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Quality of chrome layers of coining dies and its impact on their reliability and lifetime in operation

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Abstract

Traditional methods of relief coating – chroming – have been used to increase the coining die lifetime for many years. This article is aimed at the quality evaluation of Cr layer on the coining dies surfaces. Three specimens – coining dies – were dipped in the electrolyte at different intervals of time. The quality and thickness of the Cr layer were examined and evaluated. The results were then compared with results of the reference coining die, which achieved the optimum of lifetime (represented in number of coins per minute).

Key words: coining dies, Cr layer, technological process of coating, coating time, quality and reliability, lifetime

1. Introduction

The technology of coining has been continuously improved from the times of manual forge production to the current usage of modern coining machines, where the lifetime of coining die in interval from 750 000 up to one million pieces of coins per coining die is achieved. The increasing of coin volume production in mints is accompanied with high consumption of coining tools; their lifetime has a great impact on the economic aspect of the production process. The prerequisite for achieving of the optimum lifetime of coining dies is the usage of high quality tool steel for their manufacturing, which will provide required properties after the heat treatment process. Application of adequate methods to enhance their resistance to wear is also justified in manufacturing of tools.

2. Operating conditions of coining dies

Technological operation, where cold plastic deformation occurs in the compression stress of material in the die, is called coining. During this deformation, a concave or convex relief on the surface of plates has been formed [1].

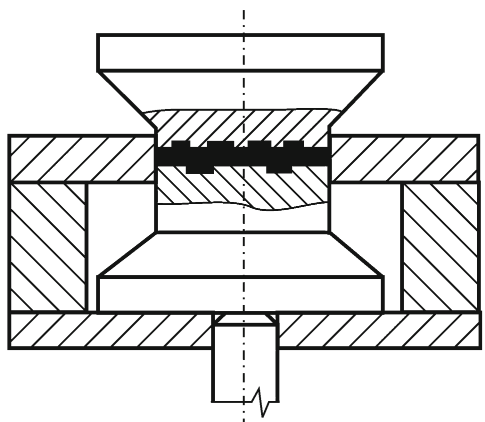

Fig. 1. Scheme of coining [1].

The coining die is a tool for coining of metals; its main parts are an upper die and bottom die. A cavity with negative shape is formed between them. The diagram of a coining tool is in Fig. 1. One part of die is in Fig. 2.

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Fig. 2. One part of die.

The stress of material during coining is similar to the forging in closed die. The semiproduct – circular plate is compressed in the instrument and acquires the shape of the cavity of the tool. Specific pressure depends on material properties and shape of relief of the formed piece [2]. For lower thickness of the formed piece, more complex shapes of relief and higher specific pressure need to be applied in coining. The values of specific pressures are usually 1 500 up to 1 800 MPa in case of coining of silver and nickel coins. Manufacturing of coining dies is a difficult process. At first, an artistic design of relief as a plasticine model is created. After that a plaster model and dentacryl cast is made. The relief is reduced on the reduction machine to the size of the future coin. Finally, the shape of the first die is created. The first die serves as a tool for production of the relief on the coining tool. This one is worn out during coining, so it is necessary to produce new tools for coining [3].

2.1. Requirements for coining tools

The requirements for coining tools in terms of accuracy of shape, quality of surface and strength of structure are high. The tools transfer high forming forces, and therefore their design needs to be adapted. A great attention is paid especially to the surface treatment of the relief of the upper die and bottom die. Coining dies are made from tool steel hardened and tempered at low temperatures to the hardness from 60 up to 62 HRC [1].

The requirements for material of coining dies are as follows:

– high hardness, sufficient toughness, good retention of shape,
– high abrasion wear resistance,
– pressure strength,
– suitability for heat treatment, resistance to crack formation in hardening,
– suitability for some coating methods (depends on tempering temperature),
– good workability,
– good shapeability [4].

2.2. Degradation of coining die material properties

The production and operational degradation has a significant influence on material properties, and also on the reliability and lifetime of tools. Coining dies are made from tool steel, whose properties are considerably influenced by the heat treatment duration. The content and form of individual elements in steel cannot be guaranteed for hundred percent (whereby the risk of adverse phenomena occurrence arises). In addition to the heat itself, the production degradation is also influenced by process of steel heat treatment. It is important to include, e.g., annealing between forming operations in manufacturing of coining dies to eliminate tension, whereby the tendency of the material to formation of cracks in consequent operations of heat treatment is reduced. Overheating of the material and formation of an inappropriate structure, which supports the premature formation of defects, is prevented by observing the procedure and parameters of heat treatment (temperature of heating, required temperature duration, etc.).

The operational degradation in coining operations shows mainly in a fatigue failure of the coining die due to the cyclic action of fluctuating stress [5]. The coining dies operate with the frequency of approximately 750 strokes per one minute. The requirement for lifetime of the coining dies is approx. 750 thousand pieces per a die.

2.3. Selection of materials for manufacturing of coining dies

Tool steels which were made by forming or powder metallurgy methods are used for manufacturing the coining dies. The required properties are met for the following steels, e.g.: *Böhler K390 Microclean, Böhler K340, K455, K605, K720, S690, alloyed tool steel 9KhS, KhVG, and Kh12M, Vancron 40 Super Clean*[3] *steel, chrome molybdenum and chrome nickel steel – STN 41 9614, tungsten tool steel – STN 41 9733, low alloyed tool Cr-W-Si-IN steel – STN 41 9735.*

Each type of steel has a specific chemical composition, corresponding to heat treatment. To increase corrosion resistance, but also wear resistance, the PVD and PACVD coatings are deposited on surfaces. Hard PVD coatings (nitrides, carbides, carbonitrides, oxides) are applied on different types of materials such as steel, plastics, glass, in order to improve their functional properties – optical, electrical, mechanical. The diversity of properties, which are affected by applying a suitable coating, is also reflected in the width of application possibilities: from the protection of surfaces and decorative features to the increasing of the life of tools and components in engineering and health [5]. The choice of optimal layer is determined by the material being processed and by the working conditions of the instrument. PACVD layers can be used in applications where CVD technology can not be used because of the high coating temperature. CVD coating is used at the temperature of about 1 000 ℃, PACVD at 500 ℃ [6].

Considerable influence in selecting materials for the manufacture of dies has the suitability of the coating material. Coatings on the relief of dies can cause increasing of resistance to wear, and subsequently a higher surface quality of coins and medals can be reached.

However, plating is the most used method of increasing lifetime of the functional areas of dies at present.

Chroming is currently one of the most used methods of galvanizing. Chrome layer which is made by metallurgical method has the hardness of approx. 300 HV; electrodeposited chrome coating has the hardness from 700 up to 1100 HV. It has a good resistance to abrasion and temperatures up to 500 ℃. That predetermines it for formation of hard coating for surface treatment of tools and parts exposed to increased pressure or abrasion wear. Hard chroming is not intended for decorative and anticorrosion purposes, but solely to enhance the surface hardness. These layers are usually 2 till 3 times thicker than layers of decorative chrome. However, layers of hard chrome cannot substitute hardening, as they would be pressed into the soft core with an insufficient hardness of pressure stressed basic material of tools and parts. Therefore they need to be heat processed by hardening and tempering first. The significant increasing of the lifetime is caused by chrome coating. However, the hardened steel has the highest internal stress, whereby the hazard that stress can be released and the layer may crack in chroming associated with evolution of hydrogen occurs. Therefore it is necessary to decrease the internal stress by tempering the hardened steel so that the hardness by about 3-4 HRC lower is reached, as specified by the steelmaker. Dehydrogenation is carried out after chroming operations. It is heated to the temperature of 190–220 ℃, with the time of 2–18 h according to the properties and dimensions of parts [8].

3. Experimental evaluation of chrome layer quality on coining dies

The experiment in this paper is dealing with analysing of the chrome layers quality on the relief of three unused coining dies, which were coated at different duration. All three coining dies were made of tool steel Bohler K455. The chemical composition is in Table 1. Heat treatment of coining dies was performed according to the recommendations of the manufacturer. For the experiment, the reliefs of coining dies were chrome-plated pursuant to the procedures of the tool manufacturer.

Identification of experimental coining dies:
Coining die R1: chroming time 25 min.
Coining die R2: chroming time 12 min.
Coining die R3: unknown time of coating.

Table 1. Composition (%) of tool steel Bohler K455 [9]

C	Si	Mn	Cr	IN	W
0.63	0.60	0.30	1.10	0.18	2.00

4. Layers quality evaluation methodology

Quality of Cr layers on the coining dies was evaluated by microscopic analysis using an optical microscope and thickness of the layers was measured by software for image analysis.

4.1. Microscopic analysis

Thickness and quality of layers were evaluated on a longitudinal section of the coining dies. The microstructure was etched by 2 % Nital.

The chrome layer on the coining die R1 (Fig. 3a–d) is deposited throughout the examined relief, flaked off and cracked sporadically. Cracks in the layer are presented in places, where globular non-metal immixtures are presented in the structure in the surface of the relief, which caused the formation on adverse structural stress which is displayed in Fig. 3. The maximum thickness of Cr layer was 16.89 μm, minimum thickness of layer was 10.98 μm, measured on the coining die R1. The method of measuring thickness by software for image analysis is shown in Fig. 3e, f.

Cr layer on the coining die R2 (after 12 min of coating) is non-continuous, sporadically not deposited, very thin (Fig. 4a–d). The maximum thickness of the layer was 2.53 μm; the minimum thickness of the layer was 1.20 μm.

The sequence of Fig. 5a–f documents the conditions of the relief on the coining die R3. The layer was not deposited on one edge of the coining die at all; it is continuous like a thin, cracked layer. The quality of layer varies throughout the relief; it is thicker, cracked in places.

Figure 6a,b documents the measurement of layer

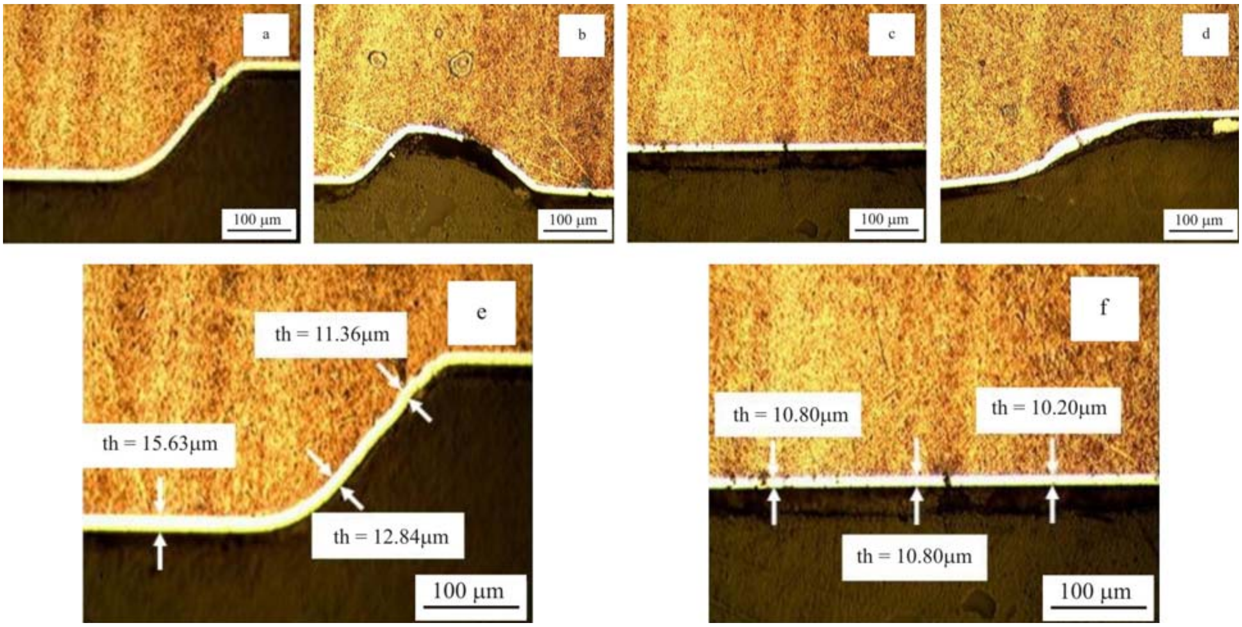

Fig. 3. Coining die R1. a–d – condition of Cr layer on the relief, e, f – thickness measurement points.

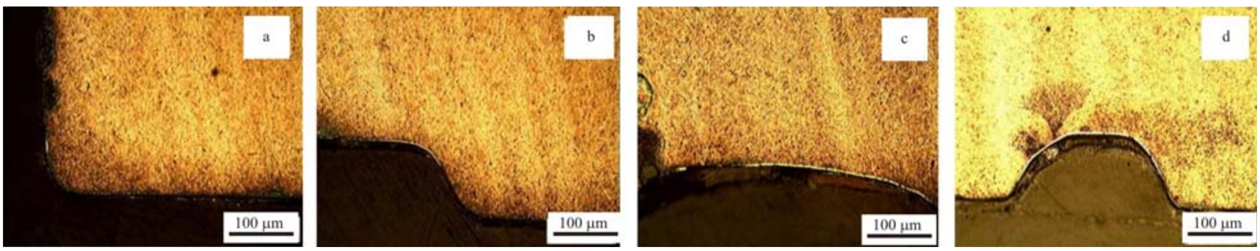

Fig. 4a–d. Coining die R2 – condition of Cr layer on the relief.

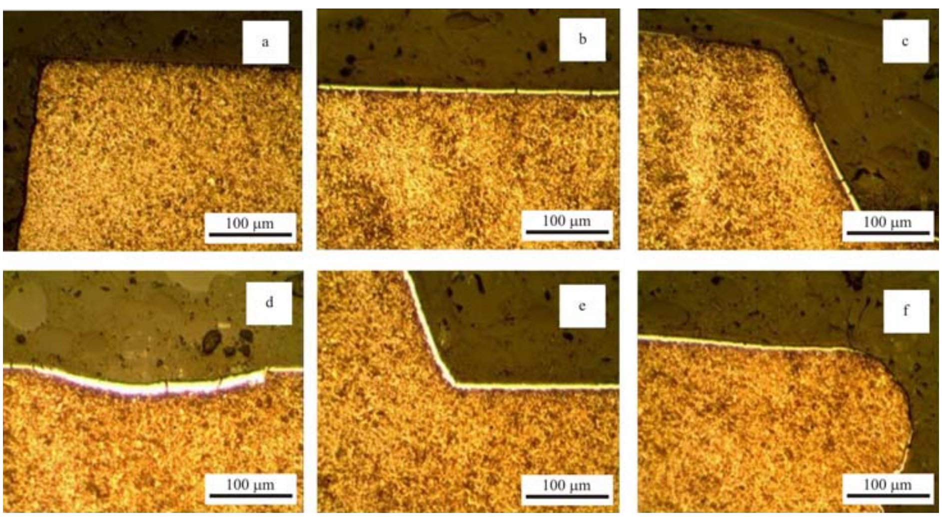

Fig. 5a–f. Chrome layer on the coining die R3.

thickness on the coining die R3 by using NIS Elements program. The measured values are shown in Table 2. The maximum thickness of the layer was 3.62 µm; the minimum thickness was 2.89 µm.

5. Conclusion

Layers on the coining die, which struck 450 000 pcs of coins during the lifetime, were evaluated a long

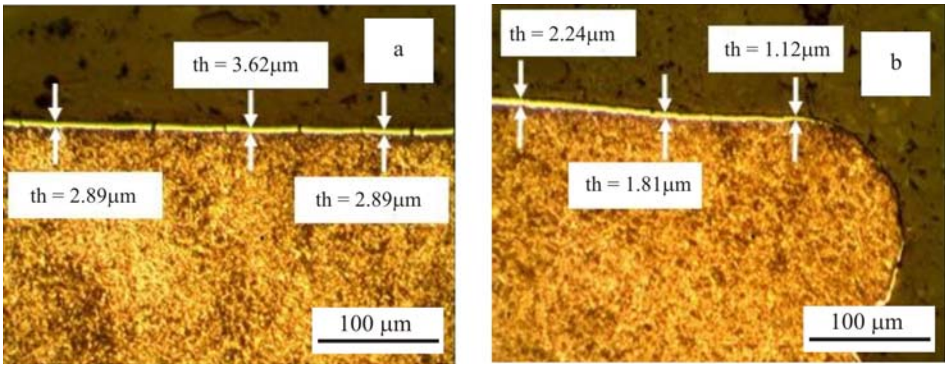

Fig. 6a,b. Thickness measurement points – coining die R3.

T a b l e 2. Measured values of chrome layer thickness – R3

Number of measurements – Fig.	Thickness (μm)	Number of measurements – Fig.	Thickness (μm)
1a	2.89	1b	2.24
2a	2.89	2b	1.82
3a	3.62	3b	1.81
4a	3.38	4b	1.39
5a	2.89	5b	1.12
Mean value	3.13	Mean value	1.68
Directional deviation	0.31	Directional deviation	0.39
Minimum	2.89	Minimum	1.12
Maximum	3.62	Maximum	2.24

time ago. The thickness of layer from 5 up to 11 μm was measured on the coining die, after discarding from coining process. These values could be deemed optimum with regard to the declared lifetime; therefore the experimental results of the examined coining dies are referred to them.

Low thickness of layers was measured on the coining dies R2 and R3; the quality of layers in terms of evenness and integrity throughout the examined relief was unsatisfactory.

On the coining die R1 coated for 25 min, the layer thickness from 11 μm up to 16 μm was measured, but according to the information from the manufacturer of coining dies, the thick layers over 10 μm tend to flake under load in operation. The cracks present in the Cr layer on the coining die R1 could facilitate this phenomenon prematurely as well.

Although the lifetime of coining dies is influenced by a set of factors as stated above, the quality of Cr layers belongs to the most significant ones. The results of experiments show that the quality of chrome layers depends on the time of coating. The experiment was focused exactly on determining the impact of this parameter on thickness of the deposited layer.

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