STUDY OF MECHANICAL - PHYSICAL AND METALLOGRAPHIC CHARACTERISTICS OF COMPOSITE MATERIALS OF COPPER FRICTION ALLOY - STEEL - COPPER FRICTION ALLOY POWDER METALLURGY

NGHIÊN CỨU ĐẶC TÍNH CƠ – LÝ VÀ KIM TƯƠNG HỌC VẬT LIỆU COMPOSITE HỢP KIM ĐỒNG MA SÁT – THÉP – HỢP KIM ĐỒNG MA SÁT LUYỆN KIM BỘT

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ABSTRACT

The article introduces the experimental research results of fabricating a three-layer composite material of friction copper alloy - steel - friction copper alloy by powder metallurgy method, applied as a plasma welding blank of friction disk in the clutch transmission of large power engine and heavy transport vehicles. The characteristic properties of the composite material are investigated according to criteria such as: porosity, density, microstructure of the material at the interface between the friction copper alloy layer and the steel substrate layer, investigated according to the cross section of the sample.

Keywords: *Copper alloy friction composite materials; Powder Metallurgy; Clutch disks.*

TÓM TẮT

Bài báo giới thiệu kết quả nghiên cứu thực nghiệm chế tạo vật liệu composite 3 lớp hợp kim đồng ma sát - thép - hợp kim đồng ma sát bằng phương pháp luyện kim bột, ứng dụng làm phôi hàn plasma đĩa ma sát trong bộ ly hợp truyền động máy động lực công suất lớn và phương tiện vận tải hạng nặng. Tính chất đặc trưng của vật liệu composite được khảo sát theo các tiêu chí như: Độ xốp, mật độ, tổ chức tế vi vật liệu vùng biên giới giữa lớp hợp kim đồng ma sát và lớp thép nền khảo sát theo mặt cắt ngang mẫu thử.

Từ khóa: *Vật liệu hợp kim đồng ma sát; Luyện kim bột; Đĩa ma sát.*

1. INTRODUTION

In foreign countries, powder metallurgy friction materials based on copper powder mixed with Sn, SiO_2, Al_2O_3 powders with different contents [1÷5] (hereinafter abbreviated as HKCuMS) are used. Some typical composite material grades are often used to fabricate friction disk details in the clutch transmission of cars, power machines in mining, construction, agriculture with a capacity of 500 ÷ 1000 horsepower (HP) aiming to replace traditional friction materials and have allowed to improve wear resistance, thermal resistance and stability when working.

In Vietnam recently at the Institute of Mechanical Research, there have been some experimental studies on the issue of fabricating HKCuMS composite materials with different compounds by powder metallurgy technology such as: Pb, Sn, Zn, Cgr, SiO_2, Al_2O_3, Fe,… [6÷9] achieved promising results. However, due to many limitations in the capacity of powder metallurgy equipment currently available in the country, the size of the composite material blanks obtained has a geometric size that is not large enough to meet the application requirements for production. details of friction disks in large power clutch transmission. Especially in the mining and mineral industry in Vietnam today there are a large number of equipment, machinery and mining transport vehicles in operation that are imported (Figure 2). In their operation process, every year it is necessary to periodically replace many worn parts that quickly break down, including friction disks (Figure 3a).

This article introduces the results of applying powder metallurgy technology to fabricate copper - lead - tin - zinc - graphite - Al_2O_3 - Fe composite materials, used as friction disks in the clutch of mining transport vehicles [10], contributing to orienting mechanical engineering enterprises in the country to absorb new technologies and products.

2. RESEARCH METODOLOGY

2.1. Fabricating copper alloy - steel - copper alloy composite materials:

To determine the feasibility of the experimental product in the country by powder metallurgy technology, choose a type of friction disk in the clutch transmission of mining transport cars available in the country.

Figure 1 is a schematic diagram of the technology for fabricating copper alloy friction - steel - copper alloy friction composite materials (HKCuMS) by powder metallurgy method (PM). Figure 2 is a picture of a few self-dumping trucks produced by the Russian Federation operating on open-pit coal and mineral mines in Vietnam. Photo of some details of the clutch transmission of trucks manufactured by the Russian Federation (Figure 3a) and introduce the test stand for friction disks made from HKCuMS - steel - HKCuMS composite materials on a laboratory scale (Figure 3b) [8].

Figure 3b is a microstructure image of the border area of 2 layers of steel - copper alloy friction examined on imported friction disk samples. Using TRIBOTESTER fast wear tester of TRIBO-technic company (Germany) used for experiments according to the diagram of rotating disk carrying friction alloy sample on Figure 4.

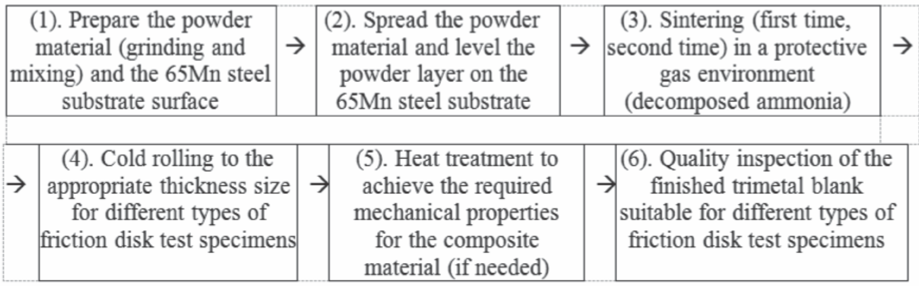

Figure 1. Schematic diagram of the principle of creating composite sheet blanks by powder metallurgy technology [8]

The basis for selecting friction alloys for experiments: powder metallurgy materials based on copper matrix, usually working in an environment with lubricating oil and having mechanical - physical characteristics as shown in table 1. The frictional characteristics of the corresponding friction alloys are shown in table 2 [8].

Table 1. Characteristics of some grades of copper friction alloy materials manufactured by the Russian Federation [8]

Friction material grade LKB	**Chemical composition, %**	**Mechanical – physical properties of friction alloy materials**					
		Volumetric porosity, γ, %	**Density, ρ, g/cm^3**	**Stiffness, HV**	**Cutting strength, σ_c, MPa**	**Thermal conductivity, Cal/cm, ^{O}C.s (20÷500 ^{O}C**	**Coefficient of thermal expansion, α, 1.10^{-6}, (20 ÷ 500 ^{O}C)**
MK5	71Cu; 9Sn; 9Pb; 7C; 4 Fe	3 ÷ 5	6 ÷ 6,3	250 ÷ 350	60 ÷ 90	0,1 ÷ 0,11	-
ФОБ	74Cu; 6Sn; 9Pb; 4Fe	3 ÷ 5	6,1÷6,3	300 ÷ 450	60 ÷ 90	0,1 ÷ 0,11	-
ФАБ	74Cu; 6Al; 9Pb; 7C; 4Fe	3 ÷ 5	6,2÷6,3	500 ÷ 650	120 ÷ 150	-	-
ФАОБ	74Cu; 4Fe; 7C; 2Sn; 9Pb; 4Al	3 ÷ 5	6,0÷6,3	450 ÷ 550	120 ÷ 150	-	-

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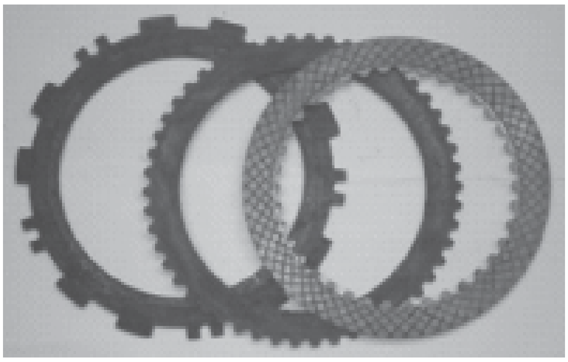
Table 2. Working conditions, application range of copper friction alloy materials manufactured by powder metallurgy by the Russian Federation [8]

Friction material grade LKB	Reciprocal Friction Details	Coefficient of Friction		Wear resistance		Limit of use	
		lubrication	No lubrication	lubrication	No lubrication	Sliding speed, m/s	Pressure, MPa
MK5	65Mn Steel; C.40; C.45	0,055 at: v=5; p=100; W_r=10	0,17÷0,19 at: v= 5; p=100; W_r=10	1,5 µm/ 1000 cycle	0,125 mm/ 1000 cycle	60	3,5
MK5	65Mn Steel; C.40, C.45	0,04 at: v=20; p=350; W_r=25	0,19 at: v=12; p=400; W_r=45	8,0 µm/ 1000 cycle	8,0 mm/ 1000 cycle	60	3,5
ФОБ	65Mn Steel; C.40, C.45	0,055 at: v=15; p=150; W_r=6	-	1,6 µm/ 1000 cycle	0,085 µm/ 1000 cycle	-	-
ФАБ	65Mn Steel; C.40, C.45	0,065 at: v=15; p=150; W_r=6	-	2,3 µm/ 1000 cycle	-	-	-
ФАОБ	65Mn Steel; C.40, C.45	0,06 at: v=15; p=150; W_r = 6	-	2,0 µm/ 1000 cycle	-	-	-
Note: v – Speed at start of braking (m/s); p – compression pressure of friction elements (MPa); W_r – specific function when braking ; K_{cp} – coverage factor; CK – brake cycle							

a) b)

Figure 2. Images of KrAZ-6510 (a) and KAMAZ-55111 (b) cars imported from the Russian Federation operating on the mine site in Quang Ninh




a) b)

Figure 3. Images of the details of the KAMAZ-55111 car transmission clutch (a) and the test stand of the friction disk made from HKCuMS - steel - HKCuMS composite material (b)

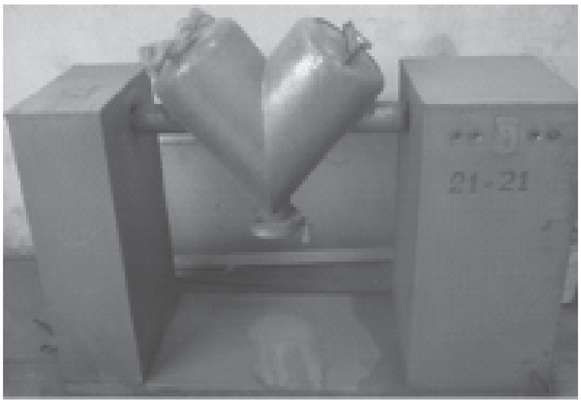
3. EXPERIMETAL RESULT

3.1. Experiment to create composite sheet blanks of copper alloy - steel - copper alloy

According to the schematic diagram shown in Figure 1, carry out the sintering and plastic deformation process to create composite sheet blanks and test the main criteria to evaluate the mechanical properties and microstructural characteristics of copper friction alloy materials with the composition of selected mixed elements. The images shown in figure 4 introduce the general steps of the experiment and the main results as follows:

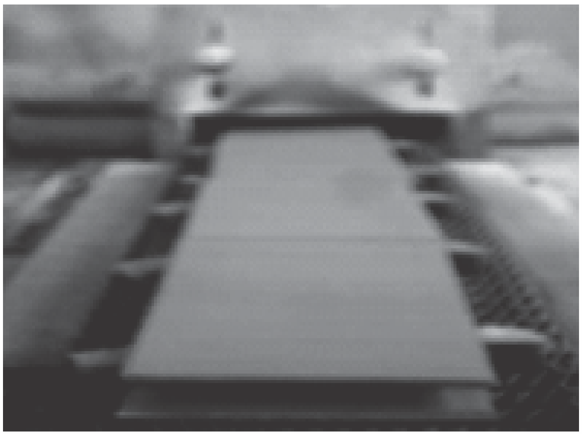
To create a 3-layer composite material blank of copper alloy - steel - copper alloy using experimental equipment including: grinding and mixing machine for input powder material for sintering type "V" (figure 4a), step furnace for sintering metal powder in a protective gas environment is decomposed ammonia NH_4NO_3 (Figure 4b), rolling fine-tuning composite blank on Duo 100 rolling machine (Figure 4e) at mechanical manufacturing enterprise automobile in Vietnam [8].

The chemical composition of the powder material with the symbol ($73Cu6Sn6Zn3Pb4Fe4Cgr4Al_2O_3$) is a copper friction alloy (by mass %) selected to be put into grinding and mixing and has a change compared to the material grade MK-5, ФОБ of the Russian Federation. The grinding and mixing regime and sintering of the copper friction alloy powder layer on both surfaces of the steel layer are carried out according to a reasonable regime based on the experimental results of the author's work [8]. The size of the steel substrate sheet is 2.5 x 100 x 300 mm. The copper friction alloy coating layer after sintering on the surface of the steel layer has a thickness of about $\delta_b ro = 2.0 \div 2.5$ mm, after rolling is $\delta_b rc = 1.2 \div 1.5$ mm. Figure 4f shows images of some 3-layer composite material blanks after sintering and rolling to meet the requirements of total thickness size corresponding to the data given in Table 2.

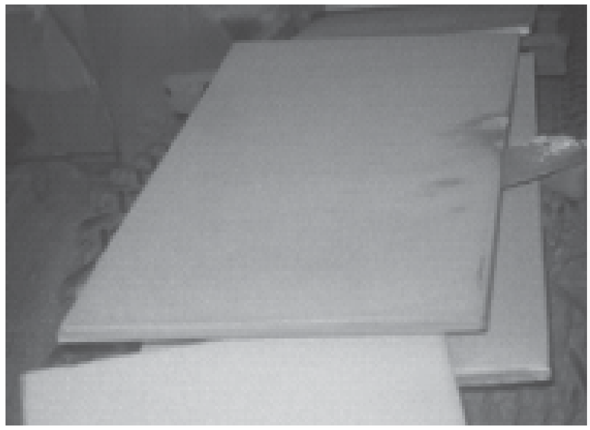


a)

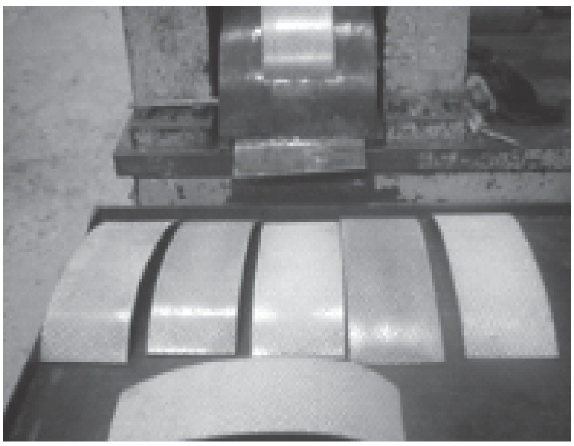
b)



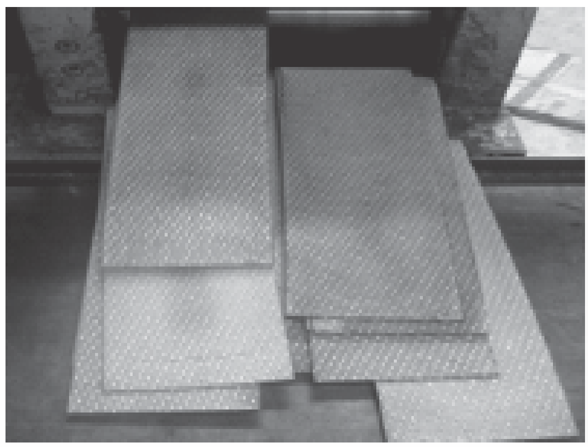
c)



d)



e)



f)

Figure 4. Image of "V" type grinding and mixing machine to mix copper friction alloy powder (a); step-type metal powder sintering furnace (b); feeding blanks into the heating chamber (c); composite material out of the furnace after sintering and cooling in the step furnace chamber (d); Duo 100 rolling machine (e) to deform the sample after sintering [8]

3.2. Mechanical properties of composite material of copper friction alloy - steel - copper friction alloy:

The mechanical and metallographic properties of the HKCuMS - steel - HKCuMS composite material are studied on samples obtained at different sintering and plastic deformation regimes according to the proposed experimental procedure in the previous section given in Table 3.

Table 3. Technical characteristics of HKCuMS - steel - HKCuMS composite material after sintering and plastic deformation using plasma welding blanks:

No.	Material type composite	Specifications for samples of composite materials made by powder metallurgy technology	Unit
1	HKCuMS - steel - HKCuMS composite material centerpiece after the first and second sintering	- Thickness of 3 layers after sintering: HKCuMS (δ_{br} = 2.3 ± 0.2) x steel (δ_{st} = 2.5) x HKCuMS (δ_{br} = 2.3 ± 0.2) - Width x length (100 x 300) ± 0,5 - Porosity of HKCuMS layer after first sintering (γ_{o1}): 19.52 ÷ 16.72 - Porosity of HKCuMS layer after second sintering (γ_{02}): 14.48 ÷ 13.98 - Density of HKCuMS layer after 1st sintering (ρ_{01}): 5.72 ÷ 6.09 - Density of HKCuMS layer after 2nd sintering (ρ_{02}): 6.38 ÷ 6.41 - Microhardness of HKCuMS layer after sintering: 70 ÷100	mm % % g/cm^3 g/cm^3 $H_{V0,05}$
2	HKCuMS - thép - HKCuMS composite material centerpiece after total rolling deformation $\varepsilon_{\Sigma} \approx 10 \div 15$ %	- Thickness of 3 layers of composite material after plastic deformation: HKCuMS (δ_{br} = 1.3 ± 0.1) x Steel (δ_{st} = 2.5) x HKCuMS (δ_{b} =1.3 ± 0.1) - Width x length (100 x 300) ± 0,5 - Porosity of HKCuMS layer after rolling deformation (γ_c): 4.52 ÷ 3.98 - Microhardness of HKCuMS layer after rolling deformation ($H_{V0,05}$): 80 ÷ 110 - Hardness of steel substrate after rolling deformation: 214 ÷ 240 - Adhesion strength of 2 layers of steel – HKCuMS after sintering and rolling deformation (σ_c): 56.86 ÷ 93.33 - Microscopic organization of HKCuMS after rolling deformation: figure 6a ÷ d, equivalent to the sample produced by the Russian Federation (Figure 5)	mm mm % MPa HB MPa -

The experimental data for manufacturing test sheets of HKCuMS - steel - HKCuMS composite material on the existing powder metallurgy equipment line in the country basically meet the mechanical and physical criteria of the HKCuMS layer on both sides of the 65Mn steel substrate layer equivalent to the material of the Russian Federation manufacturing.

3.2. Metallographic characteristics:

Figure 5 is an image of the microstructure of the 3-layer composite material HKCuMS - steel - HKCuMS by optical microscope, studied on the cross section on the imported sample manufactured by the Russian Federation, while figure 6 is on some typical experimental samples obtained in the country.

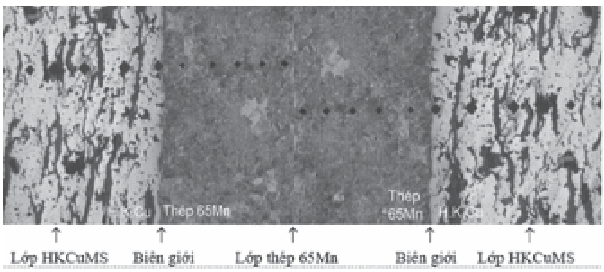
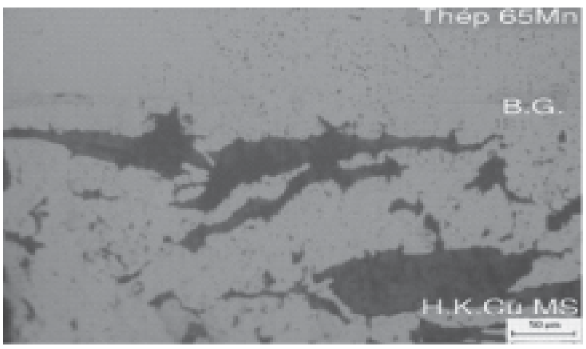
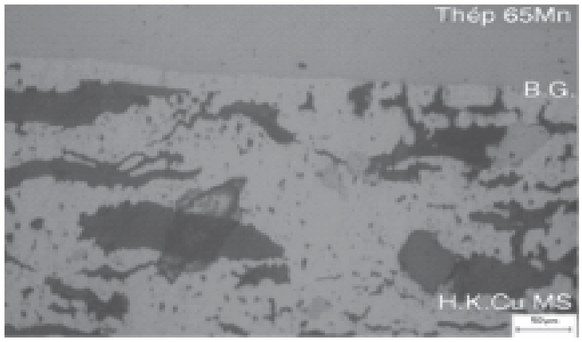


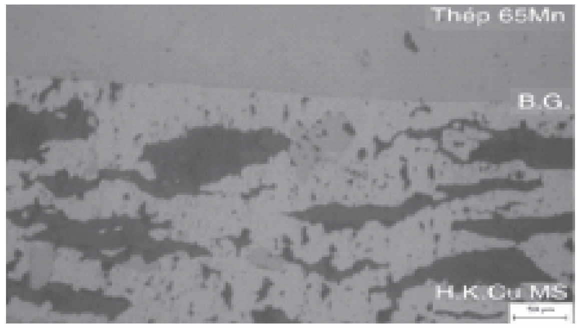
Figure 5. Image of microstructure of material at border area between steel layer and copper friction alloy studied on imported finished product sample (b) [8, 9]



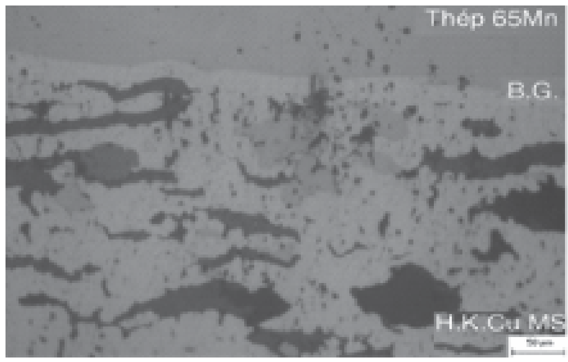
a) No.2 x200: $\gamma_1 = 19.52$ %, $\rho_{0V} = 5.72$ g/cm^3, $\sigma_c = 56.86$ MPa



b) No.6 x200: $\gamma_5 = 16.72$ %, $\rho_{0V} = 6.09$ g/cm^3 $\sigma_c = 80.96$ MPa



c) No.8 x200: $\gamma_8 = 14.48$ %, $\rho_{0V} = 6.38$ g/cm^3 $\sigma_c = 90.16$ MPa



d) No.9, x200: $\gamma_9 = 13.98$ %, $\rho_{0V} = 6.41$ g/cm^3 $\sigma_c = 93.33$ MPa

Figure 6. Image of microstructure of material at border area between 2 layers of steel 65 Mn - $73Cu6Sn6Zn3Pb4Fe4Cgr4Al_2O_3$ on sample after sintering at regime: a) No.2 (sintering time 1: p = 0; $T_{t.k} = 875^OC$; $t_{t.k} = 50$ min); b) No.6 (sintering time 1: p = 10; $T_{t.k} = 900^OC$; $t_{t.k} = 50$ min); c) No.8 (sintering time 2: p = 20; $T_{t.k} = 875^OC$; $t_{t.k} = 50$ min.); d) No.9 (sintering time 2: p = 20; $T_{t.k} = 900^OC$; $t_{t.k} = 50$ min)

Analysis of microstructure images in Figure 6 above shows:

1) Inside the HKCuMS layer ($73Cu6Sn6Pb3Zn4Fe4Cgr4Al_2O_3$) on sample No.2 there are sub-regions of black structure (pores) with different shapes and sizes. The pores have the largest size in the range of 120 ~ 180 μm, and the smallest is ~ 40 μm. The boundary between the 2 layers of 65Mn steel and HKCuMS layer has no defects such as thin film compounds or intermetallics on the entire length of the sample studied. This ensures that the adhesion strength between the 2 layers of steel substrate and HKCuMS has a relatively high value (σ_{c2} = 56.86 MPa);

2) Inside the HKCuMS layer on sample No.6 there are also sub-regions of black porous structure with different shapes and sizes ranging from 50 ~ 160 μm. In addition, some light gray sub-regions of structure with a size of about 25 ~ 50 μm are scattered in the copper alloy matrix (orange-yellow), which may be aluminum oxide (Al_2O_3) or iron (Fe) particles mixed in the raw material powder mixture before sintering. The boundary between the 2 layers of 65Mn steel and HKCuMS layer has no defects on the entire length of the sample studied. This ensures that the adhesion strength between the 2 layers of steel substrate and HKCuMS has a value equal to σ_{c6} = 80.96 MPa;

3) Inside the HKCuMS layer on sample No.8 there are sub-regions of black porous structure with different shapes and sizes ranging from 30 ÷ 160 μm. On sample No.9, the HKCuMS layer has elongated pores with sizes ranging from 120 ÷ 170 μm. Some light gray sub-regions of structure (Al_2O_3) or iron (Fe) on both of these experimental samples have a size of about 20 ÷ 60 μm and are scattered in the copper alloy matrix. The boundary between the 2 layers of 65Mn steel and HKCuMS layer has no defects on the entire length of the sample studied. This ensures that the adhesion strength between the 2 layers of steel substrate and HKCuMS has a value equal to σ_{c8} = 90.16 MPa (sample No.8) and σ_{c9} = 93.33 MPa (sample No.9);

Thus: the metallographic characteristics of the HKCuMS layer on 04 samples of composite materials manufactured domestically in the state after sintering 1 and 2 have a microstructure similar to the sample imported from the Russian Federation. Here, the sub-regions of porous structure may contain graphite (Cgr), while the sub-regions with brighter orange-yellow color are Cu alloy with other mixed metal elements, except Fe or Al_2O_3 (light gray) obtained after sintering. In case of rolling to achieve the required size in table 3, the microstructure of the HKCuMS layers will theoretically have a structure closer to the imported material sample with elongated pores (Figure 5). This allows it to be used as a blank for the experimental step of plasma welding to connect the pieces together as proposed in the work [10].

4. CONCLUSION

1) Multilayer powder metallurgy composite materials have superior technical characteristics than monometal materials, so they have been widely applied in modern machinery and equipment in the world. However, research on applying this advanced technology in Vietnam has not been systematically invested, and specialized equipment still has many limitations and does not meet the requirements of producing large-sized parts, so there is a need for research ☞

proposals to combine solutions with advanced welding technology at laboratory scale to overcome these weaknesses;

2) Two layers composite materials (65Mn steel - 73Cu6Sn6Pb3Zn4Fe4Cgr4Al_2O_3 and SS400 steel - 73Cu6Sn6Pb3Zn4Fe4Cgr4Al_2O_3) and 3 layers composite materials (65Mn steel - 73Cu6Sn6Pb3Zn4Fe4Cgr4Al_2O_3 and SS400 steel - 73Cu6Sn6Pb3Zn4Fe4Cgr4Al_2O_3), manufactured by powder metallurgy technology using metal powder sintering furnace type step currently available in the country have mechanical - physical and metallographic characteristics equivalent to materials tested on friction disks in heavy-duty vehicle clutch transmission manufactured by the Russian Federation, qualified for use for welding experiments to create blanks for machining some friction disk details with larger geometric size than allowed size for other power transmission.❖

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