Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 46 (2023) 131–135

Structural Integrity Procedia

www.elsevier.com/locate/procedia

5th International Conference on Structural Integrity and Durability

Innovation of the production process of coin dies to increase their service life

Miroslava Ťavodová[a], Pavel Beňo[a], Katarina Monkova[b,c*], Dana Stančeková[d]

[a]*Faculty of Technology, Technical University in Zvolen, Študentská 26, 960 01 Zvolen, Slovakia*
[b]*Technical University of Kosice, Faculty of Manufacturing Technologies, Sturova 31, 080 01 Presov, Slovakia*
[c]*UTB Tomas Bata University in Zlin, Faculty of Technology, Vavreckova 275, 760 01 Zlin, Czech Republic*
[d]*Faculty of Mechanical Engineering, University of Zilina, Univerzitná 1, 010 26, Zilina, Slovakia*

Abstract

The article deals with the problem related to the service life of the coin dies. The faultless condition of tools during the long-time process of the production of the coins is a basement for their quality. It is influenced by several aspects. The most important factors can be considered the material of the coin die - especially its purity, relief production technology, heat treatment - especially the correct observance to procedures and the choice of equipment, achieved mechanical properties, method of final relief treatment – e.g., coating and the existence of residual stresses in the tool. The aim of the present research was to examine the cause of the failure and damage of the coin dies after production of a small number of coins and, accordingly, to make changes in the production process to prolong their service life. By monitoring the individual steps of the production process, it was possible to identify specific causes of premature decommissioning of coin dies. Innovations have been made at each step of the production process to extend the life of the coin. The paper presents the modifications in the heat treatment of the coin dies as one of the basic improvements in their no-failure long time operation. This, together with other identified shortcomings in the tool manufacturing process, has contributed to an increase in the number of coins minted from around 6,000 to 740,000 coins.

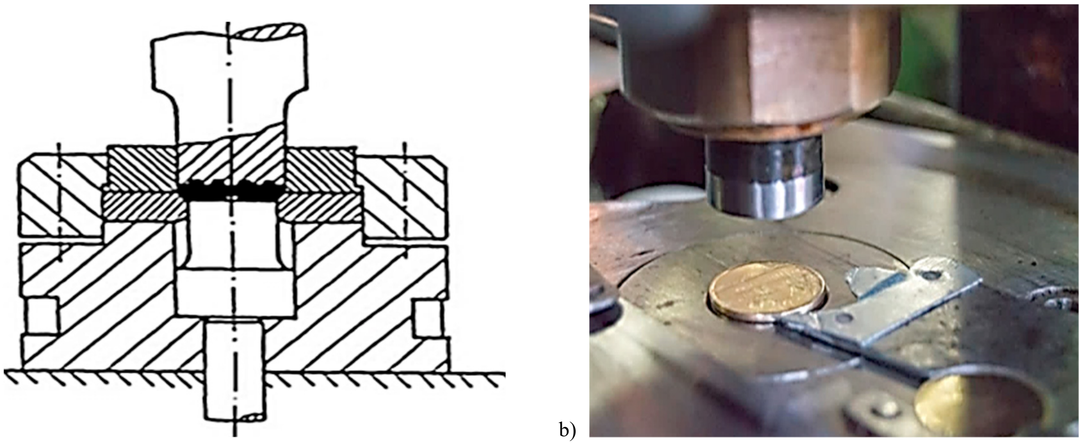
Keywords: coining; coin die damage; failure analysis; service life; chromium plating

* Corresponding author. Tel.: +421-55-602-6370.
E-mail address: katarina.monkova@tuke.sk

10.1016/j.prostr.2023.06.022

1. Introduction

Coining or coinage is the process of manufacturing coins using a kind of stamping which is now generically known in metalworking as "coining". Coining is a form of precision forming in which a workpiece is subjected to sufficiently high stress to induce plastic flow on the surface of the material. (Cora et al., 2012) It is used to manufacture parts for all industries and is commonly used when high relief or very fine features are required, for example, it is used to produce coins. A principle of coining in a closed coining die is in Figure 1.



a) b)

Fig. 1. A principle of coining in a closed die (a) schematic, (b) real views.

Coinage is a specific cold forming technology that uses a great deal of force to plastically deform a workpiece so that it conforms to a die. (Verleene et al., 2000) That is why it requires very precise preparation and production of tools. A coin die is one of the two metallic pieces that are used to strike a coin, one per each side of the coin and they are usually changeable. A die contains an inverse version of the image to be struck on the coin. Modern dies made of tool steel can produce hundreds of thousands of coins (approximately 120 coins a minute) before they are damaged or fail. (Hanes et al., 2014; Tanrikulu & Karakuzu, 2020) This rapid coining causes wear on the dies. If only about 6,000 coins is produced, it is clear that the causes of this situation need to be investigated. The damage and the failure of a coin die, which were the subject of the investigation of the presented research, are shown in Figure 2.

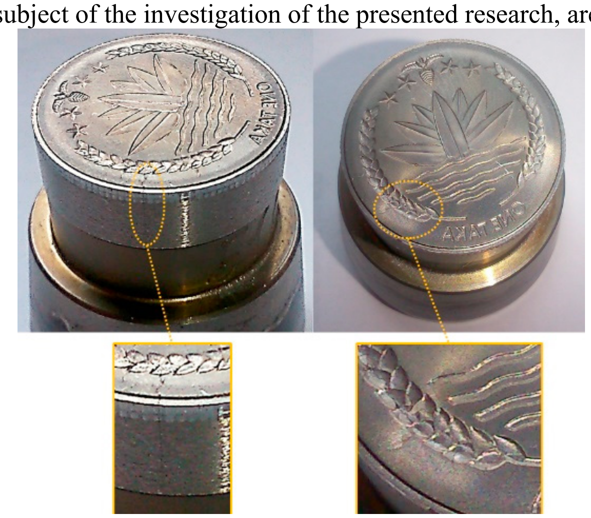


Fig. 2. Damaged areas and cracks on the embossing of the coin die.

Until now, the coin-making company has been producing coins in smaller batches, especially for foreign customers. The new order to produce a large number of euro coins was the reason why the management realized the problem with the need for a very frequent change of the coin die tools. This affected not only investments in production, but also the efficiency of the production process from a financial and time point of view. (Braut et al., 2021)

The aim of the present research was therefore to examine the cause of the failure and damage of the coin dies and, accordingly, to make changes in the production process to prolong their service life.

2. Failure analysis

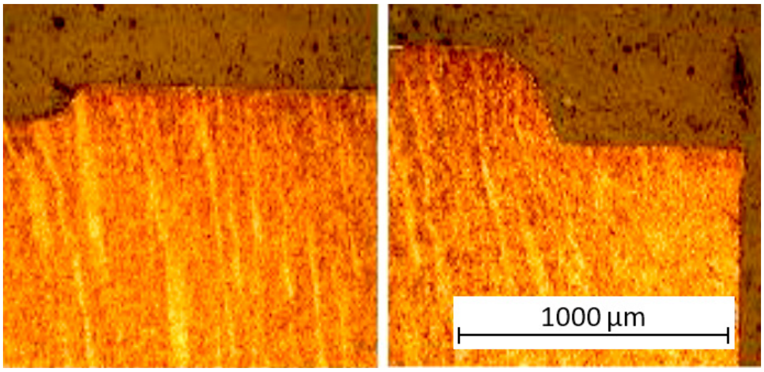
Production of tools for coinage coins, consists of several sub-processes – from the chip machining through embossing, up to heat treatment. Every process must be carefully monitored and the tool, even with a small defect, must be discarded from the next production process. (Jakubeczyová et al., 2011; Papaefthymiou et al., 2016))

To reveal the cause of the failure of coin dies after the production of only about 6,000 anti-corrosion coins, two research pieces of new coin dies were made of bar semi-finished product of Böhler K455 steel (annealed, a hardness of 230 HB) in the way as production had been taking place up to now, i.e., with the following basic steps of the technological procedure:

1. Sawing the bar to the required length and machining to achieve the required sizes.
2. Extrusion of relief on a semi-finished product with a stamp at a pressure of 600 MPa.
3. Heat treatment, consisting of hardening (in a quenching furnace with a protective nitrogen atmosphere at a temperature of 890 °C and cooled in oil at a temperature of 200 °C and low-temperature tempering.
4. Formation of the surface layer on the relief by diffusion plating - chrome plating.
5. After heat treatment, the coining dies were finally machined, and the relief was polished.

1.1. A reference sample (unused in service)

Parts of the relief of the coin die after etching and microstructure of a reference sample (no. 1) not used in operation are shown in Fig. 3. The microstructure consists of fine-grained tempered martensite. The sample shows row-like structure, globular carbides are visible in the rows. (Gubeljak at al., 2009) On the observed area of sample no. 1, no cracks were found on the relief or in the core.

a) 

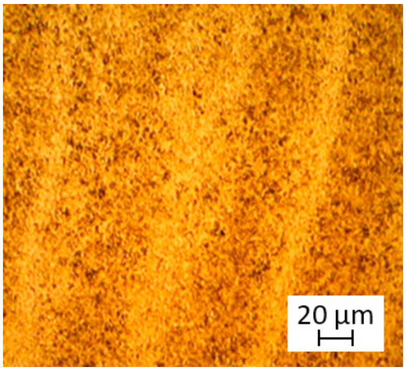
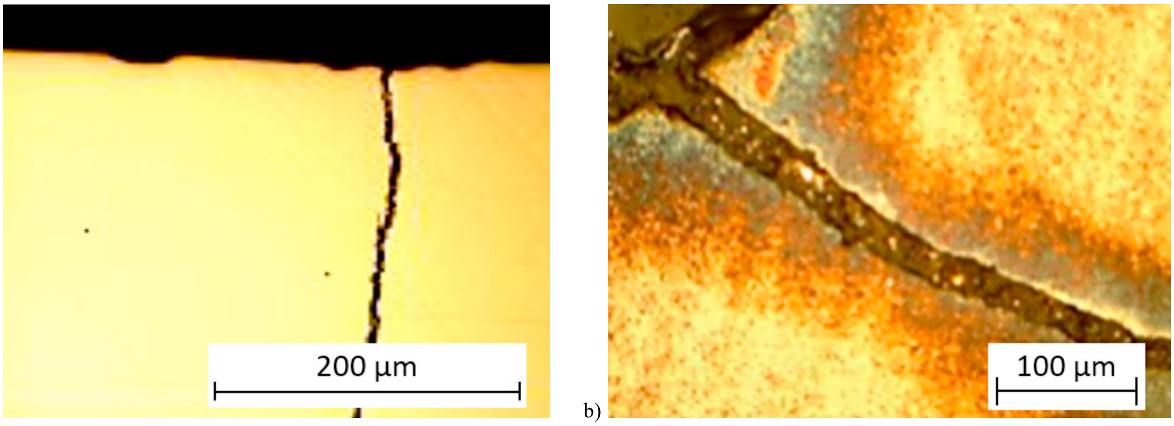
b) 

Fig. 3. Sample no. 1, (a) parts of relief of the coin die; (b) microstructure.

1.2. A sample after production of about 6,000 coins

Parts of the relief of the coin die after etching and microstructure of sample (no. 2) evaluated after production of about 6,000 coins are shown in Fig. 4. The cracks are visible at the first glance. The fact that the crack was formed during hardening is proved by Fig. 4b. (Pelcastre, et al., 2012) It is visible that a chromium solution has penetrated into the crack on the surface. If the crack had formed during the usage of the coin die, this phenomenon could not be possible to observe. (Kazakov et al., 2016; Mlikota et al., 2021)



a) b)

Fig. 4. Sample no. 2, (a) parts of relief of the coin die with a crack, (b) chromium solution penetration into the crack.

3. Problem solution

To solve the problem, every step of the coin dies production was analysed in detail and changes in the technological process were suggested. Within the presented research, a new sample was made with the different way of hardening. Sample no. 3 was hardened in a vacuum quenching furnace and the hardening in this set-up consisted of five stages:

1. creating a vacuum,
2. heating and holding at temperature (650 °C),
3. eating and holding at temperature (800 °C),
4. heating and temperature endurance (930 °C),
5. nitrogen cooling to 33 °C.

The coin die was analysed several times during the production process and only after the production of 490,000 pieces of coins, the cracks appeared. Figure 5 shows the microstructure of the material of sample no. 3. It consists of fine-grained tempered martensite. A row-like structure was also found on this cut. This state is related to the higher hardness of this die compared to samples no. 1 and no. 2.

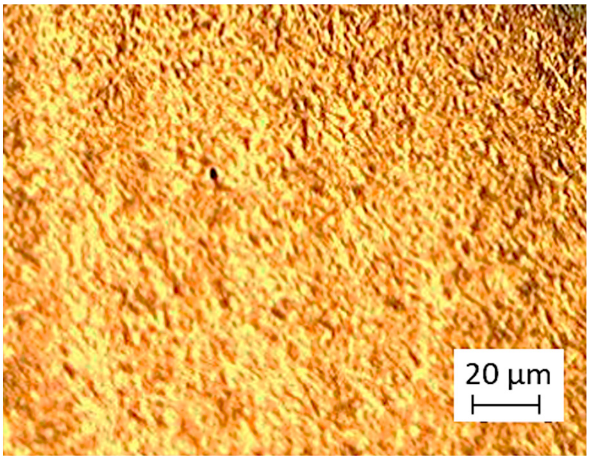


Fig. 5. Microstructure of sample no. 3.

4. Conclusions

Coins need to be produced in high quality, very precisely, without defects and in huge quantities. This means that coin dies have to withstand wear and damage for a long time. In the coin production process, coin dies are repeatedly dynamically loaded, so that each step in the technological process of their production plays a very important role and must be properly designed. A fault in one step can cause the tool to fail and the coin production process becomes inefficient. (Woo & O'Neal, 2019; Groche, & Christiany, 2013)

Comprehensive research has been done to uncover the causes of coin stamp failure. The part presented in this paper points to increasing the life of dies by changing the heat treatment.

Based on the results of a comprehensive investigation, it can also be said that other conditions for achieving the accepted life of coin dies (in the production of several hundred coins) are:

- High purity of the steel from which they are made;
- Punching on the tool should be done in open punching to eliminate internal stress;
- Adherence to the procedure of heat treatment of dies, as well as the use of modern equipment for hardening and tempering of matrices will ensure a quality input for further processing of dies. This eliminates the formation of hardening cracks on the surface of the matrix, which significantly reduces their service life;
- Replacement of hard coating technology by chromium plating by coating methods based on the principle of thin film deposition on the matrix surface (PVD, CVD, PACVD, etc.).

Adherence to the above requirements in the production of coin dies and their implementation in the manufacturing process meant that the number of coins produced by one tool approached the standards achieved by mints companies in developed European countries.

Acknowledgements

The present contribution has been prepared with direct support of Ministry of Education, Science, Research and Sport of Slovak Republic through the projects APVV-19-0550 and KEGA 005TUKE-4/2021.

References

Cora, O.N, Ağcayazı, A., Namiki, K., Sofuoğlu, H., Koç, M., 2012. Die wear in stamping of advanced high strength steels – Investigations on the effects of substrate material and hard-coatings, Tribology International, 52, 50-60.

Verleene, A., Dubar, M., Dubar, L., Dubois, A., Oudin, J., 2000. Determination of a hardening behaviour law for a cold forging TiN-coated tool steel, Surface and Coatings Technology, 127/1, 52-58.

Hanes, T. et al. Coating surface roughness measurement made on coining dies, Manufacturing technology, 3, 2014, 309-317.

Tanrikulu, B., Karakuzu, R., 2020. Fatigue life prediction model of WC-Co cold forging dies based on experimental and numerical studies. Engineering Failure Analysis, 118, 104910.

Braut, S., Tevčić, M., Butković, M., Božić, Ž., Žigulić, R., 2021. Application of modified Locati method in fatigue strength testing of a turbo compressor blade. Procedia Structural Integrity, 31, 33–37.

Jakubeczyová, D. et al., 2011. The use of indentation tests for evaluation of thin PVD coatings of (Ti,Al)N type, Powder metalurgy process., 1/1÷2, 165-172.

Papaefthymiou, S., Vazdirvanidis, A., Pantazopoulos, G., Goulas, C., 2016. Fatigue Fracture of a High-Resistance Structural Steel Component Destined to Sustain Severe Loads Under Service Conditions. Journal of Failure Analysis and Prevention, 17/1, 79–85.

Gubeljak, N. et al., 2009. An Estimation of Sufficient Impact Toughness for the Material of a Turbine Shaft, Strojarstvo, 51/4, 263-271.

Pelcastre, L., Hardell, J., Herrera, N., Prakash, B., 2012, Investigations into the damage mechanisms of form fixture hardening tools, Engineering Failure Analysis, 25, 219-226.

Kazakov A., Zhitenev, A., Ryaboshuk S., 2016. Interpretation and Classification of Non-Metallic Inclusions Materials Performance and Characterization, 5/3.

Mlikota, M., Schmauder, S., Dogahe, K., Božić, Ž., 2021. Influence of local residual stresses on fatigue crack initiation, Procedia Structural Integrity, 31, 3-7.

Woo, S., O'Neal, D. L.,2019. Reliability design and case study of mechanical system like a hinge kit system in refrigerator subjected to repetitive stresses. Engineering Failure Analysis, 99, 319–329.

Groche, P., Christiany, M., 2013. Evaluation of the potential of tool materials for the cold forming of advanced high strength steels. Wear, 302/1÷2, 1279–1285.