OPTIMIZATION OF CUTTING DIE LIFE CYCLE AND INVESTIGATION OF PARAMETERS AFFECTING DIE LIFE CYCLE

Pinar Demircioglu[1,2*] – Ismail Bogrekci[2] – Yavuz Eris[2,3] – Suleyman Can Ozkan[3]

[1]Institute of Materials Science, TUM School of Engineering and Design, Technical University of Munich, Garching, 85748, Germany
[2]Department of Mechanical Engineering, Faculty of Engineering, Aydin Adnan Menderes University, Aydin, 09100, Turkey
[3]Design Center, JMW Company - Jantsa Magnetto Wheels, Aydin, 09100, Turkey

ARTICLE INFO

***Article history*:**
Received:05.06.2023.
Received in revised form: 26.06.2023.
Accepted: 07.02.2024.

Keywords:
Coating
Cutting die
Die life cycle
Life cycle optimization
Manufacturing method
Matrix
Punch
Ventilation hole

DOI: https://doi.org/10.30765/er.2273

Abstract:

In this study, an investigation into the factors influencing the die life cycle was prompted by the substantial costs associated with punch and matrix wear in the die used for ventilation hole cutting of the disc component, featuring MW05 material. The study focused on optimizing the life cycle through a series of experiments conducted in two stages. Initially, punch life cycle studies, including geometry and PVD surface coating, were carried out. Subsequently, matrix life cycle studies encompassing hardness, manufacturing method, surface roughness, press tonnage, and alternative material were conducted. The introduction of a flat area around the cutting edge of the punches led to a significant reduction in abrasive wear, while the modification to the punch design, coupled with AlCrN surface coating, effectively decreased adhesive wear on the cutting contour, resulting in an increased punch life cycle. Notably, a transition from wire erosion to milling machining for the matrix cutting contour yielded a substantial improvement in the matrix life cycle. These advancements in die life cycle optimization will serve as vital inputs for new die designs. Quantitative results reveal a 15-fold increase in punch life cycle and a 3.33-fold increase in matrix life cycle, demonstrating the efficacy of the implemented modifications.

1 Introduction

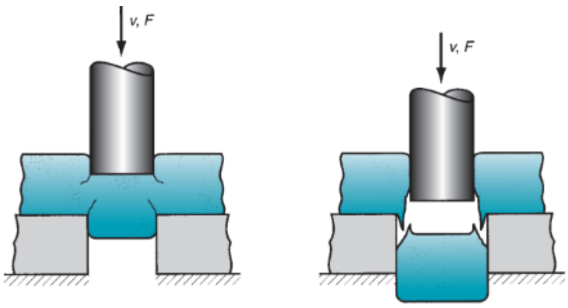
In modern manufacturing, the precise shaping of sheet metal components is viewed main across diverse industries. A central role in this process is played by cutting dies, powerful tools that exert force to transform raw materials. The significance of this technique is recognized in mass production sectors such as automotive, white goods, aviation, electronics, railway cars, and office furniture. The cutting operation reveals in three distinct stages. In the first stage of plastic deformation, the punch initiates movement towards the material to be cut. Upon contact with the material surface, forces are generated, leading to plastic strain once the material surpasses its elasticity limit [1]. The second stage, penetration, involves the actual cutting process. The material is cut with the assistance of both the punch and the matrix. Deformation occurs at the cutting edge of the punch and the radius at the bottom edge of the matrix. As a result, the material begins to be cut at the edges of the punch and matrix, subsequently progressing into the cutting clearance. Here, the material undergoes a secondary deformation, initiating the cutting process within the clearance.

The third stage, fracture, is characterized by the occurrence of resistance forces on the material within the cutting clearance due to the separation between the cutting edges of the matrix and the punch. This resistance

* Corresponding author
E-mail address: pinar.demircioglu@tum.de

force acts in a defined direction within the fracture zone. The ultimate separation of the product from the material takes place when the material's resistance is unable to withstand the cutting forces [2]. This sequential process illustrates the intricate dynamics involved in the effective execution of the cutting operation. In this study, the impact of adding or modifying various factors will be systematically monitored during mass production. The primary objective is twofold: firstly, to mitigate the incidence of high die costs, and secondly, to eliminate downtime caused by die wear in the context of mass production. Furthermore, the aim is to utilize the insights gained from these experiments to inform and enhance new die designs. Cutting dies, integral to processes in mass production, are manufactured in substantial quantities. Given the critical considerations of cost and time in mass production environments, numerous studies have been conducted to enhance the performance of dies. The existing body of knowledge on the cutting die process is well-documented in literature, encompassing various books dedicated to this specialized field. This study builds upon this wealth of knowledge, contributing valuable insights for the advancement of die design and the overall efficiency of mass production processes.

The distance between the punch and the matrix, known as cutting clearance, plays a crucial role in the cutting quality and life cycle of the die. Numerous studies have delved into the impact of the cutting gap on these aspects [1][3]. The magnitude of the cutting clearance is contingent on factors such as the quality and thickness of the cut material, as well as the geometry and precision of the die. Figure 1 visually demonstrates the consequences of improper clearances. In Figure 1a, insufficient clearance results in suboptimal fracture and heightened forces, while Figure 1b illustrates that excessive clearance leads to oversized burrs. When the clearance is too small, fracture lines tend to intersect, causing double burnishing and increased cutting forces. Conversely, if the clearance is too large, the metal becomes trapped between the cutting edges, resulting in an excessive burr [4]. These visual representations highlight the critical importance of precisely calibrated cutting clearances in achieving optimal cutting quality and prolonging the life cycle of the die.



(a) *(b)*

Figure 1. Effect of die clearance [4].

The literature reveals a study focused on optimizing the cutting clearance to enhance the life cycle of non-symmetric cutting dies. Despite the prevalence of round-cut parts in the industry, the cutting of non-symmetrical parts is equally common. In these dies, both the punch and matrix experience non-uniform wear, with the most significant wear occurring at the sharp radius. The impact of stress generated in the punch due to cutting clearance was systematically analyzed using the finite element method. Moreover, experimental studies were conducted by manipulating the cutting clearance. The contact stress on the punch, identified through finite element analysis, served as an indicative parameter for experimental punch wear. Remarkably, dies with variable cutting clearance exhibited more uniform wear in comparison to dies with uniform cutting clearance. In the field of blanking applications, the study suggests the utilization of geometry curves to design variable cutting clearance for the purpose of improving punch life cycles [3]. This innovative approach addresses the challenges associated with non-symmetric cutting dies, offering potential enhancements in wear uniformity and overall die performance. In another study found in the literature, researchers investigated the impact of different material combinations and cutting radius on die wear. The study involved a combination of experimental and finite element analysis studies.

The results from finite element analysis and the experimental findings demonstrated a high level of agreement, validating the predictive capabilities of the analysis method. The study revealed that punch wear predominantly contributes to roll-over, while matrix wear is associated with the formation of burrs. An interesting optimization strategy emerged: to minimize punch wear, a substantial portion of the cutting should be carried out by the matrix; conversely, to reduce matrix wear, the punch should undertake the majority of the cutting operation. This optimization goal can be achieved by incorporating radius into the cutting edges, showcasing a strategic approach to mitigate wear and enhance the overall performance of the die [5]. In the study, 1.2379 Cold Work Tool Steel punches underwent an enhancement through the application of AlTiN, TiSiN, and TiN PVD coatings. These coated punches were subjected to punching operations under pressure in an industrial manufacturing process, and the wear and dimensional changes of the punches were measured with respect to the number of punches. The results were significant, showing a 5000% increase in the punch life cycle compared to the traditional method when PVD coatings were applied to the cold work tool material. Beyond the significant extension of the life cycle, the traditional method's unplanned stops were markedly reduced, and the need for sharpening staples was completely eliminated. Crucial factors contributing to the punch's outstanding performance included the adhesion resistance of the coating to the main material, the microstructural smoothness of the coating, its brittleness (toughness), and the coating thickness. This study not only demonstrates an advancement in tool steel punch durability but also emphasizes the versatile considerations essential for optimizing punch performance [6]. In the study, the wear effects of CrN, AlCrN, and AlTiN coatings applied to cemented carbide surfaces were investigated. The evaluation of wear effects was conducted through cyclic impact wear and micro-scale wear tests.

The findings revealed distinct behaviors among the coatings. The CrN coating exhibited notably more severe impact deformation compared to the other two types, showing a nonlinear increase in maximum wear depth with an increasing number of impact cycles. Conversely, the AlTiN coating demonstrated the weakest impact wear resistance, primarily due to adhesive wear. In contrast, the AlCrN coating displayed a lower tendency to pick up material from the ball counterface, showing excellent impact wear resistance. Furthermore, the AlCrN coating demonstrated the best performance in both impact wear and abrasion resistance among the three coatings. Despite similar hardness, the AlTiN coating experienced more severe abrasive wear compared to the AlCrN coating [7]. These insights provide valuable considerations for selecting coatings based on specific wear characteristics and performance requirements in diverse applications. A thorough investigation was conducted on punches with varying outer diameters, different cutting surface angles, and diverse surface treatments to understand their impact on cutting quality and punch life cycle in the cutting process. The wear patterns observed on the punch encompassed side wear, face wear, chipping, cracking, and coarse fracture. Notably, it was observed that punches with convex double cutting angles of 20 degrees, coupled with surface treatment, exhibited superior straightness and surface quality in the cut hole.

The convex double cutting angle and convex length demonstrated a significant influence on the punch life cycle. Furthermore, the tool life cycle of punches with either a TiC coating or a lapping process was found to be 25–60% higher compared to punches without surface treatment. These findings emphasize the importance of punch design elements such as cutting angles and surface treatments in achieving improved cutting quality and prolonging the punch life cycle. The study provides valuable insights for optimizing punch performance in industrial cutting applications [8]. In a study conducted with hard coatings—CrTiN alloy, TiN/NbN multilayer, and a multi-layered C-composite—they were field-tested and compared for their stamping wear resistance. All coatings were deposited onto SKH51 steel punches using an unbalanced magnetron sputtering system. A 25-ton open-frame stamping machine was used for the stamping test on cold-rolled carbon steel. The wear characteristics of the coated and uncoated punches were analyzed using shearing and stripping force diagrams and optical microscopy. All three tested coatings significantly improved the wear resistance of the20 punches, with the results showing that the CrTiN- or C-composite-coated tool life be at least three- to four-fold better than that of uncoated punches [9]. The impact of Electrical Discharge Machining (EDM) on the formation of thermally induced residual tensile stress in the top layer of machined surfaces has been explored in the study.

The research focused on employing a mechanical method to measure the residual stress profile at varying depths beneath the surface, particularly on tool steels processed through wire erosion. Observations revealed that as the finishing steps increased, both the maximum tensile stress and tensile stress decreased at the penetration depth. Interestingly, there were instances where residual stresses relaxed over time following rough wire EDM. It became evident that the rough wire EDM of thin beams caused deformation in the part, making it not practical to apply additional finishing steps in certain cases [10]. These findings provide valuable insights into the dynamic behavior of residual stresses in materials subjected to wire EDM processes. In the research study, an investigation into dies manufactured by wire erosion has revealed the presence of a white layer on the cutting surface, leading to surface hardening. The study suggests that this white layer may pose a risk of fractures due to the formation of a brittle layer on the die surface [11]. The detection of such a layer underlines the importance of understanding and managing the material alterations that may occur during the wire erosion manufacturing process, as it can have implications for the structural integrity and performance of the die in subsequent applications. This finding highlights the need for careful consideration of material properties and potential surface alterations in the design and manufacturing processes of dies to ensure their durability and reliability. The direct influence of the microhardened surface layer on the resulting machined surface quality of tool steel EN X210Cr12 was investigated through Main Wire Electrical Discharge Machining (WEDM). The study focused on assessing the impact of technological parameters on both the total depth affected and the microhardness changes in the sub-surface layers of the machined surface. Significant microhardness fluctuations were observed in the hardness of the base material, which initially measured about 740 HV2, particularly in the heated affected area.

The white layer area exhibited increased hardness values, ranging from 820 to 870 HV2. In contrast, hardness values in the transition layer decreased to a range of 610–660 HV2 [12]. In the research study, toughness was identified as the most crucial factor determining working conditions under impact. It was suggested that the homogeneous distribution of small-sized carbides, achieved through powder metallurgy, would not only enhance the toughness property but also positively impact all other steel properties. Consequently, employing this approach with Vanadis 4 is expected to result in longer-lasting dies exposed to wear and impact [13]. In the thesis study, the effects of cutting gap and punch hardness on punch wear in a punching die, and how this wear impacts the quality of the sheet material, were investigated. ST37 material with a thickness of 2 mm served as the sheet material, and punches made from 1.2379 steel with varying hardness values were used. As the hardness of the punch increased, a noticeable decrease in surface and edge abrasions was observed. Breakages in the cutting edge were noted during examinations of the punch with a hardness of 60 HRC at 3% and 5% cutting gaps, indicating that a hardness value of 60 HRC may not be suitable for these particular cutting gaps. Comparatively, the punch with a hardness of 55 HRC exhibited fewer breakages on the cutting edge at 3% and 5% cutting gaps than the punch with a hardness of 60 HRC. It was observed that selecting a smaller cutting gap led to smearing and difficulties on the cutting surfaces. Additionally, a smaller cutting gap value was found to reduce the life cycle of the punch [14]. The purpose of this paper was to investigate the wear that occurs in the punching tool in order to increase the tool life and, at the same time, increase the quantity and quality of production in the factory. Simulation results have been obtained at different angles, from 4.5 degrees to 12 degrees.

The shear angle changed from 4.5 degrees to 12 degrees, and from the simulation, the result showed that when the shear angle increased, the stress did not really increase gradually with the stress. When it reaches 6.5 degrees, the stress starts to decrease until it reaches 8.5 degrees and then starts to increase again. Different thicknesses have been tested for the punching tool. When the thickness of the punching tool changes from 5mm to 10mm, the result shows that the maximum stress will decrease. Because when the thickness of the punching tool increases, the contact area between the punching tool and work piece also increases. When the results are evaluated, the tool with a shear angle of 8.5 degrees will have a higher tool life than the tool with a shear angle of 6.5 degrees, and the effect of thickness on the tool life is important [15]. In a study, the tool life was examined using five different die materials. The die materials consist of carburized 4Cr13, conventional SKD11, Caldie, A2 and tungsten steel D60. According to the results of the measurements, it was observed that Caldie and A2 have higher wear resistance performance than SKD11 and 4CR13. In addition, it was found that the most severe wear location is at the intersections of straight lines with circular arcs [16]. The finite element method was used in a study for parameters affecting the tool life. FE simulations were conducted to study the effect of various parameters such as punch-die clearance, punch tip geometry, stripper pressure, punch corner radius, and coefficient of friction on punch stress, part edge quality, and punch load on a round punch. Geometry-dependent, with a straight edge and different radius, optimal punch-die clearance was designed for a specific case study. The effect of variable die clearance has been compared with an experimental study. The stress of the punch increases linearly with the sheet thickness and the strength of the sheet material. The variable die clearance, depending on the geometry, provides a more than threefold increase in tool life compared to uniform die clearance [17].

2 Materials and methods

2.1 Disc

The wheel comprises disc and rim components. This experimental study specifically targets die parts involved in the production of disc components, which are formed using sheet metal processes. The disc component is made from MW05 material, with specifications (Tables 1 and 2) belonging to CLN Group/MW, and its equivalent material is S420MC. Figure 2 illustrates the 3D model of the disc component of the wheel.

Table 1. The properties of mechanical MW05.

Properties	Unit	Value
Thickness	mm	6
Yield Strength	MPa	420-530
Tensile Strength	MPa	470-600
Elongation – A5		Min. %22

Table 2. Chemical composition of MW05.

Chemical composition % max of MW05						
C	Mn	P	S	Si	Al	Nb
0.1	1.4	0.025	0.015	0.12	0.06	0.065

Figure 2. Disc component of wheel 3D model.

2.2 Die

The die parts are employed in cutting ventilation holes for the disc component. The ventilation hole cutting die consists of five punches and five matrices, with the punch and matrix components experiencing the most wear in this operation. The high volume of mass production results in significant wear on die parts, leading to both time wastage and increased die costs. The ventilation hole cutting die operates on a 1000T eccentric press. Wear on the material can cause burrs on the ventilation hole of the disc. Table 3 presents die properties along with their respective hardness values, while Table 4 outlines the chemical composition percentages of the material in relation to die properties.

Table 3. Die properties and corresponding hardness values.

Die	Material	Hardness
Punch	Caldie	58 – 60 HRC
Matrix	Unimax	58 – 60 HRC

Table 4. Chemical composition percentages of the material and associated die properties [18,19].

Chemical composition % of material						
Material	C	Si	Mn	Cr	Mo	V
Caldie	0.2	0.2	0.5	5	2.3	0.5
Unimax	0.5	0.2	0.5	5	2.3	0.5

The punch is manufactured through milling, with a current life cycle lasting around 1000 pieces before wear. Employing angled cutting in punch technology reduces cutting tonnage and improves cutting quality. Figure

3 presents a 3D model of the punch. Figure 4 depicts the punch deformation mode, with Figure 4a showing adhesive deformation along the cutting contour, and Figure 4b displaying abrasive deformation around the cutting edge.

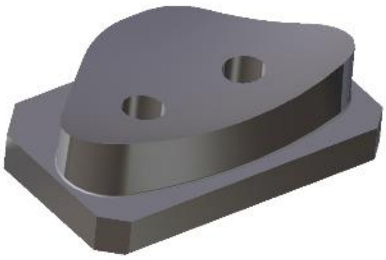
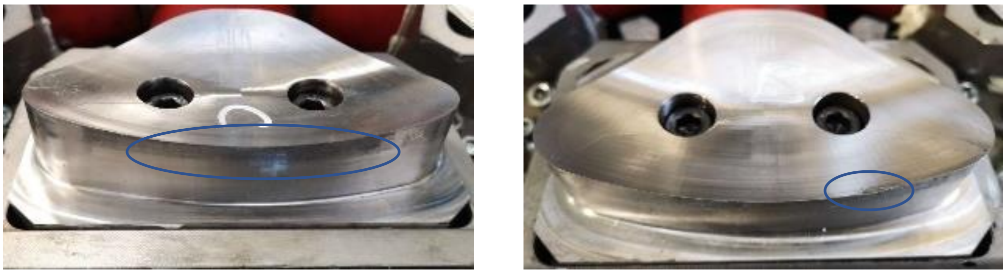


Figure 3. Punch 3D model.



(a) *(b)*

Figure 4. Punch deformation mode.

The matrix part is manufactured using milling and wire erosion processes. Milling is utilized for machining the matrix surface, while both external and internal profiles are cut using a wire erosion machine. The internal profile is cut in two steps. The current life cycle of the matrix lasts for approximately 3000 pieces before wearing out. Figure 5 displays the 3D model of the matrix, and Figure 6 shows the deformation mode of the matrix. The deformation shown in Figure 6 shows cutting edges breakage.

Figure 5. 3D model of the matrix.

(a) *(b)*

Figure 6. Matrix deformation mode.

2.3 Die Life Cycle Improvement Experiments

Experiments involving die geometry and coatings are underway for the punch, encompassing hardness, surface roughness, manufacturing method, and press tonnage. For the matrix, experiments include hardness, surface roughness, manufacturing method, and press tonnage. The die clearance remains unchanged, having been optimized during the product commissioning phase for cutting quality. Both the punch and matrix are configured for a variable cutting gap based on the cutting quality around the ventilation hole. Although there is no configuration of parameters that provide an advantage to tool life, such as variable cutting gap and angle punch, in studies conducted in the literature, the parameters that are kept standard are similar to these. [3,8,15,17].

2.3.1 Punch Experiments

In die geometry, a flat area is introduced around the perimeter cutting edge of the matrix. This experimental modification aims to mitigate abrasive wear on the cutting edge, as depicted in Figure 7.

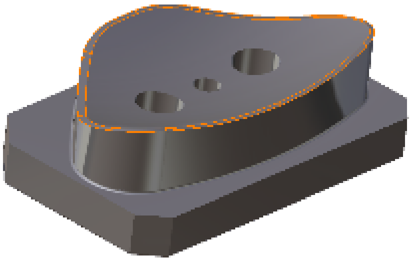


Figure 7. Flat area around the cutting edge.

In the coating experiment, matrix surfaces are coated with PVD using AlCrN. The objective of this experimental coating is to prevent adhesive wear on the cutting contour. Figure 8 illustrates the punch surface coating, while Table 5 provides die properties along with experiment descriptions.

Figure 8. Punch surface coating.

Table 5. Die properties with experiment description.

Experiment No	Experiment Description
P-1	Flat area around cutting edge
P-2	Flat area around cutting edge and AlCrN coating on surface.

2.3.2 Matrix Experiments

In the hardness experiment, matrix hardness gradually decreases to alter the deformation mode. The manufacturing method involves wire erosion for the external profile and milling for the surface and internal profile of the matrix, as shown in Figure 9, aiming to alleviate stress on the cutting edge from the wire erosion operation. Surface roughness is enhanced through polishing with the Mahr PS1 surface roughness measuring instrument, primarily to eliminate pits that may occur during processing. Furthermore, press tonnage experiments with variations in counterbalance cylinder pressure aim to understand the press's impact. In this exploration, the material is changed to Vanadis 4 Extra, known for high toughness and wear performance, for further investigation. Table 6 provides die properties, including the chemical composition percentage of Vanadis 4 Extra, offering insights into its characteristics in the experimental setup. Additionally, Table 7 presents the punch experiment list.

Table 6. Die properties with chemical composition % of Vanadis 4 Extra [20].

Chemical composition % of Vanadis 4 Extra					
C	Si	Mn	Cr	Mo	V
1.4	0.4	0.4	4.7	3.5	3.7

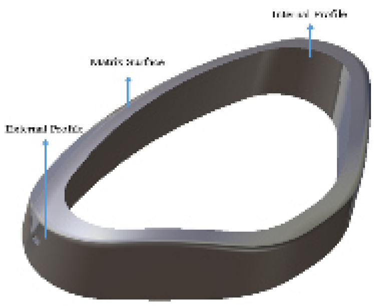


Figure 9. Matrix sections.

Table 7. Punch experiment list.

Experiment No	Experiment Description
M-1	56-58 HRC/Wire Erosion/Standard Surface Roughness/1000T/Unimax
M-2	52-54 HRC/Wire Erosion/Standard Surface Roughness/1000T/Unimax
M-3	52-54 HRC/Wire Erosion/Standard Surface Roughness/1000T/ Low Pressure into Counterbalance Cylinders/Unimax
M-4	52-54 HRC/Wire Erosion/Standard Surface Roughness/600T/Unimax
M-5	52-54 HRC/Wire Erosion/Standard Surface Roughness/1250T/Unimax
M-6	52-54 HRC/Wire Erosion/Polishing on Surface and Cutting Contour/1000T//Unimax
M-7	52-54 HRC/Wire Erosion/Polishing on Cutting Contour/1000T//Unimax
M-8	52-54 HRC/Wire Erosion and Milling Machining/Different Surface Roughness/1000T//Unimax
M-9	52-54 HRC/Wire Erosion/Standard Surface Roughness/1000T/ Vanadis 4 Extra

3 Results and discussion

3.1 Punch Life Cycle Improvement Experiment Result

Conducting experimental studies is essential to mitigate the high die costs that arise under mass production conditions. Experimental punch configuration studies were conducted using the matrix specified as standard. The experiments involved operating the die on a 1000T eccentric press and consisted of two configurations, as outlined in Table 8. Die configurations in the experiments were initiated at the beginning of mass production, and the life cycle counter, monitored through an Excel file, was stopped upon the observation of wear.

Table 8. Experimental studies result for punch.

Experiment No	Average Life Cycle
Standard	1000 pcs
P-1	3000 pcs
P-2	15000 pcs

In the P-1 experiment, the observed deformation mode is adhesive on the cutting contour, with no abrasive deformation around the cutting edge. Subsequently, in the P-2 experiment, the P-1 configuration punches were employed based on the findings from the P-1 experiment. In this phase, the coating is removed from the cutting contour, revealing no deformation beneath the coating. Remarkably, after 15000 pieces, the punch can be recoated and reused. Visual representations of punch deformations can be found in Figure 10. The effect of coating on tool life corresponds to the studies conducted in the literature [6,7,9]. As a result of negotiations with the coating supplier, AlCrN was recommended for the die used in the operation. In a study published in the literature, the AlCrN coating effect on tool life was found to be superior to AlTiN and CrN coatings [7].

(a) *(b)*

Figure 10. The deformations observed in punches from the P-2 experiment.

3.2 Matrix Life Cycle Improvement Experiment Result

After completing the punch life cycle improvement study, matrix experiments were initiated to observe the effects of variability in other dies and factors while maintaining one die constant. The experiments, consisting of nine configurations detailed in Table 9, began at the onset of mass production, with the life cycle counter monitored in an Excel file and stopped upon wear detection. Throughout the matrix experiments, the P-2 configuration punch was utilized. The experimental studies have concluded. A notable reduction in the life cycle during the experiments was attributed to low press counterbalance cylinder pressure, falling below the standard value.

This issue was considered in the ongoing experiments, as it evidently impacts die life cycles. Following the conclusion of its life cycle, the matrix surface undergoes milling for rework and reuse. Matrixes with a hardness exceeding 56 HRC experience cutting edge breakage, as shown in Figure 11 for 56-58 HRC. The deformation in Figure 11a is magnified in Figure 11b. Excessive wear contributes to increased costs due to reduced rework capacity. To gain a deeper understanding of the matrix composition, Figure 12 presents microstructural insights at both x50 and x500 magnifications. The matrix core microstructure is characterized by tempered martensite and secondary carbides, showcasing the inherent intricacies of the material at a microscopic level. The tempered martensite imparts toughness to the matrix, while the presence of secondary carbides influences hardness and wear resistance.

Table 9. Experimental studies result for matrix.

Experiment No	Average Life Cycle
Standard	3000 pcs
M-1	3000 pcs
M-2	3000 pcs
M-3	300 pcs
M-4	2000 pcs
M-5	7000 pcs
M-6	6500 pcs
M-7	4500 pcs
M-8	10000 pcs
M-9	400 pcs

(a) *(b)*

Figure 11. Deformation in matrix for 56-58 HRC.

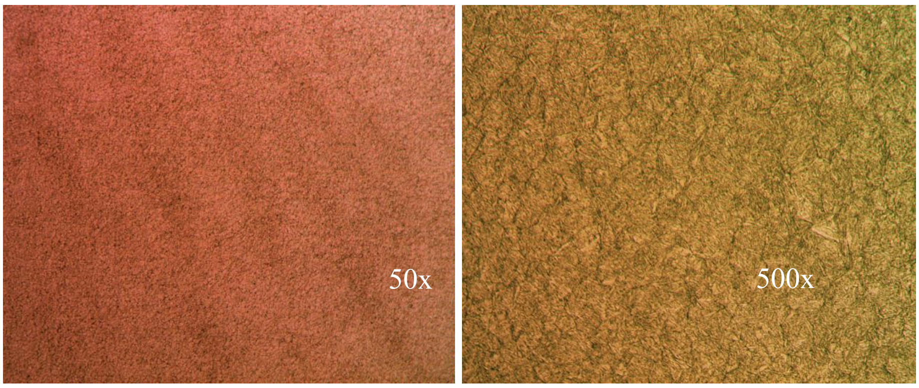


Figure 12. Matrix core microstructure (x50 and x500 magnification) for 56-58 HRC.

In the 52–54 HRC matrix, deformation modes involve bending and cracking around the cutting edge. Deformation in the 52–54 HRC matrix is less compared to that in matrixes with hardness exceeding 56 HRC, leading to more rework opportunities. Matrix deformations are illustrated in Figure 13, with Figure 13b showing plastic deformation on the cutting edge, and Figure 13c revealing cracks on the cutting edge. Matrix cutting contours were examined, and microstructure pictures (x50 and x500 magnification), are displayed in Figure 14. Notably, there is no white layer on the contour due to sanding. In the matrix core microstructure (x50 and x500 magnification), shown in Figure 15, no segregation is observed in the material, and the microstructure consists of tempered martensite and secondary carbides.In a study of the literature, when the tool life at the specified die clearance was examined, it was observed that as the die hardness increased, there were more cutting-edge breaks [14].

(a) (b) (c)

Figure 13. Deformation belongs to the matrix, whose hardness ranges from 52 to 54 HRC.

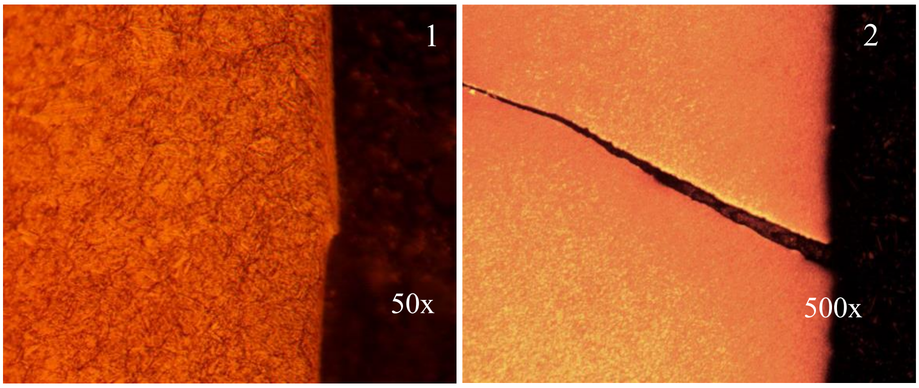


Figure 14. Matrix cutting contour microstructure (x50 and x500 magnification) for 52-54 HRC.

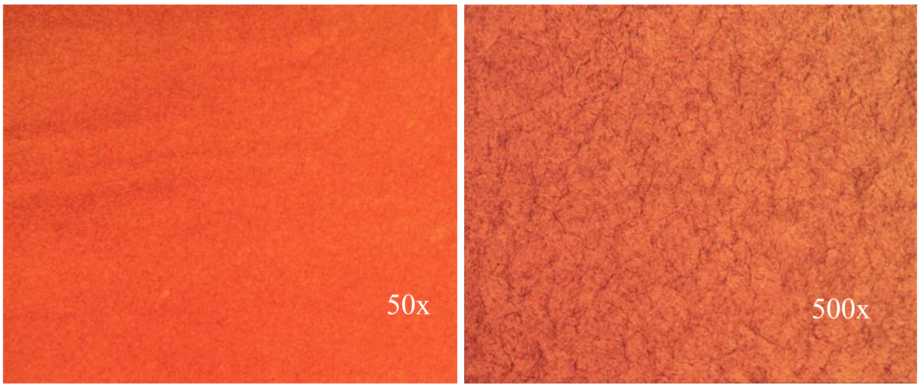


Figure 15. Matrix core microstructure (x50 and x500 magnification) for 52-54 HRC.

In the Vanadis 4 Extra matrix, the rear side is completely broken, as depicted in Figure 16. After reaching the end of their life cycle, matrixes are scrapped due to breakage. Similar results were observed in a cutting die material experiment study [11]. Unfortunately, the expected life cycle of the Vanadis 4 Extra material has not been achieved. Figure 17 illustrates the matrix core microstructure *(x50 and x500 magnification)*, indicating that the material's microstructure consists of tempered martensite and powder metallurgical primary carbides.

Figure 16. Deformation belongs to the matrix, whose material is Vanadis 4 Extra.

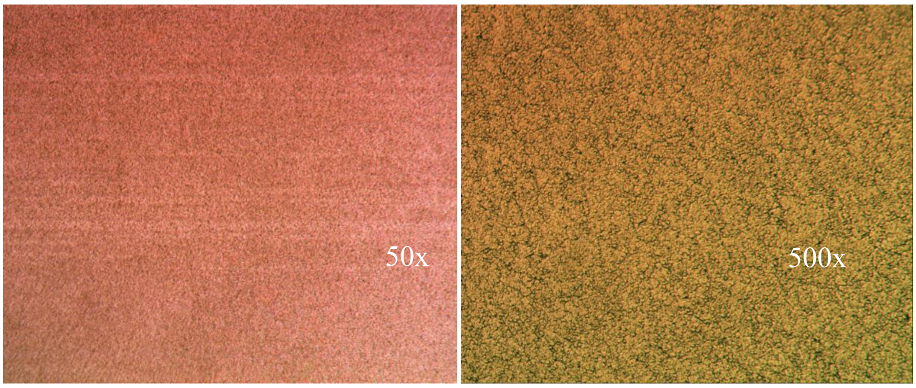


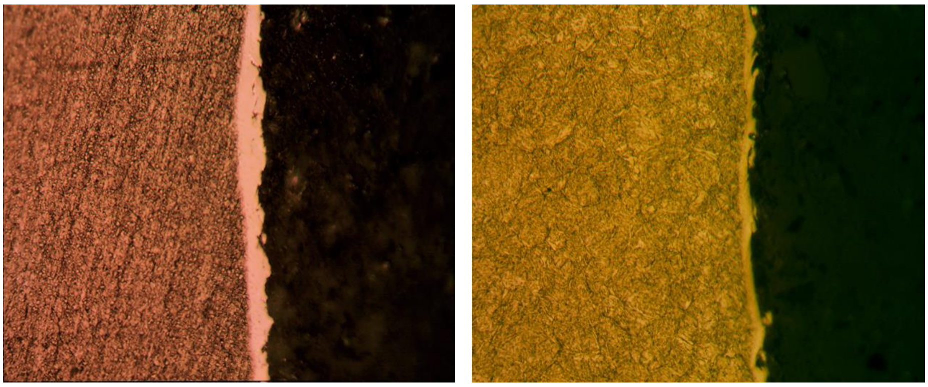
Figure 17. Matrix core microstructure (x50 and x500 magnification) for Vanadis 4 Extra.

Surface roughness is a critical factor influencing the functional and mechanical properties of machined components, particularly in the context of tool matrixes used in industrial applications [21, 22]. The precision and quality of the surface play a vital role in determining the matrixes' performance, durability, and overall life cycle. In this study, the surface roughness values of two matrixes manufactured by different processes were meticulously measured. This comprehensive analysis aimed to provide valuable insights into how variations in surface roughness may impact the matrixes during their operational life.

Table 10. Experimental studies result for punch.

Matrix	Matrix Surface (Ra)	Cutting Contour (Ra)
Standard Surface Roughness – 1	1.3 µm	1..9 µm
Standard Surface Roughness – 2	1.9 µm	2.3 µm
Polishing on Surface and Cutting Contour – 1	0.2 µm	0.13 µm
Polishing on Surface and Cutting Contour – 2	0.16 µm	0.19 µm
Polishing on Cutting Contour – 1	1.2 µm	0.25 µm
Polishing on Cutting Contour – 2	0.8 µm	0.19 µm
Different Surface Roughness – 1	1.2 µm	0.28 µm
Different Surface Roughness – 2	1.1 µm	0.38 µm

When inspecting the white layer formed on the material cutting surface due to wire erosion, it has been observed that a residual white layer persists to some extent even after polishing. However, in certain cases, the white layer is entirely removed when sanding is performed. Figure 18a illustrates the wire erosion cutting surface, and Figure 18b showcases the cutting surface after wire erosion followed by polishing. In studies conducted in the literature, results that will have a negative impact on the tool life of the material after the wire erosion process have been observed [10,11,12]. There is a study that provides findings that the residual stresses will decrease as the finishing processing steps increase [10]. According to a study in the literature, the white layer after the wire erosion process may cause hardening on the surface and increase the risk of fracture caused by it [11]. In another study, it was observed that a material with a hardness of about 740 HV2 increased to values between 820 and 870 HV2 in the white layer and decreased to values between 610 and 660 HV2 in the transition layer [12]. When the results of the studies in the literature were evaluated, the milling processing was tried instead of obtaining the cutting top-up by wire erosion, and an increase in tool life was observed.



(a) *(b)*

Figure 18. White layer resulting from wire erosion.

4 Conclusion

In this comprehensive study, various experimental analyses were conducted to enhance the life cycle of both the punch and matrix components. The disc material, featuring ventilation hole cuts produced by the die, adhered to specified material specifications, and experiments were meticulously carried out within the designated disc dimensions. The introduction of a flat area around the cutting edge for punch life cycles served as a preload before cutting operations, effectively reducing abrasive wear. Additionally, the application of AlCrN coating on the cutting contour mitigated adhesive wear. The coating not only improved surface quality for optimal adhesion but also prevented wear on the material beneath, owing to the coating's inherent hardness. Consequently, the incorporation of flat areas around the cutting edge for preloading and AlCrN coating on the punches emerges as essential design elements in future die designs, resulting in a remarkable 15-fold increase in punch life cycles. Among the various experiments conducted for matrix life cycles, the most significant performance enhancement was achieved through a change in the matrix manufacturing method and an increase in press tonnage. While increasing press tonnage may pose challenges to the current production process, altering the matrix manufacturing method demonstrated a notable increase in its life cycle.

This study highlighted that stresses formed on the matrix cutting contour during wire erosion and the presence of a white layer weaken the matrix cutting contour. Implementing surface polishing as an improvement on the cutting surface proved effective in enhancing the matrix life cycle. Surface roughness measurements indicated that the surface quality achieved through milling machining closely approximated that of polished surfaces. Therefore, machining the cutting contour solely through milling appears sufficient for life cycle improvement. Overall, a noteworthy 3.33-fold increase in matrix life cycles was observed. Consequently, the application of an additional process to eliminate the white layer and stresses resulting from wire erosion, and milling machining on cutting surfaces emerges as a crucial consideration for future die design inputs. In shaping the future of die manufacturing, key directions include exploring advanced coating technologies, optimizing manufacturing processes for increased efficiency, and delving into innovative approaches for eliminating the white layer and mitigating stresses during machining. The integration of smart materials and the adoption of digital twin technologies hold promise for transformative die design. Furthermore, a comprehensive lifecycle assessment of dies, considering both environmental and economic factors, will guide sustainable die design practices. Finally, fostering collaborative industry-academic partnerships will facilitate knowledge exchange and innovation, paving the way for cutting-edge technologies and methodologies that address the evolving challenges in die manufacturing.

Acknowledgements

Sincere gratitude is hereby expressed to JMW Jant ve Ticaret A.Ş. for the invaluable contributions made to the experimental aspects of this study. Additionally, profound appreciation is extended to Uddeholm for the significant contributions to the examinations of matrix materials. The crucial and indispensable role played by their unwavering support and collaborative efforts in the successful execution and completion of this research effort is acknowledged.

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