length up to 200 µm perpendicular to the fusion line were found (Fig.5a - detail „B"). In order to eliminate the cracks in HAZ it is necessary to apply the preheating prior to cladding process. The recommended temperature of preheating as well as interpass temperature should be at least 200°C. In Figure 5b the characteristic dendritic structure of alumina bronze CuAl9Fe3 was be observed in the middle region of the clad layer. The structure consists of bright crystals of solid solution α, and dark regions of half eutectoid ($\alpha+\gamma_2$) and also small precipitations of iron-based phase. In turn, Figure 5c shows clearly that the solidification of the melt pool began as a planar front, next transformed into a cellular solidification front with a size of single grains approx. 10-15 µm, and finally proceeded as a dendritic solidification front with dendrites oriented perpendicularly to the fusion line.

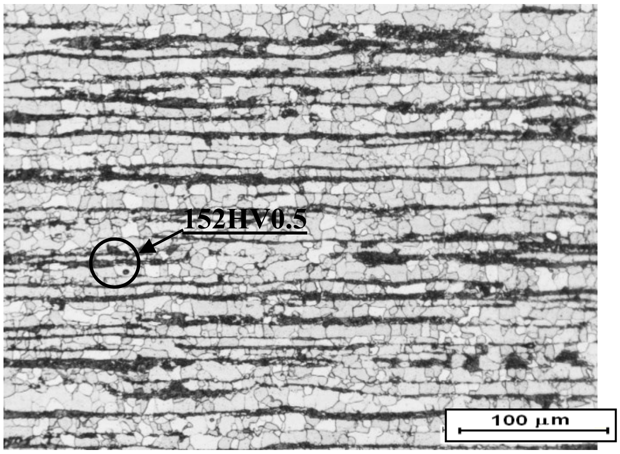

Fig. 4. Microstructure of S355J2 steel in the delivery condition; Mag. 200x; Etching- Nital, longitudinal microsection

Results of EDS analysis in the heat affected zone (Fig.6a,b) showed presence of Fe and high amount of C. The weight concentration of these elements indicates the presence of iron carbide (Fe_3C). Presence of such iron carbides in the mild steel S355J2 confirmed its ferritic-pearlitic structure. Since the pearlite is a mixture of ferrite and cementite (Fe_3C). On the other hand the microanalysis above the fusion line and in the middle region of the clad (Fig.6c) indicates increased share of elements from the aluminum bronze, mainly Cu an Al. Simultaneously decrease of elements from the steel substrate can be observed (clear decrease of Fe from approx. 75% to 48%).

The measurements of hardness were performed in order to determine the hardness of the clad layer of aluminum bronze CuAl9Fe3, and also hardness of the substrate via the fusion line, heat affected zone to the base metal of substrate. The way of hardness measurements and results of the measurements are presented in Fig. 7 and in Table 2, respectively. The substrate of the steel S355J2 exhibited hardness in a range from 155 to 170 HV0.5 (Fig. 7). In the heat affected zone of the steel substrate a slight increase of the hardness was observed to approx. 200 HV0.5. Such increase of hardness in a case of laser processing is typical. It is a result of the thermal cycle and associated rapid cooling during laser cladding (Table 2). In turn, in the vicinity of the fusion line the maximum hardness of 250 HV0.5 was determined. Such high hardness in this region is caused by the dilution of the clad material by the steel substrate and also by simultaneous effect of rapid cooling, confirmed by presence of cellular structure along the fusion line. In the next region of clad layer the hardness was ranged in 178 - 189 HV0.2.

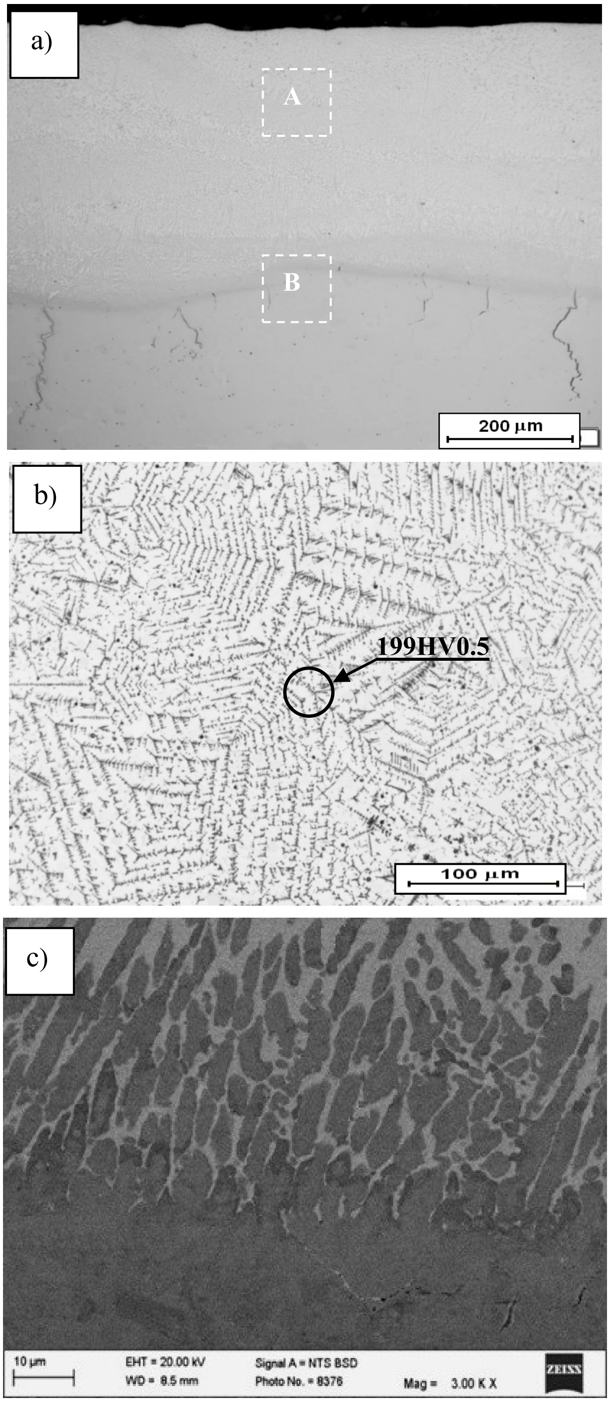

Fig. 5. Cross-section of the single layer clad of CuAl9Fe3 bronze on the substrate of S355J2 steel produced by laser cladding (a), transverse section unetched, Mag. 100x; b) detail "A" from the Fig. a - microstructure of CuAl9Fe3 bronze, etched longitudinal section, Mag. 200x; c) detail "B" from the Fig. a - fusion line under SEM examination

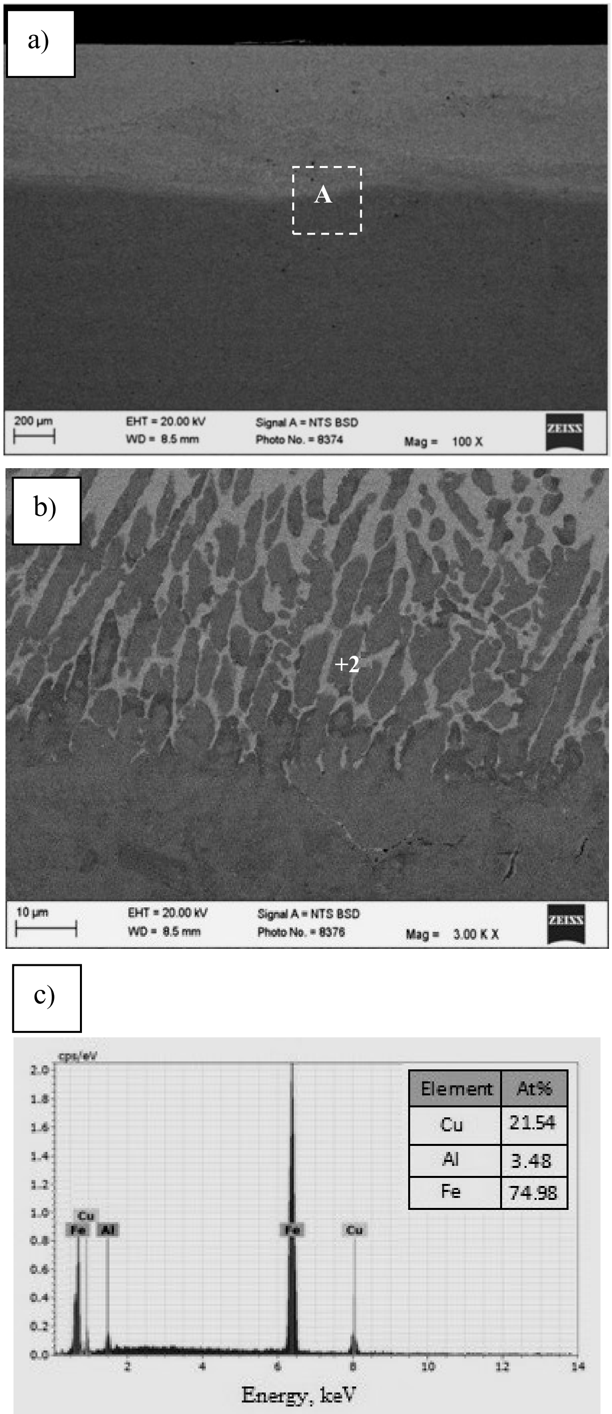

Fig. 6. Microstructure of the single layer clad of CuAl9Fe3 bronze on the substrate of S355J2 steel produced by laser cladding (a), transverse section unetched; b) detail "A" from the Fig. a - microstructure of CuAl9Fe3 bronze, under SEM examination; c) microanalysis obtained from point (2)

Table 2.
The hardness results of laser cladding steel S355J2 with CuAl9Fe3, transverse microsection

Place of measure -ment	Hardness, HV0.5					$\overline{HV0.5}$
	Number of measurement					
	1	2	3	4	5	
Clad	180.9	178.8	188.7	179.3	179.9	181.5
Fusion line	245.9	249.8	246.5	251.7	247.6	248.3
Substrate	196.1	197.4	199.7	200.0	198.1	198.2

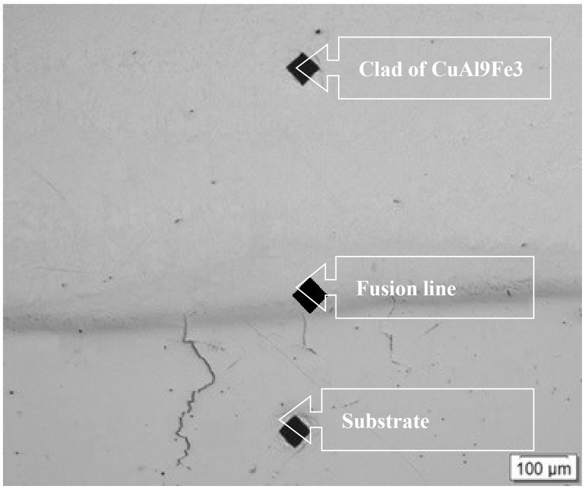

Fig. 7. Cross-section of the single layer clad of aluminum bronze CuAl9Fe3 on the steel substrate with marked points of hardness measurements

The results of study on the wear behavior of steel samples with and without grease, and samples covered by aluminum bronze CuA19Fe3 by laser cladding are presented in a Fig. 8 and Fig. 9.

Figure 8 presents summary report of the complete wear of the samples for the four subsequent test series, when the test sample was pressed to the counterbody at the force of 350 N. On the basis of the results obtained during the study, it was found that most intensive wear during all four tests occurred for the samples in a case of the steel samples without any grease (not lubricated - average of approx. 88 mg) and without the clad layers of bronze. The difference in the wear of samples not lubricated and without the clad layers, compared to the samples laser cladded by the aluminum bronze CuA19Fe3 is significant for all test series. The lowest wear showed samples with aluminum bronze clad layers (average of approx. 10 mg) and steel samples with lubricated surfaces (average of approx.7.5 mg). The wear of the samples was similar during all four series. Thus, it can be assumed that the application of aluminum bronze CuA19Fe3 clad layer will allow avoiding any inconveniences and disadvantages, resulting from the need for lubrication.

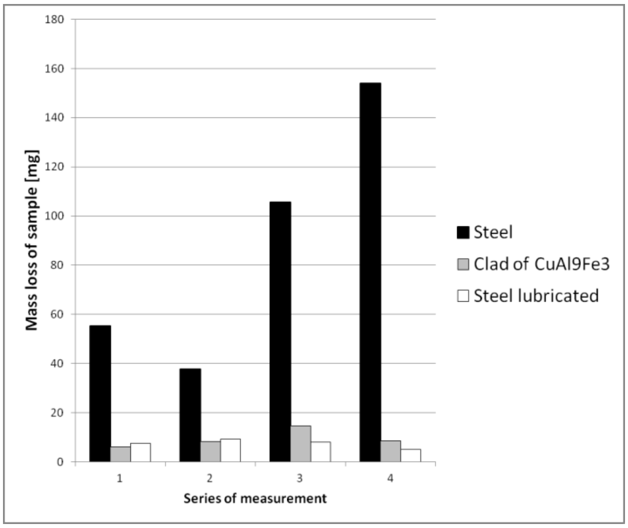

Fig. 8. The mass loss of tested samples after 200 revolutions, at the normal force 350 N

Figure 9 presents detailed results of wear of the tested samples in each measurement series, obtained at every 25 revolutions. On the basis of conducted study, it was found that the wear of all tested samples was at very similar level until 125 revolutions. However, with the increase of revolutions over the value of 125, a sharp increase in wear of the steel samples was found. This phenomenon was probably caused by the accumulation of products of wear which, after a certain time, began to scratch the surface of samples, resulting in the increased abrasive wear (up to 264.7 mg). In turn, the other samples (laser cladded by the aluminum bronze CuA19Fe3 and steel sample covered by graphite grease) were characterized by almost linear relationship of the wear with respect to the number of cycles. On the basis of conducted study and test of abrasive wear, it was found that the lowest wear was exhibited by the steel sample with a greased sample (just 19.3 mg) and the steel sample with clad layer of aluminum bronze CuA19Fe3 (about 67.5 mg).

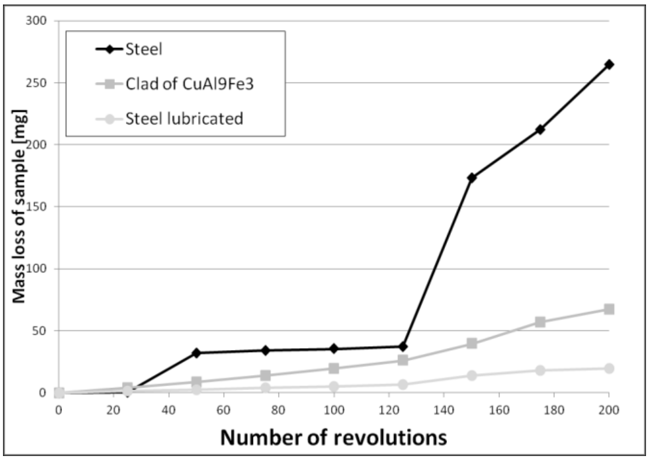

Fig. 9. The mass loss of tested samples after 200 revolutions, at the normal force 700 N

4. Concluding remarks

On the basis of conducted study were, the following conclusions were drawn:

1) It is possible to produce high quality clad layers of aluminum bronze CuA19Fe3 on the steel substrate, without any internal imperfections such as voids or structural discontinuities and characterized by fine-grained dendritic structure in the fusion zone of the clad.
2) However, it is necessary to preheat the steel substrate before laser cladding by the aluminum bronze CuA19Fe3 to the temperature at least 200°C, and also keep the interpass temperature at similar level to avoid cracks in the heat affected zone of the substrate, due to its carbon equal 0.40%.
3) The clad layers of aluminum bronze CuA19Fe3 produced on the buffer heads by laser cladding will allow extending the durability of buffer working surfaces and also can eliminate the need of periodically greasing those surfaces.

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