Metal coin error study using 3D modelling and FEM Analysis

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Abstract. Mints around the world produced a large amount of metal coins currency. Besides the coin basic design, in most of the situations, various amount of coins wearing different error types are released. The error type is depending on the coin metal, dimension and also by manufacturing step where it could appear. This coins and medals with mint errors are searched by collectors around the world. The paper presents some aspects about the cracked dies error, which appear at the coin striking tools or coin properly strike, because of some dies misalignments, failures and the reduced relief dimension. In the first part of the paper, some aspects about the cracked dies error are presented, with some particular examples. Then, the simplified dies 3D model is presented. Also, the finite element analysis on this model is realized and is achieved for different initial conditions. In the paper final part the analysis results and conclusions are presented.

1. Introduction

Metal coin currency manufacturing process is followed in most of the situations by a various amount of error types. The error type is depending on the coin manufacturing step where it could appear. There are known errors on the coin metal alloy, on the coin blank manufacture, at the striking tools manufacturing and, respectively, on the properly coin striking. The coins and medals with mint errors are most valuable on the collectors market: for increased spectacular error on coin or medal, the increased value for the subjected piece [1].

The metal coin is manufactured by pressing at high loads the coin blank with hardened steel negative dies, which forms a closed space to be filled by coin material. Generally, the model on the negative die is incused. After the coin striking, result the relief model on coin. The negative die is obtained before hardening, by pressing with a hardened steel positive die (also known as hub) with the relief model. A positive die is used to obtain a number of negative dies, used after hardening to strike the large amount of coins [2, 3]. If some errors or model changes appear on dies, the pressed coins will result with same error or model changes.

The cracked letters (or broken letters) can be observed as missing parts of some letters of the impressed inscription. The literature doesn’t reveal exactly the causes of this error in the coins manufacturing process. Moreover, the Romanian pieces wearing this error are often considered variants from the basic design [4]. In figure 1, a is presented a Romanian 1 ban bronze coin, minted in year 1900, with cracked letters on the obverse inscription. In figure 1, b the same error type is presented at Romanian 2 bani bronze coin, minted in year 1879, with cracked letters on the reverse inscription, respectively a 2 bani bronze coin from year 1882 with cracked letters on the obverse inscription, presented in figure 1, c.

a. b. c.

Figure 1. The cracked letters at various types of bronze coins

There are known various other coins with cracked letters at inscriptions; well known are also 2 bani 1900 (bronze), 1 leu 1873 (silver), 3 lei 1966 (nickel clad steel) or 50 lei 1994 (brass clad steel) [4].

From figure 1 it can be observed that the font used for the upper case letters inscription presents some thin portions, as the top and bottom of O, C, R. Also, the letters are round shape, eventually closed, or open with sharp edges. The coin diameter is also important: the 1 ban coin has 15 millimetres and 2 bani coin, 20 millimetres. At this coin size, the details of royal effigy, country armour and inscription should be clearly distinguished.

a. b.

Figure 2. The straight cracked dies impressed on coins

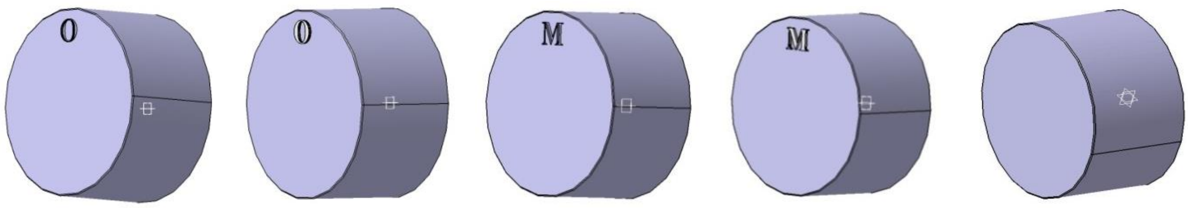
The cracked negative dies error is known at various Romanian and foreign modern coins [1, 4]. The properly die crack could be observed at coins, as a straight or curved rib impressed over the coin relief. Usually, there is one crack impressed on one coin face, but multiple cracks on the same face or cracks on both coin faces should not be excluded. The coins showing this error are considered by literature as properly error coins. In figure 2 there are presented two examples of dies cracks, pressed on Venezuelan 5 bolivars obverse, issued in 1989 (nickel), and also on Romanian 20 lei obverse, issued in 1943 (zinc). If the damaged die is not replaced, the crack increase and finally lead to the loosing of a die portion. In figure 3 can be observed the die crack in two different stages, on Romanian 20 lei 1944 coin reverse (zinc): from simple rib on coin face, to the die missing part; in that area, the coin has no model pressed.

a. b.

Figure 3. The crack evolution impressed on coins

2. The virtual model

As was presented, on a coin face there are multiple complex details. On a virtual model, these details cannot be faithfully reproduced. So, simplified models should computed for study. Were chosen two simple positive and also negative dies, each wearing a round closed letter O and also an open and sharp letter M. The CATIA software is used [7, 8].



a. Negative die, letter O | b. Positive die, letter O | c. Negative die, letter M | d. Positive die, letter M | e. Blank cylinder

Figure 4. The 3D model

The each die simplified model consist in a cylinder with engraved letter, for negative die, respectively a cylinder with a relief letter, for positive die. After the sketching of the parts, it follows the each part's virtual model computing, using the Part Design module. To simulate the dies loads, each die will be pressed on a blank cylinder. Using the Assembly Design module, the device assembly is computed, following the corresponding constraints.The dies and blank model are presented in figure 4, a, to 4, e.

3. Finite element analysis, simulation and results.

For the analysis, the ANSYS software is used. The analysis objective is to determine the pressed dies ensemble behaviour under the load. For the analysis, the simplified version of the virtual model is used, as is presented in figure 5. The material properties, for dies material (steel) and coin material (aluminum), as Young modulus, Poisson coefficient, Tensile Yield Strength, Ultimate Strength should be defined [6, 8].

In the contact area it is chosen a smooth mesh with the minimum edge length equal with 0.001 mm. The applied normal force is equal with 650KN, in order to obtain high contact pressures, over the allowable stress – 1600 MPa [2, 8].

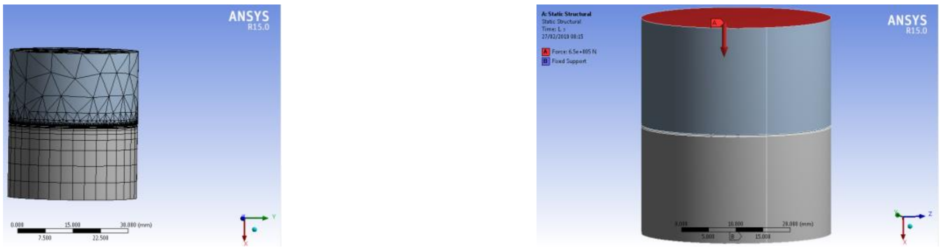


Figure 6. The finite element model

The each model of negative and positive dies will be pressed on the blank cylinder. For the dies models the considered material is steel. For the blank cylinder, the considered material may is steel. The results, presented in figures 7 to 10 and also in table 1, consist in the contact pressure maximum values and also the maximum values of the penetration in material.

Figure 7. The negative die with letter M pressed on steel

Figure 8. The negative die with letter O pressed on steel

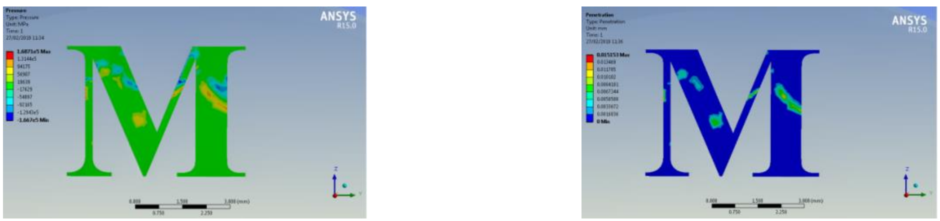


Figure 9. The positive die with letter M pressed on steel

Figure 10. The positive die with letter O pressed on steel

4. Conclusions

When the negative die is pressed on the blank, the first contact appears on the full circle area, except the incused letter. If the letter shape is closed, as O, the interior portion of it should be added to the contact area. So, the contact pressure and the penetration in material are relatively reduced. For studied letters, the penetration is larger to the fat details than to the thin details. The contact could be reduced to a circular segment if appear some misalignments between involved parts. In this case, the properly die crack could appear, only to the negative die. Following this, the crack is pressed on the coin together with the entire model. If the negative die crack appears at the coin striking, a reduced number of coins with the same error are released. If this error appears when the positive die is pressed, it is transmitted from negative die to the produced positive dies; then, to the next number of negative dies and finally to a large number of coins pressed with the same error.

When the positive die is pressed on the blank, the first contact appears on the area defined by the small letter contour. This area is dramatically reduced and the contact pressure and the penetration in material are highly increased. The positive letter profile penetration in the material is deeper, but the thin details of the letter are exposed to be damaged. The letter shape has a direct influence on the contact area: in the studied case, the O letter is in a slightly better condition than M, but the damages could also appear. This led to the case of the letter crack on the positive die, which led to the negative pressed with the broken letter having a missing part, which is finally pressed on the coins. Also, the appearance of this error can be combined with some misalignments between involved parts, which led to worse conditions. The coins wearing this error could be considered properly error coins.

Table 1. The contact pressure and the penetration in material, maximum values

The dies combination	Contact pressure, MPa	Penetration in the material, mm
Negative die with letter M pressed on steel	1743.4	0.0034622
Negative die with letter O pressed on steel	3909.3	0.00032802
Positive die with letter M pressed on steel	168710	0.015153
Positive die with letter O pressed on steel	160990	0.013837

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