Microstructure and Properties of the First-Republic Czechoslovak Circulation Coins

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In this work, the microstructure and properties of the first-Republic Czechoslovak circulation coins were studied. The variety of the coins at that time was shown. Significant differences in microstructure in the direction of forming and in the normal direction to the surface direction have been confirmed. For some coins, visible features of recrystallization were shown, which suggests the coinage at higher temperatures. The chemical composition of coin alloys was also studied. In most cases, it was consistent with the declared chemical composition by mint. Significant differences in the hardness of the coins were found, which confirmed the different experience of numismatics with the abrasive resistance and the preservation of different coins. The quality of the design and the material composition of the coins confirm the long-standing experience with coinage in the Czech lands, despite the fact that, after the Austro-Hungarian Empire, the mining industry was struggling with big problems (eg stolen raking machines, lack of Czech mining experts). The first-Republic circulation coins represent the best in the history of the Czech and Czechoslovak coinage industry.

Keywords: metallic materials, circulation coins, microstructure, hardness, numismatics

1 Introduction

One of the symbols of state power and the sovereignty of every single state is its own currency - coins and paper money. The production of coins has a deep tradition in the Czech lands since of ever. Determining exactly when the metal coin production started in our country is not easy. Among the first coins are Celtic golden iris produced in Western and Central Europe in the period from 3rd to 1st century BC. The biggest expansion of coin production in our country dates back to the early Middle Ages.

The most important coins of domestic origin were silver coins - "denarii", "bracteates" and later from the high Middle Ages the famous silver "Prague Gros". From the 16th century, the "Jáchymov tolar" was coined in Jáchymov, which gave its name "tolar" to other coins in Europe and beyond. Our base currency was a "florin", also known as "golden", "goldsmith" or "gulden" after the Prussian-Austrian War of 1867. Since 1892, the florin and krejcar currency has been replaced in our territory by the Austro-Hungarian crown and the heller's currency.

After the establishment of the independent Czechoslovak Republic, a "Czech-Slovak crown" was introduced after a long decision in 1919. At that time, the names of the future currency were quite different in their attempts to accept nothing from the then-hated Austro-Hungarian monarchy. There was not much left, and instead of the crown, we could pay today with a lion, falcon, denarius, gros, hryvnia, dollar or a frank. Instead of the current hellers, "hundreds" or "buzzards" were played in the game [1]. The Czechoslovak currency could differ fundamentally from the neighboring countries also with the material for the production of coins. It was considering also the use of porcelain coins, because its production and processing had a long tradition in the Czech lands. The Czechoslovak crown, in addition to the Protectorate Crown of War, in various changes, in terms of graphic design and material composition, existed until 1992. Since 1993, the monetary unit of the Czech Republic is "Czech crown". Heller coins have definitely ceased to be used in 2009.

The material composition of the coins always corresponded to that of the metal production technologies, the quality and the availability of raw materials for their production. The first documented material for the production of metal coins was gold, available in nature in elementary form. The silver, copper and their alloys were most used to produce medieval coins on our territory. It was only at the end of the 19th century that other copper-based materials (various types of bronze) and other materials (iron, nickel, nickel copper, zinc, and aluminum) were also used to produce coins

Tab. 1 *Material composition of the Austro-Hungarian koruna currency valid on our territory in the period 1892 - 1918 and period of its emission [2]*

1 h	2 h		10 h		20 h		1 K	2 K	5 K	10 K	20 K	100 K
1892 - 1916	1892 - 1915	1916 - 1918	1892 - 1911	1915 - 1916	1892 - 1914	1915 - 1918	1892 - 1916	1912 - 1913	1900 - 1909	1892 - 1915	1892 - 1916	1909 - 1915
Cu Sn4 Zn1	Cu Sn4 Zn1	Fe	Ni	Cu Zn40 Ni10	Ni	Fe	Ag Cu16,5	Ag Cu16,5	Ag Cu10	Au Cu10	Au Cu10	Au Cu10

Fig.1 *Austro-Hungarian koruna currency valid on our territory in the period 1892 - 1918*

The beginnings of the 20th century were the most interesting in terms of the variety of materials used for the production of coins in our country. In the last phase of the existence of Austria-Hungary the coins shown in Fig.1 were used in our countries. Chemical composition of these coins is in Tab.1 [2, 3]. The composition of the Czechoslovak Republican coinage coins in some cases comes from the Austro-Hungarian coins.

First-ever Czechoslovak coins

The first Czechoslovak coins began to be minted in the Kremnica mint in 1921. At first, the production of twenty-hellers, then fifty-hellers, were started. Since 1922, the production of ten-hellers and crowns has begun, since 1923 two-hellers and five-hellers. The last one in the series was the twenty-five-hellers, five-crowns, ten-crowns and twenty-crowns. The material composition of theese coins is shown in Tab.2.

Tab.2 *Material composition of the First Republic Czechoslovak coins and period of their emission [1]*

2 h	5 h	10 h	20 h	25 h	50 h	1 Kč	5 Kč			10 Kč	20 Kč
1923 - 1925	1923 - 1938	1922 - 1938	1921 - 1938	1933	1921 - 1931	1922 - 1938	1925 - 1927	1928 - 1932	1938	1930 - 1933	1933 - 1934
Zn	Cu Zn8	Cu Zn8	Cu Ni20	Cu Ni20	Cu Ni20	Cu Ni20	Cu Ni25	Ag Cu50	Ni	Ag Cu30	Ag Cu30

As can be seen from Tab.2, both pure metals (Zn and Ni) and copper-based alloys (CuZn8 tombak, CuNi20 and CuNi25 copper alloys) and silver-based alloys (AgCu50 and AgCu30) were used for coining at that time. An interesting development was the mintage of five-crown coins. In the early period of the First Republic, they first coined CuNi25 alloy, then converted to AgCu50 silver alloy, and finally, just before the start of World War II, they produced five-crowns from nickel. During the First Republic, the materials used as coinage materials were very diverse, with significantly different mechanical properties and corrosion resistance, which had a considerable effect on the preservation of coins to date. At the same time, these materials have different microstructure, which significantly influences the process of plastic deformation during the embossing process [1].

Microstructure of alloys

The process of coinage requires the processed coinage metals to facilitate their easy plastic deformation. There-

fore, in the microstructure of these materials hard intermediate phases should not be present, which would complicate the process of plastic deformation. Either pure metals or alloys forming homogeneous solid solutions best meet this requirement. The size and shape of grains affect the mechanical properties of the metal. Microstructure of pure zinc and nickel is very simple compared to other coin alloys. It consists of individual grains separated by boudarries. Nevertheless, these two materials differ in their properties. Zinc has a hexagonal crystalline structure, which does not allow this metal to achieve deformation reinforcement during plastic deformation. Therefore, zinc coins are not very mechanically resistant. The nickel has a cubic face centered crystal structure, and deformation reinforcement progressively occurs during plastic deformation. Nickel coins have generally high mechanical resistancy.

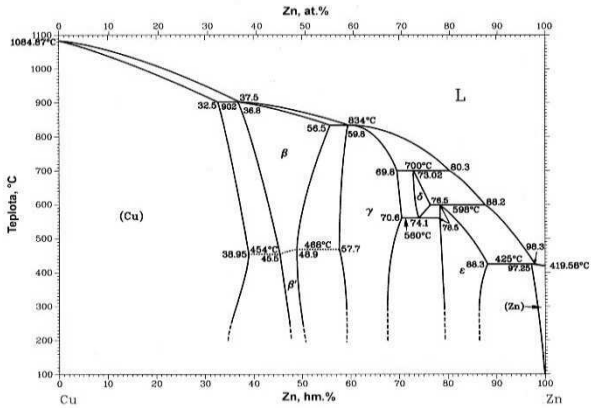

Fig.2 *Equilibrium phase diagram Cu-Zn [5]*

The coining process is accompanied by grain deformation on the microstructure of alloys - a deformation texture is formed. The intensity of plastic deformation at different locations in the same coin may reach significantly different values depending on the complexity of the embossed surface relief. For this reason, the coinage of a number of coins is carried out at elevated temperatures, eliminating the undesirable consequences of the deformation reinforcement, which would otherwise cause the coin to crack. In some cases, their subsequent heating to a suitable temperature and gradual cooling eliminate excessive internal stresses in cold coins is used. Recrystallized grains may appear in the microstructure of these alloys as a result of heat treatment [4]. Eequilibrium phase diagrams of Cu-Zn, Cu-Ni and Ag-Cu can help estimate the microstructure of coinage metals, see Figs.2-4 [5].

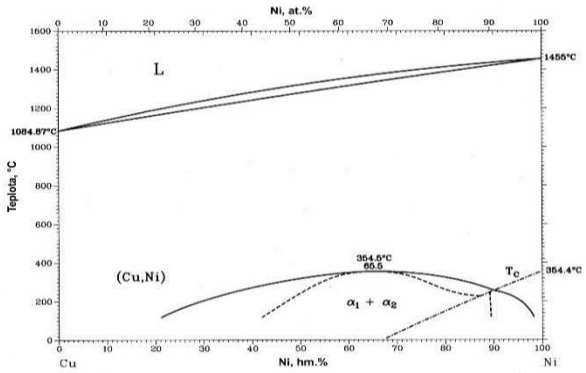

Fig.3 *Equilibrium phase diagram Cu-Ni [5]*

The microstructure of the CuZn8 alloy should be single-phase and formed from solid copper zinc grains, see Fig.2.

Copper CuNi20 and CuNi25 alloy coins should again be a single-phase. The copper nickel alloy should be formed by grains, see Fig.3.

The most interesting microstructure form Ag-Cu alloys. Silver and copper together form a phase diagram (Fig.4) of the eutectic character with limited solubility of elements in solid solutions. Thus, the presence of copper dendrites and copper and silver eutectic can be expected in the AgCu50 microstructure. In the case of the AgCu30 alloy, it is an alloy of almost eutectic composition. It should theoretically therefore consist of only eutectic contained of copper and silver.

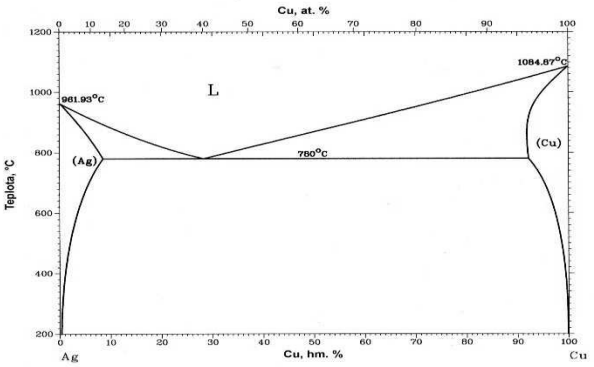

Fig.4 *Equilibrium phase diagram Ag-Cu [5]*

2 Experiment

In this work, 12 coins of different denominations, including all types of circulation coins used at that time, were studied. The preview of studied coins is shown in the Tab.3. Fig.5 shows all types of coins used in this experiment.

Tab. 3 *Overview of the First Republic Czechoslovak studied coins*

Coin	2 h	5 h	10 h	20 h	25 h	50 h	1 Kč	5 Kč			10 Kč	20 Kč
Vintage	1923	1938	1937	1926	1933	1922	1922	1926	1929	1938	1932	1933
Composition	Zn	Cu Zn8	Cu Zn8	Cu Ni20	Cu Ni20	Cu Ni20	Cu Ni20	Cu Ni25	Ag Cu50	Ni	Ag Cu30	Ag Cu30

Metallographic samples for microstructure study both in the transverse and the longitudinal directions were made by the classic method involving grinding, polishing and etching. Metalographic samples were also used for measure the microhardness of alloys by Vickers method at a load of 100 grams in both longitudinal and transverse cuts.

Fig.5 *Overview of the First Republic Czechoslovak coins used for study*

3 Results and discussion

Microstructure

The microstructure of studied coins was formed in the case of pure metals (Zn, Ni) only by grains. During the coining of the zinc two-heller, the grain was significantly deformed, as can be seen from the differences in the microstructure in the longitudinal and transverse directions, see Fig.6. There are no visible features of recrystallization. This demonstrates the cold coinage process was used for this coin, which is not surprising. In the case of the nickel five-crown from 1938, the microstructures in the transverse and longitudinal directions are practically identical, which suggests hot coining, see Fig.7.

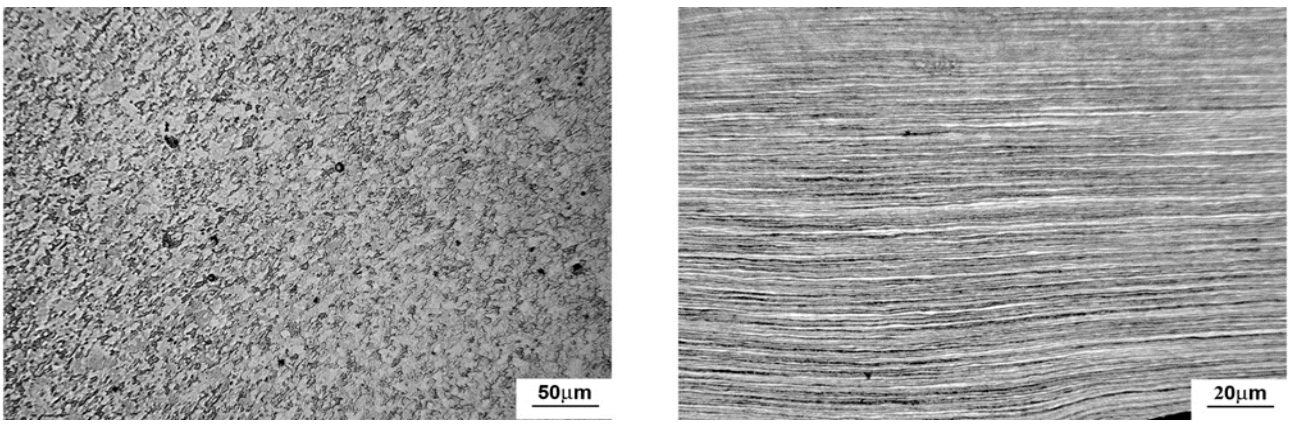

Fig.6 *Microstructure of 2h 1923 (Zn), cross section (left) and longitudinal section (right)*

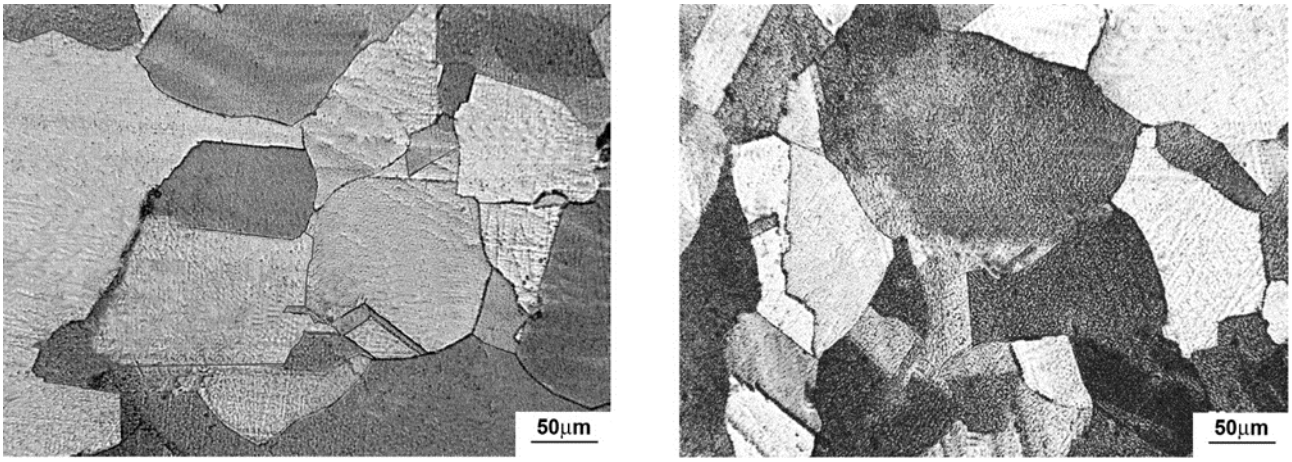

Fig.7 *Microstructure of 5Kč 1938 (Ni), cross section (left) and longitudinal section (right)*

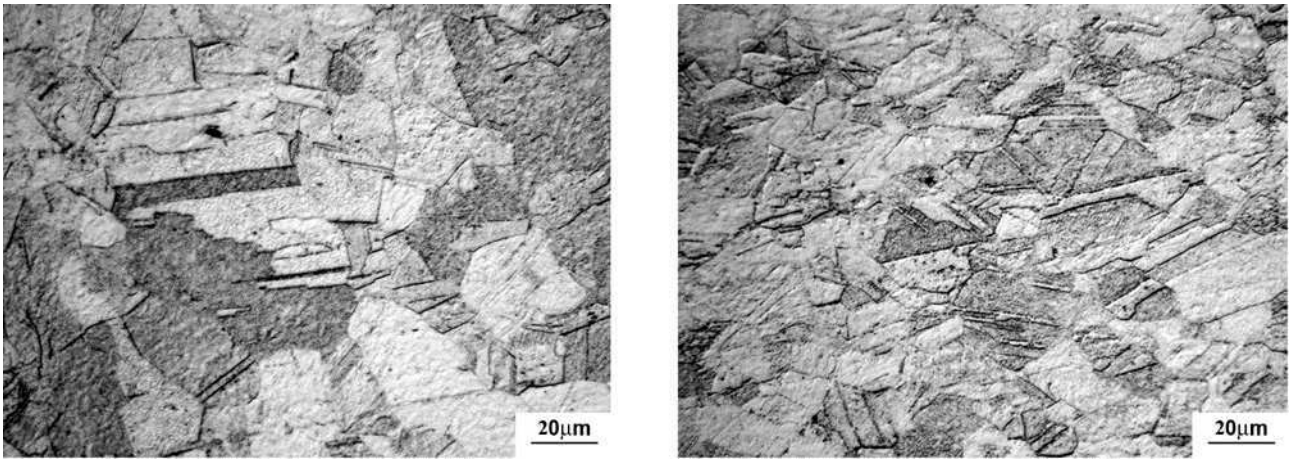

Fig.8 *Microstructure of 5h 1938 (CuZn8), cross section (left) and longitudinal section (right)*

A similar situation to the nickel five-crown is in the case of CuZn alloy coins. Fig.8 illustrates the microstructure of the coin 5h 1938. The microstructures in the transverse and longitudinal directions do not show significant differences, which again shows the hot coining process, which confirms the presence of typical recrystallized grains. Grains are formed by a solid solution of zinc in copper. All studied copper coins had a very similar microstructure. Fig.9 shows the microstructure of the CuNi20 alloy (20h 1926). The grains of the material are formed by a solid solution of nickel in copper. Significant differences in the microstructure in the longitudinal and transverse directions are evident. The longitudinal section shows a considerable deformation texture (grain elongation) and the features of recrystallization are also clear. This again confirms the coinage of coins from these materials at elevated temperatures.

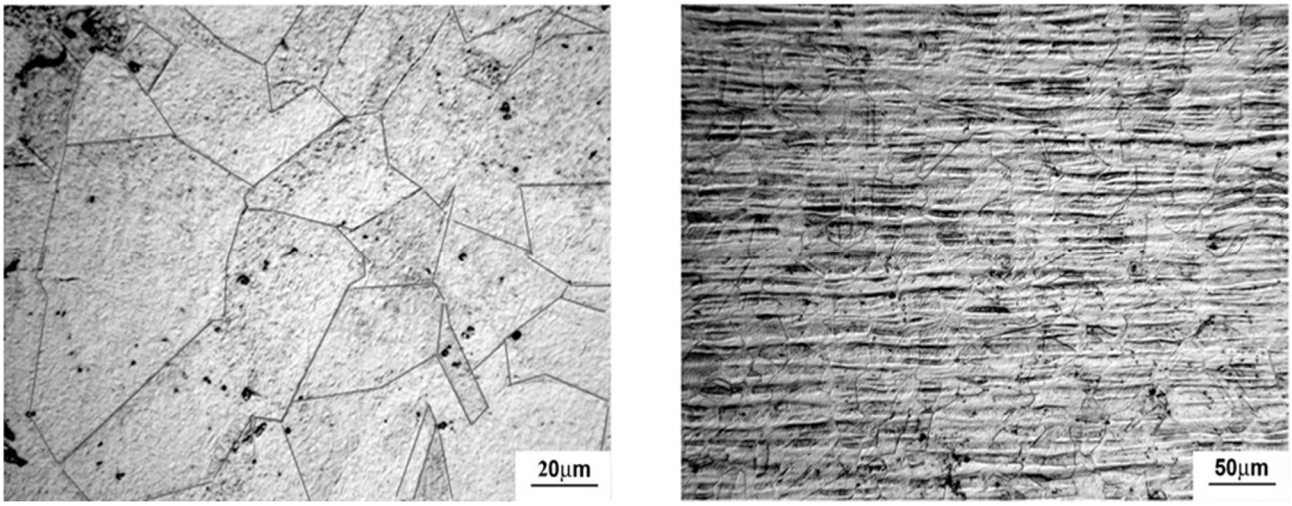

Fig.9 *Microstructure of 20h 1926 (CuNi20), cross section (left) and longitudinal section (right)*

In the case of AgCu alloys, the microstructure is different. Fig.10 is the microstructure of the AgCu50 alloy (5 Kč 1929). It consists of Ag-Cu eutectic and Cu dendrites (gray-black color). Deformation texture can bee seen in longitudinal section. It is very similar to the microstructure of the AgCu70 alloy (20 Kč 1933), but it is much finer, see Fig.11. Although the microstructure should theoretically have almost pure eutectic character, there are copper dendrites, which is typical feature of anomalous eutectics [6].

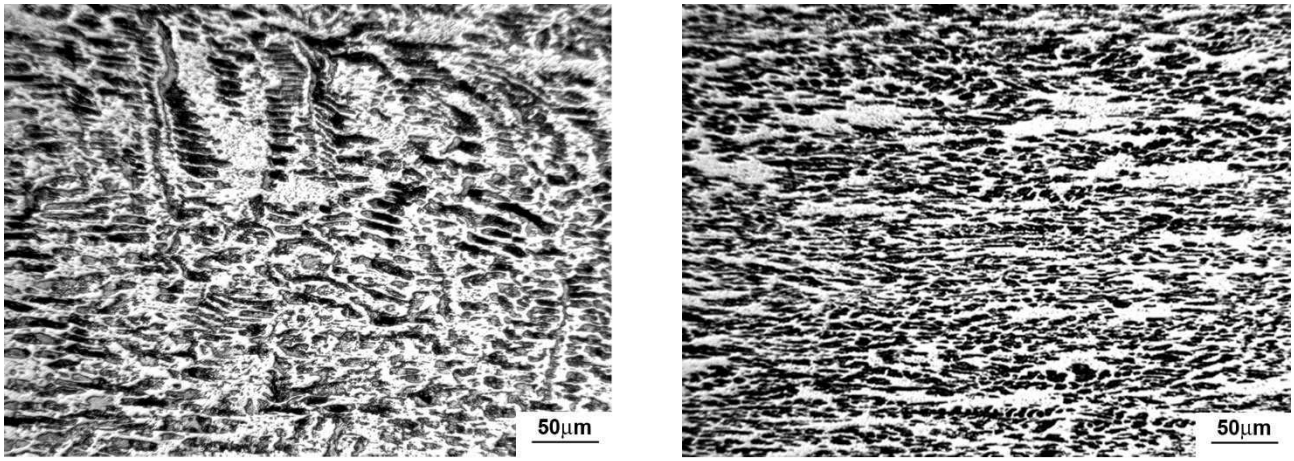

Fig.10 *Microstructure of 5 Kč 1929 (AgCu50), cross section (left) and longitudinal section (right)*

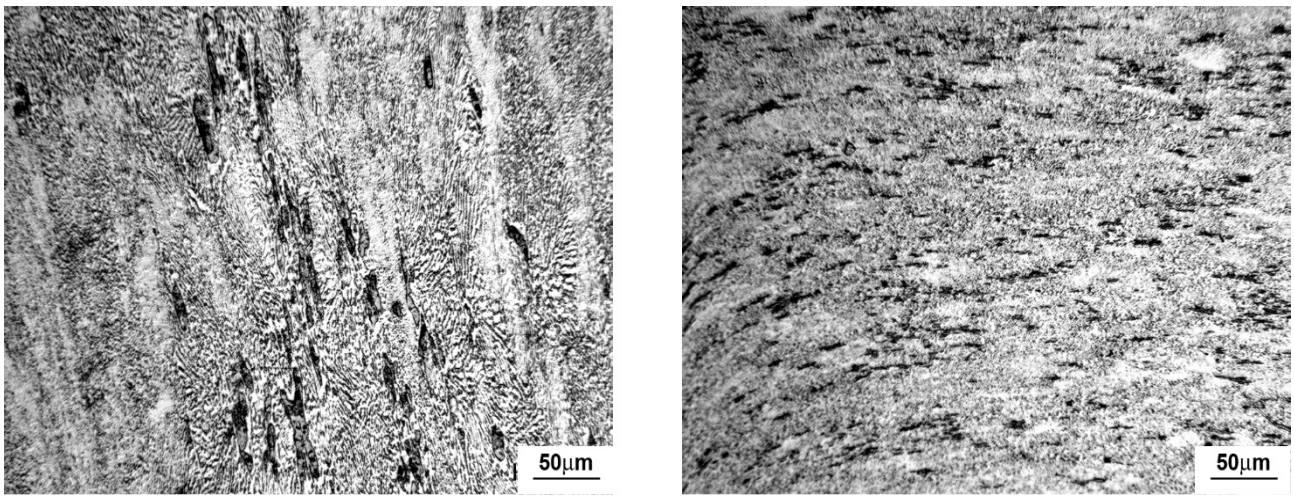

Fig.11 *Microstructure 20 Kč 1933 (AgCu30), cross section (left) and longitudinal section (right)*

The chemical composition of the coins was also verified by means of electron microanalysis. Size of the analyzed surface during the measurement was approximately 8.4 mm^2, the depth of the analyzed area was about 1 μm. The results in most cases correspond to declared chemical composition, see Tab.4.

Tab. 4 *Chemical composition of studied First Republic Czechoslovak coins [wt.%]*

		Al	Ag	Cd	Co	Cu	Fe	Ni	Zn
2h 1923	**Zn**	0.1	-	0.1	-	-	-	-	99.8
5h 1938	**Cu Zn8**	-	-	-	-	92.5	-	-	7.5
10h 1937	**Cu Zn8**	-	-	-	-	92.8	-	-	7.2
20h 1926	**Cu Ni20**	-	-	-	-	79.3	-	20.7	-
25h 1933	**Cu Ni20**	-	-	-	-	78.6	-	21.4	-
50h 1922	**Cu Ni20**	-	-	-	-	79.8	-	20.2	-
1Kč 1922	**Cu Ni20**	-	-	-	0.1	79.0	-	20.9	-
5Kč 1926	**Cu Ni25**	-	-	-	-	75.0	-	25.0	-
5Kč 1929	**Ag Cu50**	-	68.9	-	-	31.1	-	-	-
5Kč 1938	**Ni**	-	-	-	-	10.3	0.2	89.5	-
10Kč 1932	**Ag Cu30**	-	83.1	-	-	16.9	-	-	-
20Kč 1933	**Ag Cu30**	-	78.4	-	-	21.6	-	-	-

Low levels of Al and Cd in zinc (2h 1923) was foud, which is not supprising. In this amount, the combination of Al and Cd was applied to effective grain refinement and, therefore, to achieve a slight increase in the strength and hardness of zinc. The chemical composition of tombak coins (5h 1938 and 10h 1937) and copper coinage coins (20h 1926, 25h 1933, 50h 1922, 1Kč 1922 and 5Kč 1926) corresponds to the expected values. Surprisingly, the analyzes of all "silver" coins (5Kč 1929, 10Kč 1932 and 20Kč 1933) show different content of silver, against to declared values. However, the greatest surprise was the significant content of Cu in a nickel coin (5Kč 1938). This five-crown is said to be a pure nickel coin. However, due to copper solubility in nickel, this does not occur in the microstructure of the alloy.

Tab.5 *Hardness of the First Republic Czechoslovak Coins*

Coin	Composition [wt.%]	Microhardness HV0,1	
		Horizontal cut	Cross-section
2 h 1923	**Zn**	65.2	65.1
5 h 1938	**Cu Zn8**	104.7	119.8
10 h 1937	**Cu Zn8**	105.4	110.4
20 h 1926	**Cu Ni20**	141.9	130. 8
25 h 1933	**Cu Ni20**	146.7	142.0
50 h 1922	**Cu Ni20**	137.9	145.3
1 Kč 1922	**Cu Ni20**	122.2	132.2
5 Kč 1926	**Cu Ni25**	127.7	157.4
5 Kč 1929	**Ag Cu50**	128.4	131.7
5 Kč 1938	**Ni**	180.0	173.1
10 Kč 1932	**Ag Cu30**	111.2	123.4
20 Kč 1933	**Ag Cu30**	101.0	123.7

The mechanical properties of the circulation coins, in addition to their corrosion resistance, significantly affect their service life. The most important factor in common use of coins is abrasion. The higher the abrasion resistance of the coin material, the longer the coin can circulate. The resistance of coins can also be judged on the basis of their hardness. The higher the hardness of the coin metal, the higher will be the assumptions for higher abrasion resistance. The higher hardness of the coin metal, on the other hand, means higher demands on the coinage device.

Tab.5 shows the hardness of the studied coins. Zinc has the lowest hardness as expected. Same hardness values were achieved in both the transverse and the longitudinal directions. For other coins, the hardness value in the longitudinal section is usually higher than in the cross section. The highest hardness was found with a nickel coin (5Kč 1938). Copper coins achieved also relatively high values of hardness. These results are consistent with numismatic practice. Nickel and cupronickel coins are among the most durable, while zinc coins in a top state are rare.

4 Conclusion

The presented work summarizes the results of study of the circulation coins of the first–Republic Czechoslovak. The variety and quality of the materials used at that time were demonstrated, unlike today's coins based on galvanized low-carbon steel. Differences in microstructure, chemical composition and hardness of the first–Republic Czechoslovak coins were shown.

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