sustainability

Article

Sustainable Approach to Metal Coin Canceling Methods, Using 3D Modeling and Finite Element Method Analysis

Cornel Cătălin Gavrilă [1,*], Mihai Tiberiu Lateş [1] and Gavril Grebenişan [2]

1 Department of Product Design, Mechatronics and Environment, Transilvania University of Braşov, 500036 Braşov, Romania; latesmt@unitbv.ro
2 Department of Industrial Engineering, University of Oradea, 410087 Oradea, Romania; grebe@uoradea.ro
* Correspondence: cgavrila@unitbv.ro; Tel.: +40-721-948-185

Abstract: Over time, many minted coins were withdrawn from circulation, being replaced with new ones. The returned, obsolete metal coins were melted in order to ensure sustainable reuse of the alloy for other purposes. Between the withdrawal and melting, some of the metal coins were canceled by the destruction of their original shape and dimensions using adequate tools. The first part of this paper is focused on presenting some insights into the canceling method used on old Romanian nickel coins; also, some examples are presented. The introduction also includes a literature review in the field of coin manufacturing, covering subjects such as metal behavior under striking load and aspects of 3D modeling and FEM analysis as well as explaining some striking errors. The main purpose of this paper is to study the particularities of canceling methods applied to coins, which is conducted on relatively valuable collection metal pieces. In the second part of the paper, an adequate 3D model is computed for the canceling dies and the coin. Then, the assembled models are introduced, corresponding to each canceling case, consisting of the obverse and reverse canceling dies with coins inside them. For each model, the finite element analysis is realized and is achieved for different initial conditions. The final part of the paper presents the analysis results as well as the discussion and conclusions.

Keywords: metal coin; coin withdrawn; coin canceling method; metal sustainable recycling; 3D modeling; FEM analysis; collectible item

check for updates

Citation: Gavrilă, C.C.; Lateş, M.T.; Grebenişan, G. Sustainable Approach to Metal Coin Canceling Methods, Using 3D Modeling and Finite Element Method Analysis. *Sustainability* **2024**, *16*, 2322. https://doi.org/10.3390/su16062322

Academic Editors: Alina Badulescu, Constantin Bungău, Delia Mirela Tit, Cosmin Mihai Vesa and Dorina Camelia Ilieș

Received: 28 December 2023
Revised: 2 February 2024
Accepted: 23 February 2024
Published: 11 March 2024

1. Introduction

1.1. Coin Minting and Withdrawal

Coin minting is a manufacturing process that consists of pressing a coin blank using a high load and with both hardened steel obverse and reverse negative dies, which, together with the collar, form a closed space to be filled by coin metal [1,2]. Usually, the relief figures on the negative dies are engraved; after the coin striking, the figures are embossed and engraved on the final metal coin [3]. Of course, the coin model also contains the circulating nominal value and the issuing authority [4].

Technical coin characteristics such as diameter, weight, alloy content and represented figures are provided by adequate legal provisions [5]. Also, the issuing terms are provided for the wider public. Following the circulation period, coin withdrawal is necessary, and it is also mandated by legal provisions, terms and conditions [5]. Valueless coins are retracted and, following the sustainable reuse of the metal alloy, are subjected to melting [6].

But not all issued coins are returned to the issuing authority. Some are retained by the public for different reasons: the metal pieces can be kept as a valuable memory from different times and places, as possible collector's items or without any reason [7]. Some other pieces were lost in different circumstances and found after many years [8].

Most of the obsolete metal coins, especially those with former small denominations, remain on the market after the withdrawal period as scrap metal pieces without any chance to be sustainably recycled. Different metal quantities, such as brass, nickel, bronze, aluminum and steel, can be found scattered as valueless metal discs in many places.

In the best case, over time, a valueless coin can acquire another value as a collector's item, depending on its age, state, rarity or metal; its price can subsequently fluctuate [4,9].

1.2. Coin Canceling

Countries around the world have been canceling the metal coins withdrawn from circulation. This is mainly carried out to prevent the metal coin from returning to circulation. Metal coin canceling (or metal coin defacing) consists of destruction if a coin via pressing between different die patterns [4]: lines, circles or other figures. A variety of these metal coin canceling figures are also known in the literature as waffle designs [10]. Some of the metal coins were canceled by perforating holes. Usually, the canceling is followed by melting in order to realize sustainable recycling of the coin's metal content, especially if the subject metal is precious. But, for different reasons, some of these canceled coins are placed on the collector's market. Due to the pieces' state of conservation, visual appeal and rarity, some are more valuable than others.

The literature indicates many canceled coins from different countries, such as the United Kingdom, Germany, the United States, Malaysia and the Philippines [10–12]. In Europe, the introduction of the euro currency generated a large hoard of canceled coins in the form of the former currency of the involved countries. For commercial purposes, some of them are presented in lots or sealed numismatic sets and are highly appreciated by collectors; for example, in Figure 1, there is a coin set containing the canceled coins of Belgium's former franc. After the euro currency introduction, some of the metal coins were defaced because of their inconsistent manufacture or eventual deterioration; these pieces are also recorded by specialty catalogs and internet sources [12,13].

Figure 1. Collectible numismatic set of canceled coins, obverse view.

In Romania, metal coin canceling was introduced by authorities during the interwar period and was applied to some withdrawn coins in order to recycle the precious metal but also to the discovered coin fakes to prevent their reintroduction into circulation before melting [5]. For example, in Figure 2, there are some canceled Romanian coins from the interwar period.

(**a**) (**b**) (**c**)

Figure 2. A few canceled Romanian metal coins: (**a**) a counterfeit 100 lei from 1932 which imitates the original made of silver, (**b**) perforated withdrawn silver 100 lei from 1932, (**c**) silver 250 lei from 1935.

The best-known Romanian coins that have been widely canceled are the nickel coins of 50 and 100 lei, minted between the years 1936–1938. These coins made of fine nickel, weighting 5.38 and 8.2 g, respectively, were circulated until 1941 when, due to the country's political changes and outbreak of war, they were withdrawn from circulation [4,5]. Their metal, fine nickel, was considered important to supply the war industry needs, and these obsolete coins had to be returned and replaced by other currency [14]. In order to prevent their reintroduction into circulation, their cancellation was mandated by law and had to be realized by those companies who indented to recycle the metal [14]. As a result, for each nominal value, more than 80% of the initial mintage was retracted [5], as shown in Table 1, where the valueless remaining pieces are also indicated. It has to be mentioned that the remaining undamaged pieces, less appreciated in the past than their undamaged counterparts, became valuable decades later on the collector's market [4,9]. But, to date, the exact number of melted pieces of the withdrawn coins which remained on market is still unknown.

Table 1. Issued, withdrawn and remaining pieces of 50 and 100 lei nickel coins.

Coin Nominal Value	Year	Issued Pieces	Withdrawn Pieces	Remaining Pieces [1]
50 lei	1937 1938	12,000,000 8,000,000	16,731,147	3,268,853
100 lei	1936 1938	16,750,000 3, 250,000	17,030,101	2,969,899

[1] Counted at the end of withdrawal period in early 1945.

These factors may lead collectors or interested customers to experience, on one hand, apprehension about acquiring an item of little value that they do not truly require [6]; on the other hand, they must also take into account the inclination to purchase the piece with the intention of capitalizing on it later at a higher price.

Today, the specialty literature [4,10,15] records a large number of canceled 50 and 100 lei nickel coins, as presented in Figure 3. Some of those canceling methods were previously used on other previous Romanian coins, as already presented in Figure 2.

The high demand for canceled coins to be melted and also the low maintenance costs of this operation led to a relatively deep print being obtained for the same type of cancellation; while on properly canceled pieces, the original coin pattern is hard to recognize, on superficially canceled ones, the coin pattern is almost unaffected by the cancellation method applied. Figure 4 presents well and poorly manufactured examples of the parallel lines canceling pattern.

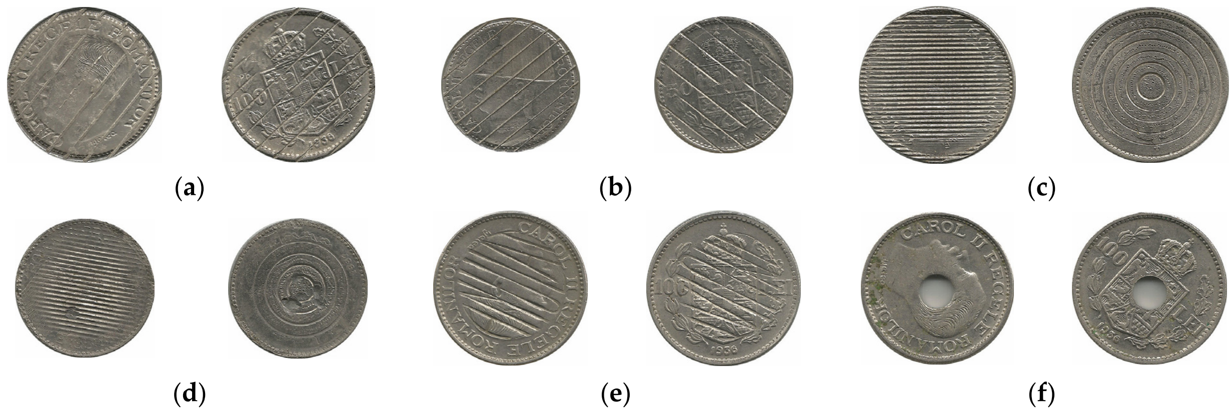


Figure 3. Various canceled Romanian nickel coins: (**a**,**b**) with parallel lines, (**c**,**d**) with circles and fine parallel lines, (**e**) with inscription and (**f**) hole perforations.

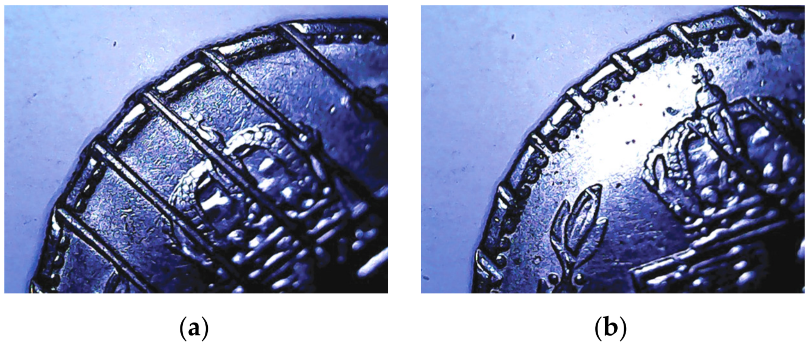


Figure 4. The parallel lines canceling pattern: (**a**) well and (**b**) poorly manufactured.

It has to be mentioned that the recorded canceling pattern fits both coin sizes: 24 mm for the 50 lei coin, and 27 mm for the 100 lei coin [4]. Also, the coin position between the canceling dies was random. It is also true that the coins were canceled in different places, using different tools and press machines [4,14]. The mentioned manufacturing conditions led to some questions about what caused some particularities of canceling patterns and which was the most productive, so the real motivation behind which canceling pattern was used may be revealed using modern study techniques.

In the literature, the coin-themed studies are focused mainly on striking procedures by considering theoretical or practical approaches. Insufficient attention has been given to studying the remaining and obsolete coins, particularly regarding specific methods for material recycling or potential cancellation procedures. A significant number of these pieces are still prevalent in the market as scrap metal, necessitating the implementation of sustainable recycling practices. Due to these aspects, this paper presents theoretical research regarding some aspects of the canceling procedure of the coins, as well as the canceling patterns.

2. Using of 3D Modeling and FEM Analysis in Coinage Field

The coin industry is guided through special regulations by most of the world's governments [1], so specific studies about the coining process are quite rare in the literature. Despite these inconveniences, the studied literature reveals important, comprehensive contributions in the coining field that should be mentioned as follows.

Brekelmans et al. [16] estimated in their work the conditions of coin material flow and also the adequate coining pressure in order to realize a conical relief feature in the central portion of a piece. The finite element method was applied in order to obtain accurate information regarding the corresponding stresses and strains. Also, the upper bound theorem was used, which offered the possibility to obtain more general results concerning the coining process; it was applied to an adequate quasistatic formulation with constitutive elastoplastic equations suitable for research into different parameters. Both methods were extensively described then evaluated, and a quantitative comparison with developed experiments was used for verification; as a result, excellent agreement was discovered. The work is considered by subsequent authors as the first application of the modern finite element method in the coin minting process.

Alexandrino et al. [2] consider that the previously studied research in the science and technology of coin minting can be structured in three main periods that cover the past five decades. In their research paper, the authors proposed a finite element method design procedure to correct the striking die relief in order to obtain an optimized pressure distribution and also the desired alignment for the resultant vertical force, measured at the end of the die stroke. This innovative design procedure for correcting the engraved die model, by tilting both the obverse and reverse die reliefs, shows that the numerical simulation is able to be used to optimize the die model shapes, in order to reduce the forces on coin minting and extend the die lifetime. The presented procedure was successfully applied at the state mint of Portugal to produce some collection coins, dedicated to the ancient age of iron and glass in Europe and also to the Portuguese ethnography. The coins were minted in 2017 [17].

In their research, Zhong et al. [1] studied the mechanism of flash-line defect appearance in the coining process. The flash line is considered by authors as one of the most important surface failures which can appear on manufactured coins. It is mostly unwanted on the silver commemorative coin. Usually, due to a lack of research into the causes of this defect, the failure requires a long time to be eliminated, through many die tryouts, leading to significant disruptions and increasing costs in the coin manufacturing process. Within the work, the mechanism of the flash line defect is revealed by the authors through metal flow analysis, using the modern finite element method. The authors concluded that the radial components of friction, which appeared between the die and the coin blank during striking, can be considered as the main reason for this defect. The authors also disclosed that the areas where defects easily manifest are those on the model field plane, which facilitates the compression and horizontal extrusion of metal flow. The die hardening effect and stress were also considered to be significant in the defect areas.

The mechanism of the flash-line defect which appeared in the coin manufacturing process was also studied by Xu et al. [18]; they estimated that the distribution of the flash-line surface defect is obtained by incrementally increasing the radial friction on the work model down to the elemental level. The large elastoplastic behavior of considered porous materials undergoing deformations is explored, and the constitutive minimization level updates are the result of the local variation problem. The material flow was studied on different die strokes during the complete coining, and it was observed that the change in the flow material direction in the coin outer rim portion may contribute to the formation of flash lines. A new method to investigate the rim geometry of the coin blank was proposed, in order to reduce the flash-line defects, which also resulted in strong alignment with the experimental findings.

In another work [3], Xu et al. developed commercial software, named CoinForm, which is able to analyze the material flow which appears during the coin manufacturing procedure. The presented software allows the prediction of the working force and the geometry optimization for the working dies.

Li et al. in their article [19] proposed an eight-node hexahedral element based on multi-point integration in a dynamic explicit framework, with a newly adopted adaptive subdivision method. Based on detailed numerical examples, the locking-free and also the hourglass-free properties of the introduced hexahedral element are validated; the accuracy of the striking simulation algorithm is also demonstrated. In the authors' opinion, this successful performance of the introduced element was validated by numerical examples without the locking phenomenon and hourglass problems taking place. Some practical coining simulations are also presented. In the first example, a simple round shape coin was designed, made from 99.9% Ag. In the second example, a complex key-shaped commemorative coin (also made from 99.9% Ag) was designed for 2010 World Expo in Shanghai. In both studied instances of practical coining, the simulation results closely matched the experimental findings, which led to the accuracy and also the stability of the proposed algorithm being determined with adaptive element subdivision.

The work of Keran et al. [20] is focused on providing an accurate estimation model of the applied force in the closed die coin striking manufacturing procedure. The authors consider that, in micro-forming procedures, such as coin striking, the microstructure of the metal and reduced size of the coined geometry may have an important influence on the coin metal deformation phenomenon. To determine the accuracy of the proposed force estimation model, the experimental and modeled data are statistically analyzed and also presented graphically by the authors.

The article of Peng et al. [21] presents adequate estimations related to stress distribution and material flow in the coin manufacturing procedure, applied in the case of a bimetallic commemorative coin, using professional software, named Deform 3D. The stress distribution and also the material flow during the coining procedures are studied and compared for a single metal and for bimetallic commemorative coins. The developed numerical examples reveal that there are three main typical stages during the entire procedure for both single and bimetallic coins. The stress concentrators appear on the striking die corners and, in addition, in the case of the bimetallic coin, on the material interface. Since the two metals with different hardness are used to produce the bimetallic coin core and also the bimetallic coin ring, the numerical results reveals that the large strains occur both at the coin's round edge and also at the interface between metals. These led to the conclusion that deep adhesion occurs on the metal's interface in the case when the soft material is used in the core. The authors suggest that adopting the hard material in the inner core and the soft one in the outer ring may cause the subsequent fall of the coin core. The findings of the article are also applicable to bimetal coins, which are eventually sustainably recycled to split the different metal cores and outer rings.

The specific literature on the studied coinage focuses on using modern methods such as 3D modeling and FEM analysis in a few main directions: creating theoretical support for the general real striking condition, resolving some particular issues appearing in striking of certain coins and studying and explaining the appearance of manufacturing errors in some coins. For each work, the obtained results are notable.

At the same time, the literature examined lacks depth in addressing coin cancellation techniques as well as the coin metal recycling issues.

The literature also lacks comprehensive studies using modern methods to explore intriguing and valuable coins as collectible items from past eras. This highlights the necessity to use the available modern techniques to study the particularities of the canceling methods used on certain former coins in order to simplify the value estimation process of the pieces as collector's items. In these cases, the collection items that have an adequate estimated catalogue value are able to increase customer satisfaction [22] and promote sustainable consumption practices in this field [7].

3. Computing the Virtual Model

As already presented, there are different types of imprinted patterns on canceled 50 and 100 lei coins: the same parallel lines or inscription applied on both coin faces and fine parallel lines applied on one face and concentric circles on the other face. The studied model contains both coin face canceling dies and also the coin. Due to the simplistic nature of the canceling die patterns, the studied coin exhibits numerous intricate details on its surface that cannot be accurately replicated in the virtual model [23,24]. Therefore, a simplified model of the 100 lei coin was developed, featuring only the main contour represented on both faces, as per the proper model. The coin angle between obverse–reverse figures, 180°, is measured: while the obverse figure is placed in normal position, the reverse figure is placed upside down. Taking account of this, the computing of the virtual model followed for all needed parts using the facilities offered by the module Part Design in CATIA V5 software [25,26]. Each canceling die model consists of a cylinder with an engraved negative contour pattern, as presented in Figure 5.

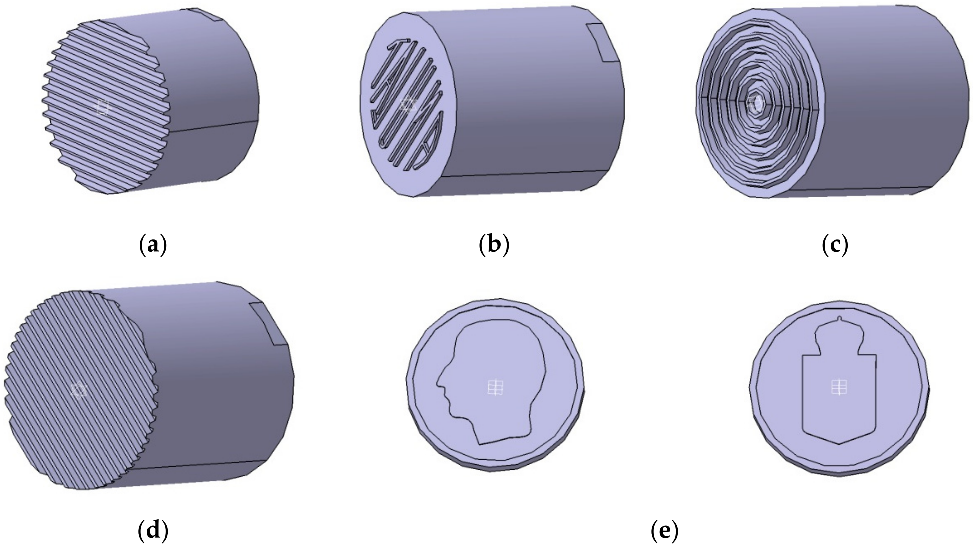


Figure 5. The virtual model parts: (**a**) canceling die with parallel lines, (**b**) canceling die with inscription, (**c**) canceling die with circles, (**d**) canceling die with fine parallel lines and (**e**) the coin from two perspectives.

To obtain each ensemble, the obtained individual parts must be combined: there are always two canceling dies having between them the introduced coins. Using the CATIA software's Assembly Design module [25,26], the device's assemblies were computed, as presented in Figure 6.

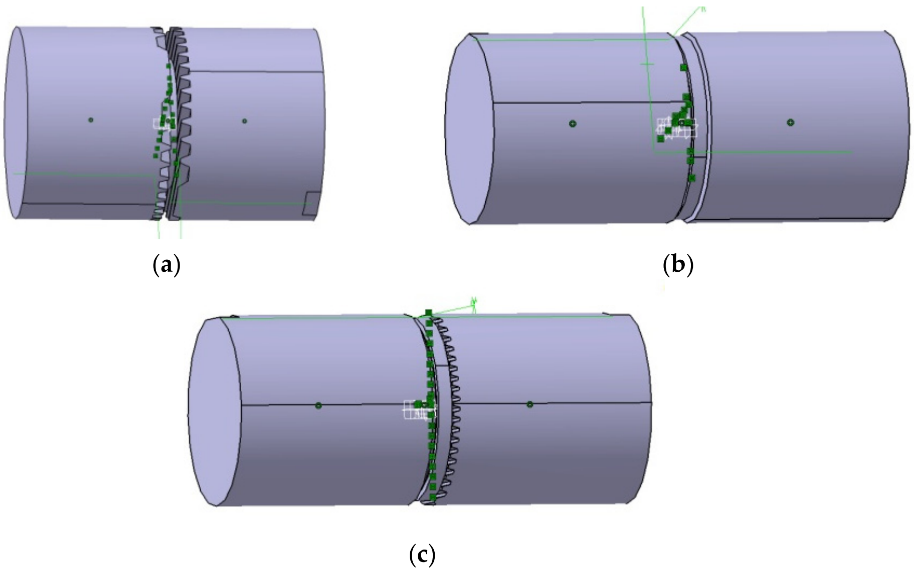
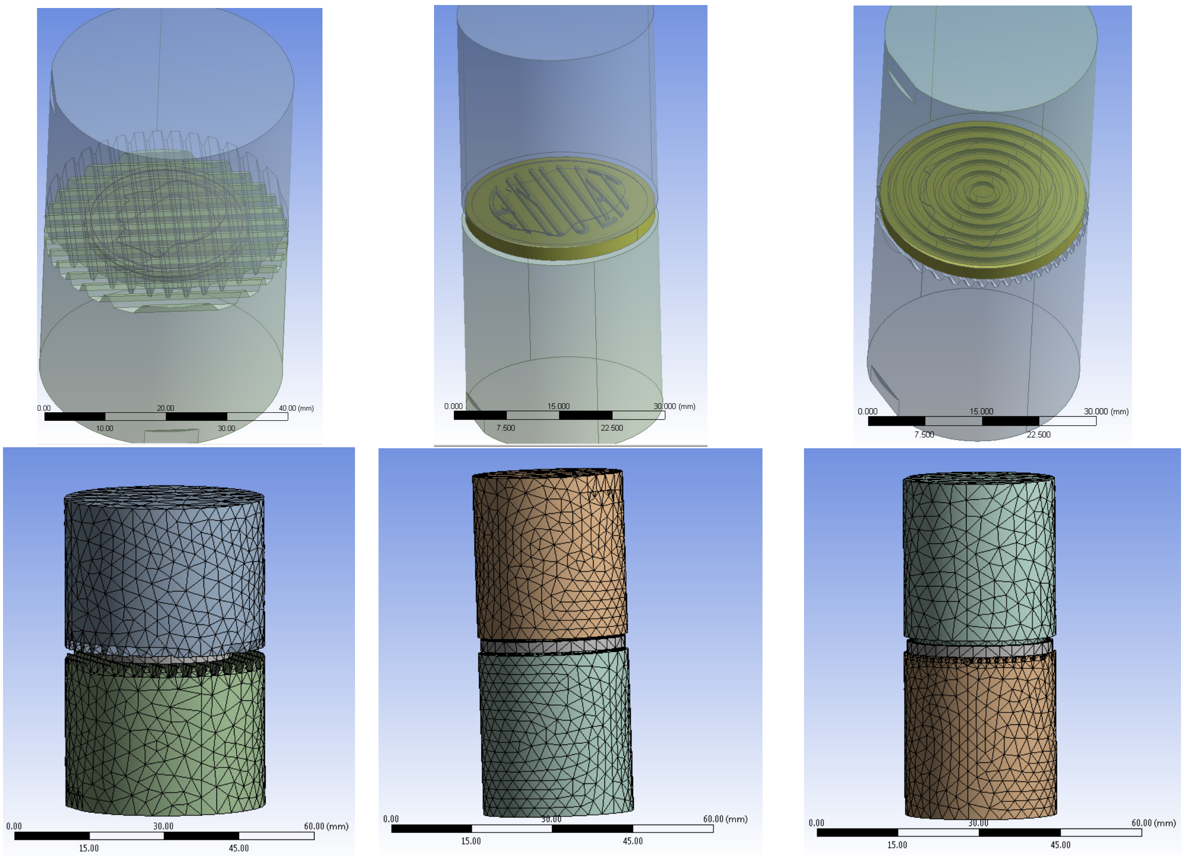


Figure 6. The ensemble models with the canceling die in contact with the coin: (**a**) both canceling dies with parallel lines, (**b**) both canceling dies with inscription and (**c**) one canceling die with circles and another with fine parallel lines.

Following the first contact surface between the pressed die pattern and coin samples, the ensemble constraints were adequately defined. The defined contact area between the canceling dies and coin samples encompasses, in the depicted figures, the entire highest common area. This situation occurs presumptively when there are no misalignments inside the pressing machine and the relief is flat [24,27]. For the first and second ensemble models from Figure 6, corresponding to both faces parallel lines and the inscription on both faces, respectively, the canceling die position in the model reproduces the real pattern position, when the obverse–reverse angle between the lines or inscription is 90^0. For the third ensemble model in Figure 6, corresponding to the fine parallel lines on one face and concentric circles on the other face, the canceling die position in the model is not relevant.

4. Finite Element Model, Analysis and Simulation

To perform the analysis, the ANSYS 15.0 software was used [28]. The evaluation aims to ascertain the behavior of the pressed canceling dies on the coin ensemble when subjected to a load. In the analysis, the previously computed virtual assembled models were used. In the following figure, Figure 7, the adequate finite element model view and geometry are presented. They were previously computed for all of three studied cases: the model with the parallel lines canceling pattern on both faces, the model with the inscription "ANULAT" on both faces and the model with fine parallel lines on one face and concentric circles on the other face as canceling patterns.



(**a**) (**b**) (**c**)

Figure 7. The obtained finite element model: (**a**) for both canceling dies with parallel lines, (**b**) for both canceling dies with inscription and (**c**) for one canceling die with circles and another with fine parallel lines.

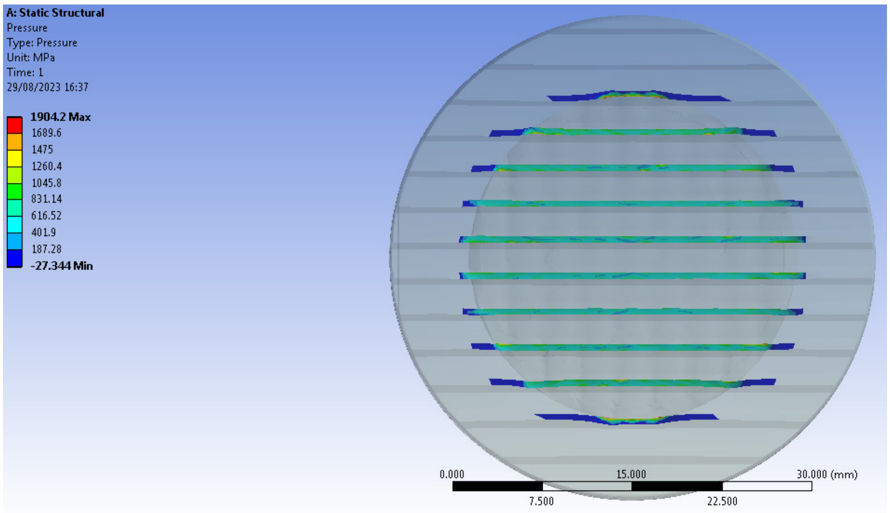
The chosen material for canceling dies is hardened steel; it has the following mechanical properties: *density of* 7850 kg/m^3, *tensile yield strength* of 250 MPa, *tensile ultimate strength* of 460 MPa, a *Young's modulus* of 200,000 MPa and a *Poisson's ratio* of 0.3 [23,28,29]. The coin material is nickel, with the following mechanical properties: *density* of 8900 kg/m^3, *tensile yield strength* of 59 MPa, *tensile ultimate strength* of 317 MPa, a *shear modulus* of 76,000 MPa and a *Poisson's ratio* of 0.31 [23,28,29]. In the studied contact area, a smooth mesh with the minimum edge length equal to 0.001 mm was chosen. Taking into account that the canceling dies do not form a closed space around the pressed coin, the literature indicates that the chosen coin material's allowable stress should be decreased by 30–50%, related to the value corresponding to the closed space coin striking [30,31].

The size of the finite elements varies between 0.15 mm and 1.2 mm, with small values in the contact region between the assembled parts. Tetrahedral-type finite elements are used. The tetrahedral shape finite element is the best 3D-type finite element, which assures the smallest discretization error [28]. The values for the size of the finite elements were established in concordance with the dimensions of the engraving patterns. In the finite element model, a bonded contact type was employed to reflect practical conditions. This decision was made because the construction assembly does not permit horizontal motion of the coins or canceling dies.

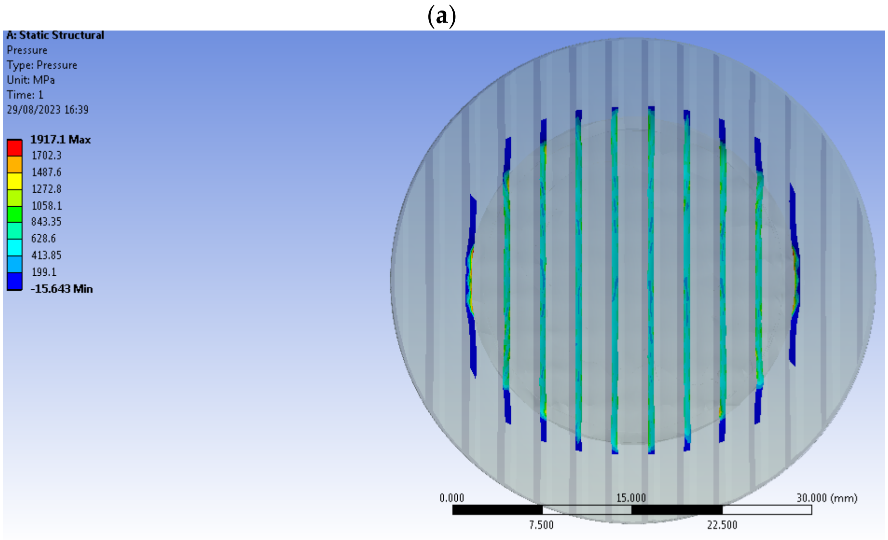
The applied normal force is equal to 60 KN in order to obtain high contact pressures, over the canceled coin material's *allowable stress*, 1000 MPa [5,30–32].

5. Results and Discussion

For all three studied cases, the results are presented in Table 2 and in Figures 8–15 and consist of the maximum contact pressure values and also the maximum penetration values on the each canceling die material. Therefore, the values presented in Table 2 should be viewed as relative and are useful when evaluating the different studied cases.

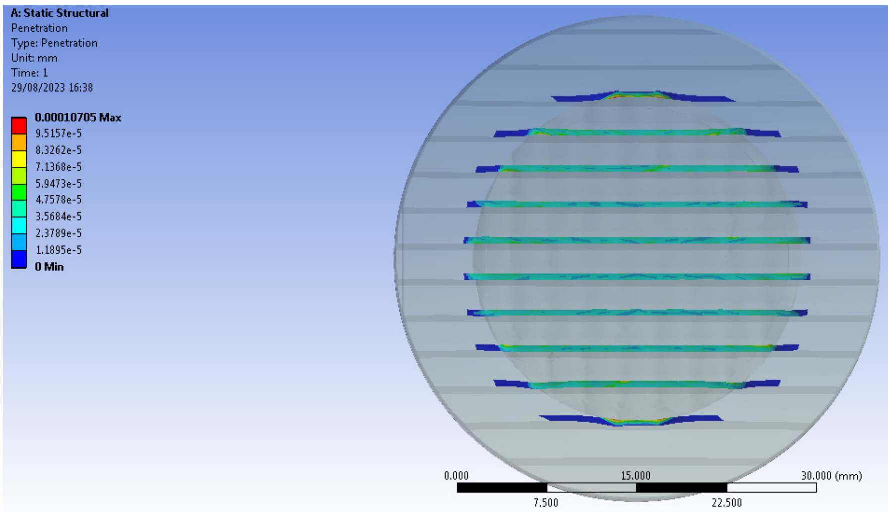


(**a**)

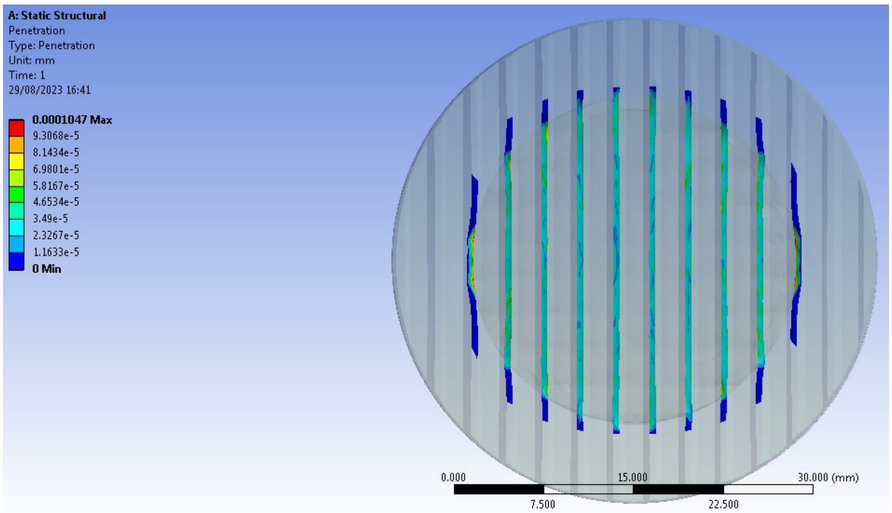


(**b**)

Figure 8. The contact pressure on the parallel lines pattern canceling dies: (**a**) obverse canceling die and (**b**) reverse canceling die.

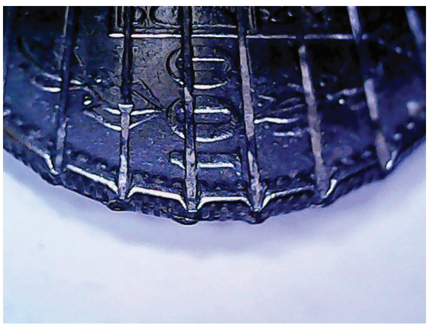


(**a**)



(**b**)

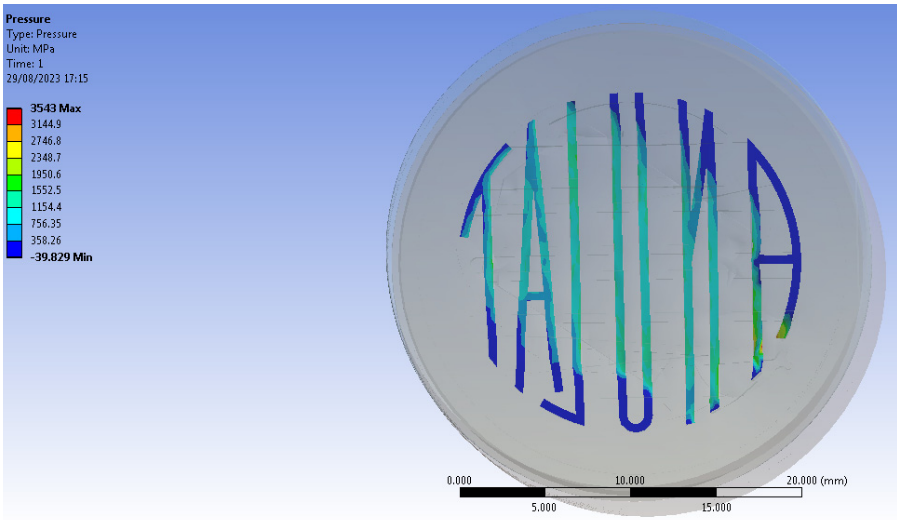
Figure 9. The penetration on the parallel lines pattern canceling dies: (**a**) obverse canceling die and (**b**) reverse canceling die.



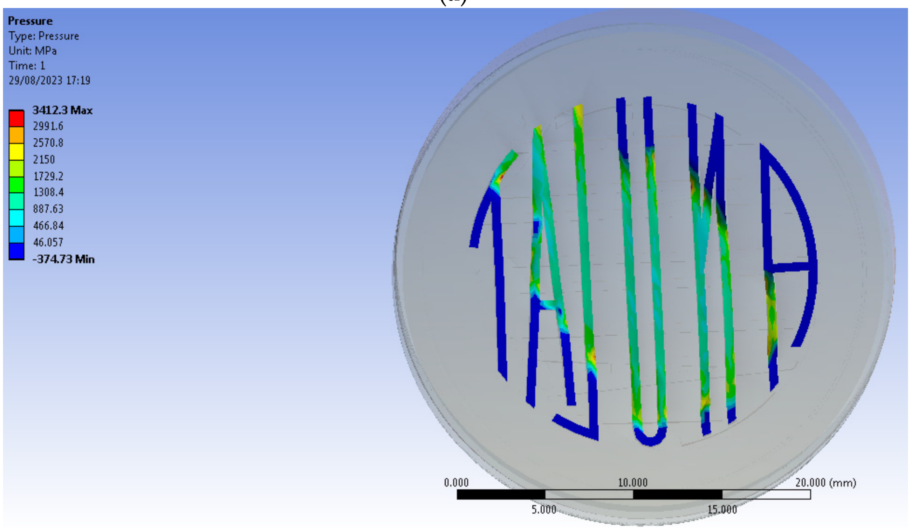
(**a**)

(**b**)

Figure 10. The dislocated edges on lines pattern canceled coin: (**a**) perspective and (**b**) normal view.

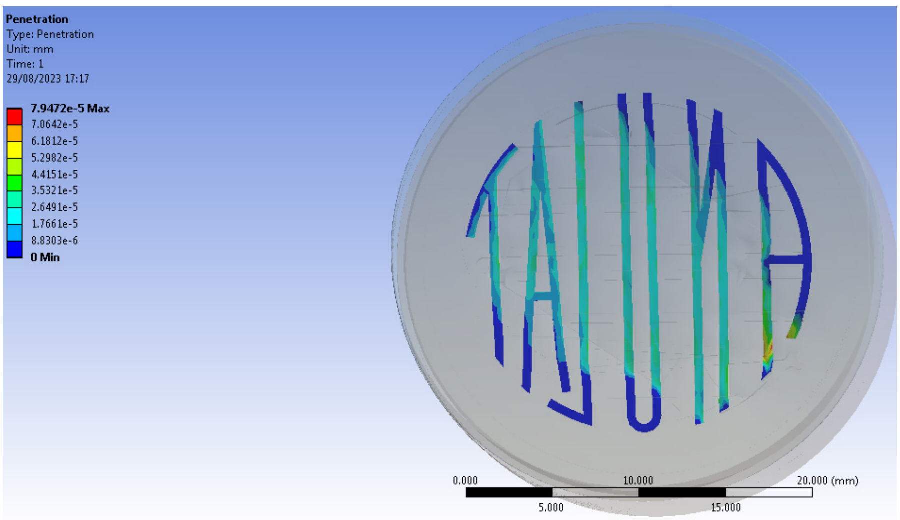


(**a**)



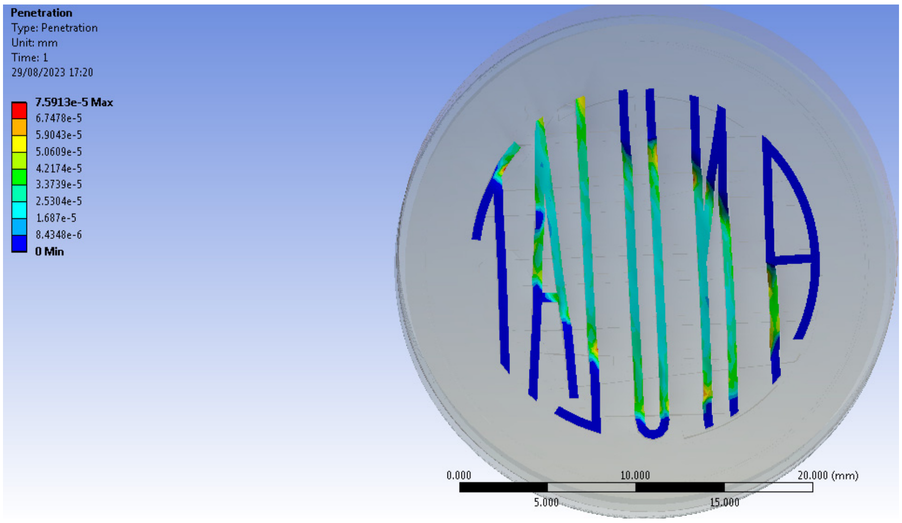
(**b**)

Figure 11. The contact pressure on "ANULAT" pattern canceling dies: (**a**) obverse canceling die and (**b**) reverse canceling die.



(**a**)

Figure 12. *Cont.*

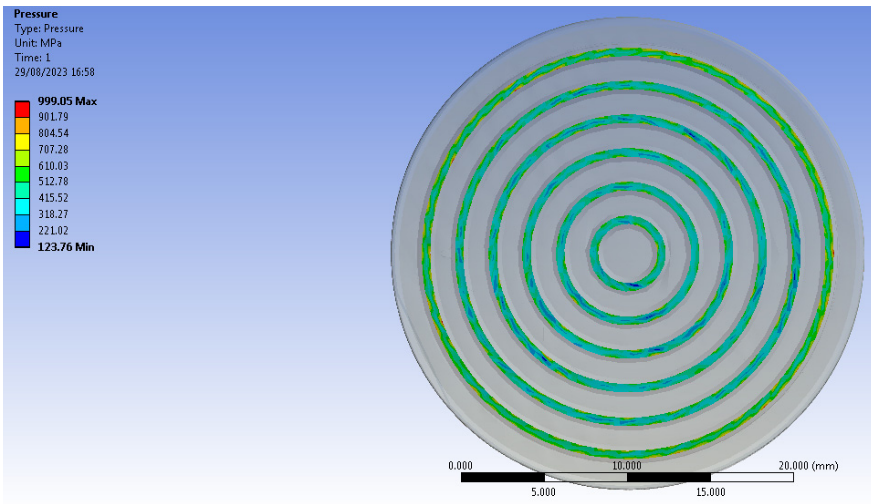


(**b**)

Figure 12. The penetration on "ANULAT" pattern canceling dies: (**a**) obverse canceling die and (**b**) reverse canceling die.

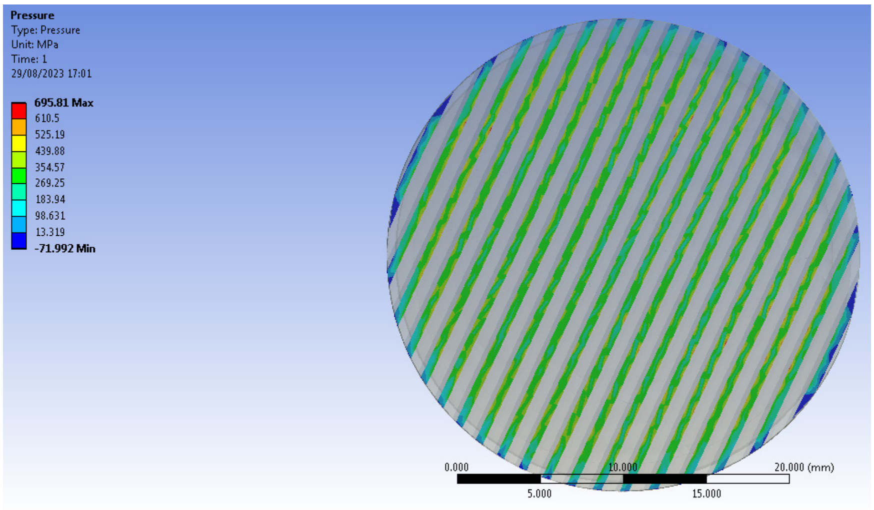
(**a**) (**b**)

Figure 13. The "ANULAT" pattern canceled coin: (**a**) obverse view and (**b**) reverse view.



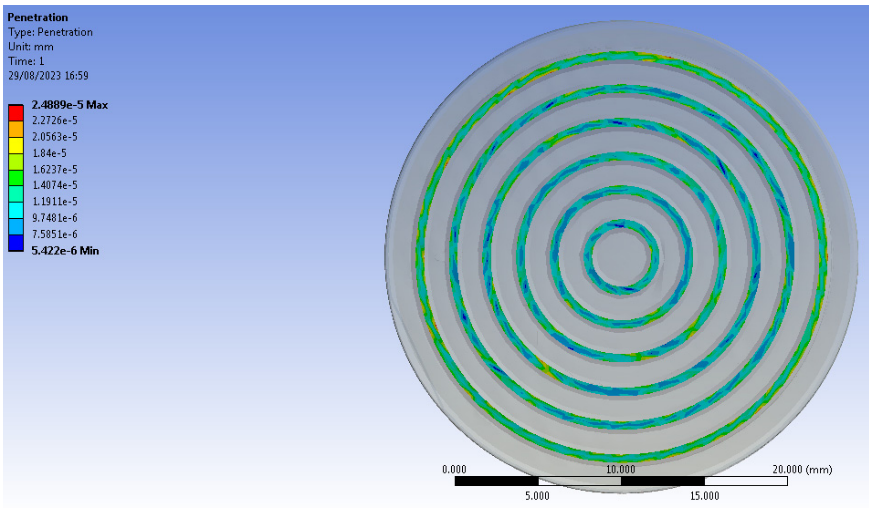
(**a**)

Figure 14. *Cont.*

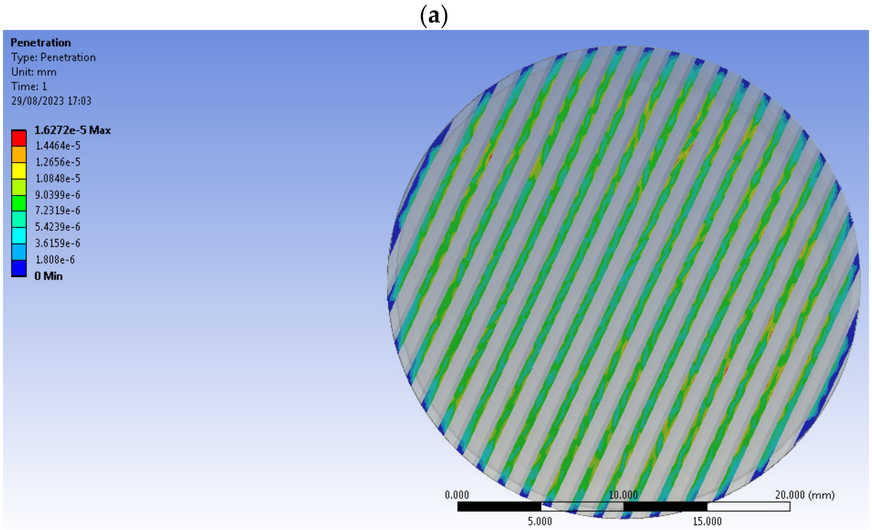


(**b**)

Figure 14. The contact pressure on the concentric circles and fine parallel lines pattern canceling dies: (**a**) obverse canceling die and (**b**) reverse canceling die.



(**a**)



(**b**)

Figure 15. The penetration on the concentric circles and fine parallel lines pattern canceling dies: (**a**) obverse canceling die and (**b**) reverse canceling die.

Table 2. The contact pressure and the penetration on canceling dies, maximum values, for the loading case of 60 KN.

The Canceling Dies	Contact Pressure, MPa		Penetration in the Material, mm	
	Coin Obverse Canceling Die	Coin Reverse Canceling Die	Coin Obverse Canceling Die	Coin Reverse Canceling Die
On both faces, parallel lines	1904.2	1917.1	0.00010705	0.0001047
On both faces, the inscription "ANULAT"	3543	3412.3	0.000079472	0.000075913
Concentric circles on coin obverse combined with fine parallel lines on coin reverse	999.05	695.81	0.000024889	0.000016272

In the initial model under examination, which features a parallel lines canceling pattern on both faces, the maximum values of related contact pressure are similar to each other. Minor discrepancies arise due to variations in the shapes of the represented contours on the coin's obverse and reverse sides. For slightly increased contact areas, the maximum contact pressure values decrease slightly. From Figure 8 it can be observed that those maximum values are recorded close to the coin outer edge, where, due to the coin metal flow, the stress concentrators are increased, as described in [18,19,21]. The other values appear in the main contact area and exceed the coin material's allowable stress. The maximum penetration values are also recorded near the coin's outer edge and are close for both obverse and reverse canceling die patterns, as presented in Figure 9. Due to the open space pressing procedure, the pieces are deformed from the original round shape; on the piece edges, the dislocated metal along the canceling lines can be observed, as is detailed in Figure 10. On the well-canceled pieces, the resulting edges are quite prominent.

For the second model, with the inscription "ANULAT" on both faces, the maximum values of the related contact pressure are closely aligned; additionally, minor variations result from the differing shapes of the depicted contours on both the obverse and reverse sides of the coin.

Because the canceling dies are smaller than the coin's outer ring, it is evident from Figure 11 that the maximum values are recorded close to each face model edge contour, as is also described in [20,21]; because of the stiffness of the coin material in the direction of the applied load, the contours of the faces influence their contact pressure in the contact area [20].

The other values appear in the main contact area and exceed the coin material's allowable stress. But some of the contact pressure values also exceed the die material's allowable stress, so the dies are damaged. This led to the conclusion that this type of canceling was applied using manually operated small pressing machines. The maximum penetration values are also recorded near the coin figures edge contour and are close for both obverse and reverse canceling die patterns, as presented in Figure 12. Due to the open space pressing procedure, the coin metal is dislocated only in the surrounding area by the canceling die letters' contours, as described in [33]. For finished pieces, the coin's round shape and dimensions remained unchanged.

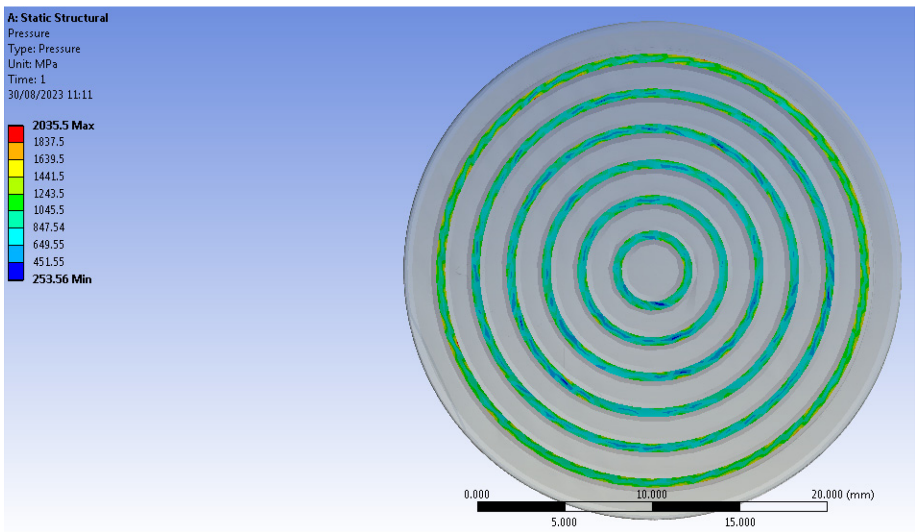
The third model has the canceling pattern of concentric circles applied on the coin obverse and fine parallel lines applied on the coin reverse. The varying patterns applied to the coin faces result in significant differences in the contact area; in this case, the coin face's model differences are less important. The decreased area under the circles pattern led to increased maximum contact pressure values; also, the increased area under the fine lines pattern led to decreased maximum contact pressure values, as presented in Figure 14.

Since the circles pattern is close to exceeding the coin material's allowable stress, the fine lines pattern remains significantly below it. The maximum penetration values, presented in Figure 15, have the same trend: for the circles pattern, the value is higher than for the fine lines pattern. It can be concluded that the load value, 60 KN, was not adequate for this canceling method. The required load must be obtained from a larger pressing machine.

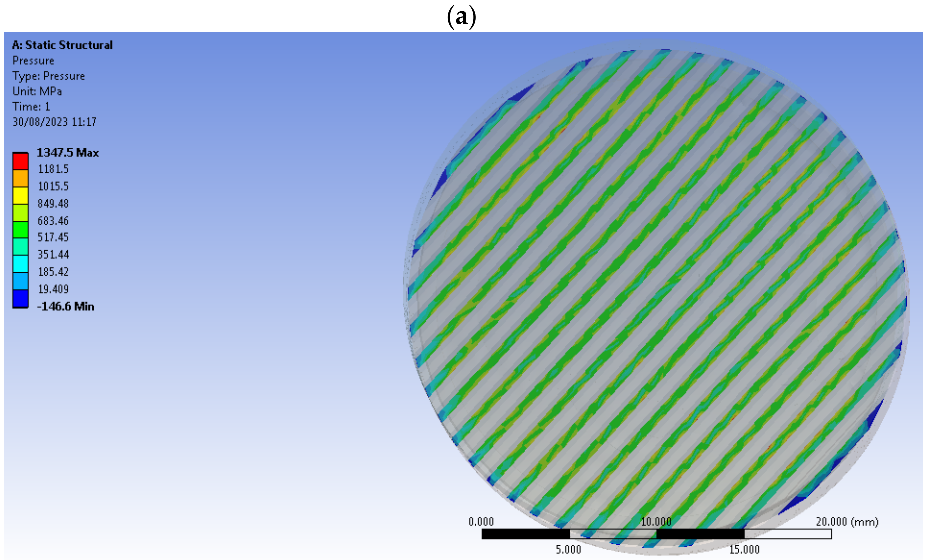
Consequently, this model was again simulated with an increased load, 120 KN [5,30–32]. The results are presented in Table 3 and also in Figures 16 and 17. The increased load led to increased contact pressure and maximum penetration values, but, due to the different contact area, the differences between the obverse and reverse values are maintained. The contact pressure on the fine line pattern eventually surpasses the material's allowable stress level for the pressed coin. But, at the same time, the values are elevated, exceeding the allowable stress of the die material. So, the circular pattern die is subjected to the most damage.

Table 3. The contact pressure and the penetration on canceling dies, maximum values, for loading case 120 KN.

The Canceling Dies	Contact Pressure, MPa		Penetration in the Material, mm	
	Coin Obverse Canceling Die	Coin Reverse Canceling Die	Coin Obverse Canceling Die	Coin Reverse Canceling Die
Concentric circles on coin obverse combined with fine parallel lines on coin reverse	2035.5	1347.5	0.000050711	0.000031489

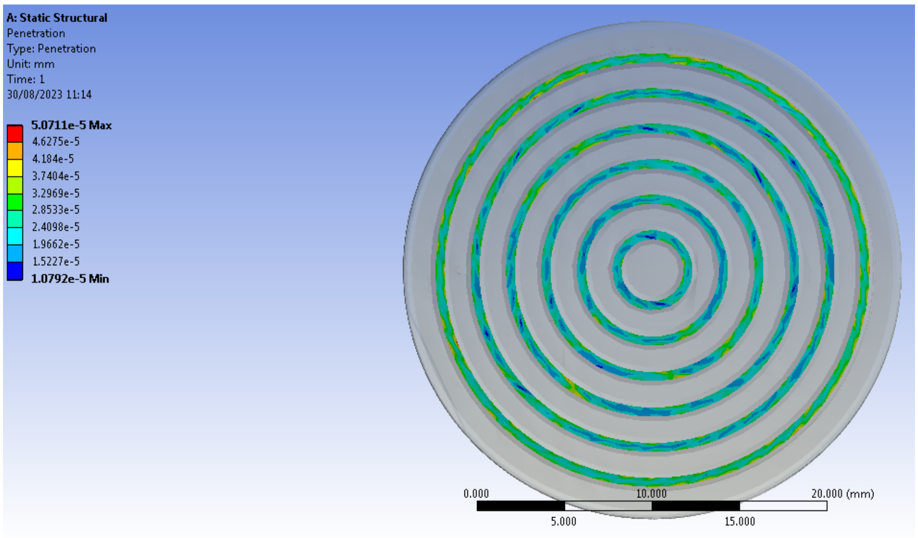


(**a**)

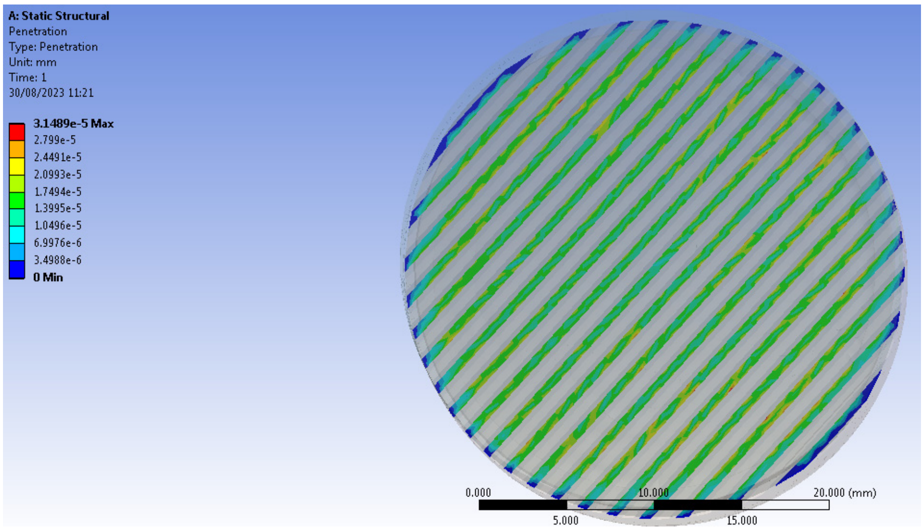


(**b**)

Figure 16. The contact pressure for the increased load on the concentric circles and fine parallel lines pattern canceling dies: (**a**) obverse canceling die and (**b**) reverse canceling die.



(**a**)



(**b**)

Figure 17. The penetration for the increased load on the concentric circles and fine parallel lines pattern canceling dies: (**a**) obverse canceling die and (**b**) reverse canceling die.

During the open space pressing procedure, the coin metal flow led to the piece's deformation on the outside, and the involved canceling dies behave like closed space striking dies. As a result, some of the coins canceled with these pattern types have flash-line defects impressed on both faces, as described in [1,18] and presented in Figures 18 and 19. In addition, the die cracks, as presented in [11,32], may occur on the circle's devaluated face, as detailed in Figure 18. It seems that this canceling die combination was not resistant to the large numbers of manufactured pieces; some sources indicate that the circle design's weak part was eventually replaced with the fine parallel lines pattern [12].

(**a**) (**b**)

Figure 18. The concentric circles and fine parallel lines pattern canceled coin: (**a**) the unaffected obverse fine lines die, (**b**) the circled reverse die, affected by the initial fine flash line on edge and a radial die crack.

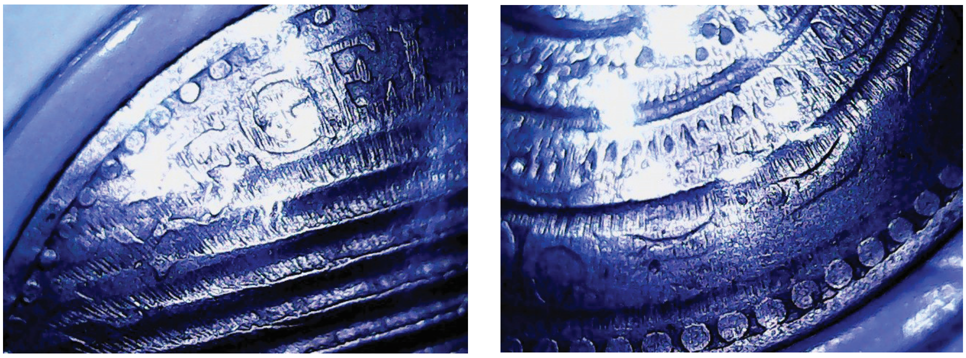


Figure 19. Another coin canceled with the concentric circles and fine parallel lines pattern, with advanced flash-line defects on both faces.

6. Conclusions

In this paper, the particularities of three different canceling methods applied on withdrawn nickel coins are studied. The research led to some conclusions, as follows:

- The withdrawal of more than 80% issued nickel coins and their canceling and metal recycling, even during wartime, can be considered today as a sustainable procedure for that time;
- The three studied models indicate that the coin canceling was carried out using different types of pressing machines. These generated different loads, not necessarily well adapted to the applied canceling method;
- The research reveals that the similar applied pattern used for both coin faces assured a longer die lifetime, and the different patterns used on the coin faces led to the destruction of overloaded dies;
- The improper mating and usage of canceling dies resulted in defects being impressed on the resulting pieces. These defects are closely related to those described by other authors for properly struck coins.
- It was found that it is easier to relate the impressed canceling pattern to the adequate value estimation for the resulting piece;
- By the proposed sustainable approach, this paper obtained results which are useful in further research on other different metal coin canceling and recycling techniques, as well as for establishing the market value of the pieces;
- The research based on the finite element analysis presented in this paper offers flexibility regarding the inputs (striking loads, materials of the coins and dies, discretization), but also there are some limitations to be improved regarding the geometrical modeling, given the size and the detailed complexity of the studied coins.

Author Contributions: Conceptualization, C.C.G.; methodology, C.C.G. and M.T.L.; software, C.C.G. and M.T.L.; validation, C.C.G., M.T.L. and G.G.; formal analysis, C.C.G. and M.T.L.; investigation, C.C.G.; resources, C.C.G., M.T.L. and G.G.; data curation, C.C.G. and M.T.L.; writing—original draft preparation, C.C.G.; writing—review and editing, C.C.G.; visualization, C.C.G. and M.T.L.; supervision, C.C.G., M.T.L. and G.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Zhong, W.; Liu, Y.; Hu, Y.; Li, S.; Lai, M. Research on the Mechanism of Flash Line Defect in Coining. *Int. J. Adv. Manuf. Technol.* **2012**, *63*, 939–953. [CrossRef]
2. Alexandrino, P.; Leitão, P.J.; Alves, L.M.; Martins, P.A.F. Finite Element Design Procedure for Correcting the Coining Die Profiles. *Manuf. Rev.* **2018**, *5*, 3. [CrossRef]
3. Xu, J.P.; Liu, Y.Q.; Li, S.Q.; Wu, S.C. Fast Analysis System for Embossing Process Simulation of Commemorative Coin–CoinForm. *Comput. Model. Eng. Sci.* **2008**, *38*, 201–215.
4. Buzdugan, G.; Luchian, O.; Oprescu, C.C. *Romanian Coins and Banknotes*; Editura Sport Turism: Bucureşti, Romania, 1977; pp. 256–259.
5. Finance Ministry. *National Mint, Ten Years of Activity*; Monitorul Oficial şi Imprimeriile Statului: Bucureşti, Romania, 1945; pp. 81–87.
6. Petean, I.; Paltinean, G.A.; Taut, A.C.; Avram, S.E.; Pripon, E.; Barbu Tudoran, L.; Borodi, G. Ag and Sn Implications in 3-Polker Coins Forgeries Evidenced by Non destructive Methods. *Materials* **2023**, *16*, 5809. [CrossRef] [PubMed]
7. Dabija, D.-C.; Csorba, L.M.; Isac, F.-L.; Rusu, S. Managing Sustainable Sharing Economy Platforms: A Stimulus–Organism–Response Based Structural Equation Modelling on an Emerging Market. *Sustainability* **2023**, *15*, 5583. [CrossRef]
8. Petean, I.; Paltinean, G.A.; Pripon, E.; Borodi, G.; Barbu Tudoran, L. Silver Depreciation in 3-Polker Coins Issued during 1619–1627 by Sigismund III Vasa King of Poland. *Materials* **2022**, *15*, 7514. [CrossRef] [PubMed]
9. Krause, C.; Mishler, C. *Standard Catalog of World Coins*; Krause Publications: Iola, KS, USA, 2001.
10. Snyder, B. World Mints Deface Coins with "Waffle Designs". *Mint Errors News* **2004**, *5*, 10.
11. de Olivier, F.; Michel, P. *Euro 4, Monnaies et Billets*; Edition Les Chevau-Lègers: Paris, France, 2007; p. 205.
12. Coin World. Available online: https://www.coinworld.com/news/us-coins/canceled-coins-can-sometimes-return-to-the-co.html (accessed on 15 December 2023).
13. Error-Ref. Available online: https://www.error-ref.com/canceled-waffled/ (accessed on 20 September 2023).
14. Romanian Government. *The Official Monitor of Romania*; Monitorul Oficial şi Imprimeriile Statului: Bucureşti, Romania, 1941; No. 189; Part I; pp. 4708–4709.
15. Romanian Coins. Available online: https://romaniancoins.org/ (accessed on 20 September 2023).
16. Brekelmans, W.A.M.; Mulders, L.H.G.; Ramaekers, J.A.H. The Coining Process: Analytical Simulations Evaluated. *CIRP Ann. Manuf. Technol.* **1988**, *37*, 235–238. [CrossRef]
17. Catalogue Euro. *Coins and Banknotes*; Leuchtturm Albenverlag GmbH & Co. KG: Geesthacht, Germany, 2019; p. 529.
18. Xu, J.P.; Khan, K.A.; Sayed, T.E. A Novel Method to Alleviate Flash-Line Defects in Coining Process. *Precis. Eng.* **2012**, *37*, 389–398. [CrossRef]
19. Li, Q.; Zhong, W.; Liu, Y.; Zhang, Z. A New Locking-Free Hexahedral Element with Adaptive Subdivision for Explicit Coining Simulation. *Int. J. Mech. Sci.* **2017**, *128–129*, 105–115. [CrossRef]
20. Keran, Z.; Kondic, Z.; Piljec, P.; Runje, B. Accuracy of Model Force Prediction in Closed Die Coining Process. *J. Mech. Eng.* **2018**, *64*, 225–232.
21. Peng, Y.; Xu, J.; Wang, Y. Predictions of Stress Distribution and Material Flow in Coining Process for Bi-Material Commemorative Coin. *Mater. Res. Express* **2022**, *9*, 066505. [CrossRef]
22. Huang, T.-C.; Ho, C.-T. Are Customers Always Right? The Importance of Sincerity and Keenness in Creating Retail Sustainable Development. *Sustainability* **2023**, *15*, 5579. [CrossRef]
23. Arndt, C.; Crusenberry, C.; Heng, B.; Butler, R.; TerMaath, S. Reduced-Dimension Surrogate Modeling to Characterize the Damage Tolerance of Composite/Metal Structures. *Modelling* **2023**, *4*, 485–514. [CrossRef]
24. Gavrilă, C.C.; Lateş, M.T. 3D Modelling and FEM Analysis on Die Clash Mint Error. *IOP Conf. Ser. Mater. Sci. Eng.* **2020**, *898*, 012040. [CrossRef]
25. Ghionea, I.G. CATIA v5. In *Application in Mechanical Engineering*; Editura Bren: Bucureşti, Romania, 2009.
26. Ghionea, I.G. CATIA v5. In *Parametric Design and Programming Applications*; Editura Printech: Bucureşti, Romania, 2021.
27. Hilbert, H. *Stanzereitechnik*; Carl Hanser Verlag: Munchen, Germany, 1938; Volume I, pp. 14+196.

28. Lee, H.H. *Finite Element Simulations with ANSYS Workbench 14. Theory, Applications, Case Studies*; Schroff Development Corporation: Mission, KS, USA, 2012.
29. Geru, N.; Chircă, D.; Bane, M.; Ripoşan, I.; Marin, M.; Coşmeleaţă, G.; Biolaru, T. *Metallic Materials. Structure, Properties, Uses*; Editura Tehnică: Bucureşti, Romania, 1985.
30. Romanovski, V.P. *Stamping and Cold Molding*; Editura Tehnica: Bucureşti, Romania, 1970; pp. 427–428.
31. Iliescu, C.; Tureac, O. *Cold Pressing Technology*; Editura Universităţii: Braşov, Romania, 1987; pp. 262–267.
32. Gavrilă, C.C.; Lateş, M.T. 3D Modelling and FEM Analysis on Holed Metal Coin Striking Die Mint Error. *IOP Conf. Ser. Mater. Sci. Eng.* **2022**, *1256*, 012001. [CrossRef]
33. Gavrilă, C.C.; Lateş, M.T. 3D Modelling and FEM Analysis on Metal Coin Edge Punching Error. *IOP Conf. Ser. Mater. Sci. Eng.* **2021**, *1169*, 012006. [CrossRef]