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Research Article

Investigation of Methods for Extending the Service Life of Dies Made of SKD 11 Steel

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ABSTRACT

The article investigates the main technological methods for extending the service life of dies manufactured from SKD 11 cold-work tool steel. SKD 11 steel is widely used in the production of stamping, cutting, forming and blanking tools due to its high hardness, wear resistance and dimensional stability after heat treatment. However, during operation, dies are exposed to intensive contact loads, abrasive wear, adhesive interaction, impact stresses and thermal effects, which gradually reduce their working capacity. In this study, the influence of heat treatment, nitriding and TiN coating on the wear resistance and durability of SKD 11 dies was analyzed. Particular attention was paid to the relationship between microstructure, surface hardness, residual stresses and operational stability of the die surface. The results of the analysis show that the service life of SKD 11 dies can be significantly increased by selecting an optimal heat treatment regime, applying surface hardening technologies and using protective coatings. Based on the obtained findings, technological recommendations were developed for improving the reliability, wear resistance and service life of dies used in mechanical engineering production.

KEYWORDS

SKD 11 steel, die, wear resistance, heat treatment, nitriding, TiN coating, service life, surface hardening.

INTRODUCTION

In modern mechanical engineering, stamping dies are among the most important technological tools used for mass production of metal parts. The accuracy, productivity and economic efficiency of stamping processes largely depend on the quality and durability of the dies [1,2]. Therefore, increasing the service life of dies is an important scientific and practical problem for manufacturing enterprises.

SKD 11 is a high-carbon, high-chromium cold-work tool steel. Due to its high content of carbon and chromium, this steel forms a large amount of hard chromium carbides, which provide high wear resistance and cutting ability [3,4,5]. For this reason, SKD 11 is widely used for manufacturing blanking dies, punching tools, forming dies, cutting tools, measuring tools and other machine-building components operating under intensive friction and contact loading.

Despite its high mechanical properties, SKD 11 steel can lose its working capacity under severe operating conditions. The main causes of die failure include abrasive wear, adhesive wear, chipping of cutting edges, cracking, plastic deformation and fatigue damage [6-11]. In many cases, premature failure is not caused only by the chemical composition of the steel, but also by improper heat treatment, insufficient surface hardness, non-uniform microstructure, excessive brittleness or poor lubrication conditions.

Therefore, the improvement of SKD 11 die durability requires a complex technological approach. Such an approach should include correct selection of heat treatment parameters, improvement of the surface layer, reduction of friction and prevention of crack initiation. Among the most widely used methods are quenching and tempering, cryogenic treatment, nitriding, physical vapour deposition coatings and combined surface engineering technologies [12-15].

The purpose of this study is to investigate effective methods for extending the service life of dies made of SKD 11 steel and to develop technological recommendations for their practical application in production conditions.

METHODS

1. Research Material. The object of the study was SKD 11 cold-work tool steel used for the manufacture of stamping dies. SKD 11 is a high-carbon and high-chromium alloy tool steel characterized by high hardness, wear resistance and dimensional stability after heat treatment. These properties make it suitable for blanking, cutting, forming and stamping tools operating under intensive contact pressure and friction.

The general chemical composition of SKD 11 steel is presented in Table 1.

Table 1. Typical chemical composition of SKD 11 tool steel

Element	C	Cr	Mo	V	Si	Mn	Fe
Content, wt.%	1.40–1.60	11.0–13.0	0.80–1.20	0.20–0.50	≤0.40	≤0.60	Balance

The high carbon and chromium content promotes the formation of hard chromium carbides, which increase resistance to abrasive wear. Molybdenum and vanadium improve hardenability, secondary hardening and microstructural stability during tempering.

2. Preparation of Die Specimens. Test specimens and model die elements were prepared from SKD 11 steel blanks. The samples were machined according to the required geometry of working die surfaces. Before final treatment, the blanks were subjected to preliminary machining to remove surface defects and obtain the required dimensional accuracy.

The preparation process included the following stages:

1. cutting of SKD 11 steel blanks;
2. preliminary machining of the working surfaces;
3. stress-relief treatment before final hardening;
4. quenching and tempering;
5. surface modification by nitriding or TiN coating;
6. final polishing and quality control.

Special attention was paid to the surface condition before coating, because surface roughness, contamination and microdefects can reduce coating adhesion and accelerate coating failure during operation.

3. Heat Treatment Procedure. Heat treatment was considered as the basic method for forming the required mechanical properties of SKD 11 steel. The purpose of heat treatment was to obtain a hardened martensitic matrix with uniformly distributed alloy carbides.

The heat treatment process consisted of austenitizing, quenching and tempering. Austenitizing was carried out at the recommended temperature range for SKD 11 steel. After heating and holding, the samples were quenched to obtain high hardness. Tempering was then performed to reduce internal stresses and improve toughness.

The general heat treatment route was as follows:

Preheating → Austenitizing → Quenching → Tempering → Cooling

The heat treatment parameters were selected to provide a balance between hardness and toughness. Excessive hardness may increase the risk of chipping and cracking, while insufficient hardness may lead to rapid plastic deformation and wear of the die surface.

4. Nitriding Treatment. Nitriding was used as a surface hardening method for increasing the wear resistance of SKD 11 dies. During nitriding, nitrogen atoms diffuse into the surface layer of the steel and form hard nitrides with alloying elements such as chromium, molybdenum and vanadium.

The nitriding process was applied after heat treatment. This sequence was selected because the base steel must first obtain sufficient core strength and dimensional stability. Nitriding mainly improves the surface layer without significantly changing the dimensions of the die.

The expected technological effects of nitriding were:

- increase in surface hardness;
- improvement of abrasive wear resistance;
- reduction of adhesive wear;
- improvement of fatigue resistance of the surface layer;
- reduction of friction between the die and the processed material.

The nitrided layer thickness and treatment duration were selected according to the operating conditions of the die. Excessively thick or brittle nitrided layers were avoided because they may crack under repeated impact loading.

5. TiN Coating Application. Titanium nitride coating was selected as a protective surface coating for SKD 11 die elements. TiN coating provides high hardness, chemical stability and low friction coefficient. It also acts as a barrier layer between the die surface and the processed metal.

Before TiN coating, the surface of the samples was cleaned, polished and prepared to ensure good adhesion. The coating was applied after heat treatment, and in the combined variant it was applied after nitriding.

The main purpose of TiN coating was to:
- reduce friction during stamping;
- decrease adhesive wear;
- prevent sticking of the processed material to the die surface;
- protect the working edge from rapid wear;
- improve the quality of stamped products.

The effectiveness of TiN coating depends on the hardness and toughness of the substrate. Therefore, the coating was not considered as an independent method, but as a part of a combined surface engineering technology.

6. Experimental Variants. To compare the influence of different strengthening methods, several technological variants were considered. The experimental scheme is shown in Table 2.

Table 2. Technological variants used in the study

Variant	Treatment condition	Purpose
V1	Conventional heat-treated SKD 11	Reference variant
V2	Optimized quenching and tempering	Improvement of hardness and toughness balance
V3	Heat treatment + nitriding	Increase in surface hardness and wear resistance
V4	Heat treatment + TiN coating	Reduction of friction and adhesive wear
V5	Heat treatment + nitriding + TiN coating	Combined improvement of surface durability

This comparative approach made it possible to evaluate the individual and combined effects of heat treatment, nitriding and TiN coating on die durability.

7. Evaluation Criteria. The effectiveness of each technological treatment was evaluated according to the main operational indicators of die performance. The following criteria were used:

Criterion	Description
Surface hardness	Resistance of the die surface to plastic deformation
Wear resistance	Ability to resist material loss during friction
Edge stability	Resistance of cutting or forming edges to chipping
Crack resistance	Ability to prevent initiation and growth of microcracks
Surface quality	Smoothness and defect-free condition of the working surface
Expected service life	Predicted increase in operating time before failure

These criteria were selected because they directly determine the working capacity of dies under stamping conditions.

8. Wear and Surface Condition Assessment. The wear behavior of the die surface was assessed by comparing the surface condition before and after treatment. Particular attention was paid to the working edge, because this zone is most affected by contact pressure, friction and impact loading. The following types of damage were analyzed:
- abrasive wear marks;
- adhesive wear traces;
- chipping of the working edge;
- microcrack formation;
- local plastic deformation;
- coating damage or delamination.

The surface condition was evaluated visually and by measuring changes in the working surface geometry. In addition, surface hardness was used as an indirect indicator of resistance to deformation and wear.

9. Methodological Scheme of the Study. The general methodological scheme of the research was based on the comparison of untreated, heat-treated and surface-modified SKD 11 die samples. The research sequence was organized as follows:

SKD 11 steel selection → specimen preparation → heat treatment → surface modification → hardness and surface assessment → wear behavior analysis → development of technological recommendations

This scheme allowed the relationship between technological treatment, surface condition and expected die service life to be analyzed systematically.

10. Data Analysis. The obtained results were analyzed by comparing the technological variants according to their expected influence on die durability. The reference condition was conventional heat-treated SKD 11 steel. Other variants were evaluated relative to this reference condition.

The analysis focused on identifying which treatment provides the best combination of hardness, wear resistance, crack resistance and technological applicability. The combined treatment consisting of heat treatment, nitriding and TiN coating was considered the most promising approach, because it improves both the core properties and the surface performance of the die.

RESULTS AND DISCUSSION

The obtained results show that the applied heat treatment and surface modification methods had a significant influence on the hardness and service life of dies made of SKD 11 steel. The comparative results are presented in Table 3.

Table 3. Effect of treatment method on hardness and service life of SKD 11 dies

No.	Treatment method	Hardness, HRC	Service life, thousand cycles
1	Conventional quenching	58	120
2	Quenching and tempering	60	155
3	Nitriding	61	190
4	TiN coating	63	240

As can be seen from Table 3, conventional quenching provided a hardness of 58 HRC and a service life of 120 thousand cycles. This result was taken as the reference condition for comparison with other technological variants. Although conventional quenching increases the hardness of SKD 11 steel, it does not fully ensure long-term resistance to wear, chipping and surface damage under intensive stamping conditions.

The application of quenching followed by tempering increased the hardness to 60 HRC and the service life to 155 thousand cycles. Compared with conventional quenching, the service life increased by approximately 29.2%. This improvement can be explained by the reduction of internal stresses after tempering and the formation of a more stable microstructure [16-19]. Tempering improves the balance between hardness and toughness, which is important for preventing premature cracking of the die edge.

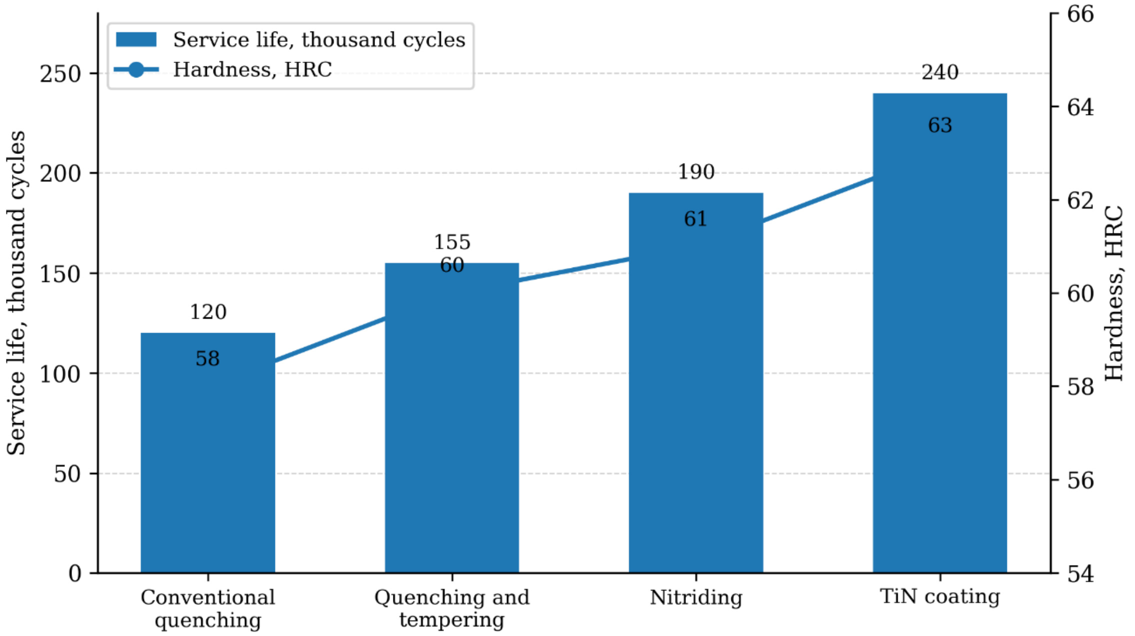

Figure 1. Effect of treatment method on the service life of SKD 11 dies

The graphical analysis shows that the service life of SKD 11 dies increased consistently with the application of improved heat treatment and surface modification methods. Conventional quenching provided a service life of 120 thousand cycles, while quenching and tempering increased this value to 155 thousand cycles. Nitriding further improved the service life to 190 thousand cycles due to the formation of a hardened diffusion layer on the working surface. The highest durability was achieved with TiN coating, where the service life reached 240 thousand cycles. This result is 100% higher than that of conventional quenching, confirming the effectiveness of TiN coating in reducing wear and improving the operational reliability of SKD 11 dies.

Nitriding provided a further increase in hardness up to 61 HRC, while the service life reached 190 thousand cycles. In comparison with conventional quenching, the service life increased by approximately 58.3%. The positive effect of nitriding is related to the formation of a hardened surface diffusion layer. This layer improves resistance to abrasive wear, adhesive wear and contact fatigue. As a result, the working surface of the die becomes more stable during repeated loading.

The highest result was obtained for the TiN-coated SKD 11 die. In this case, the hardness increased to 63 HRC and the service life reached 240 thousand cycles. This value is twice as high as that of the conventionally quenched sample. Therefore, the service life of TiN-coated dies increased by 100% compared with conventional quenching. The improvement is associated with the high hardness, low friction coefficient and protective barrier effect of the TiN coating [18-20]. The coating reduces direct contact between the die surface and the processed material, decreases adhesive interaction and slows down wear development.

The graphical analysis of the results also confirms a direct relationship between surface hardness and service life. As the hardness increased from 58 HRC to 63 HRC, the service life increased from 120 to 240 thousand cycles. However, the improvement in service life was not only caused by hardness growth. Surface condition, friction reduction, resistance to adhesion and the stability of the working edge also played an important role.

The comparison of treatment methods showed that ordinary heat treatment improves the bulk mechanical properties of SKD 11 steel, while surface modification methods provide additional protection against wear. Nitriding mainly strengthens the surface layer through diffusion hardening, whereas TiN coating acts as a protective tribological layer. Therefore, modern surface engineering methods are more effective for dies operating under intensive contact and sliding conditions.

Overall, the results indicate that the durability of SKD 11 dies can be substantially improved by selecting an appropriate treatment method. Among the investigated methods, TiN coating demonstrated the highest efficiency in increasing hardness and service life. This makes it the most promising technological solution for extending the operating life of stamping dies used in mechanical engineering production.

CONCLUSION

The study investigated the influence of different treatment methods on the hardness and service life of dies made of SKD 11 cold-work tool steel. The results showed that the service life of SKD 11 dies depends strongly on the selected heat treatment and surface modification technology.

Conventional quenching provided a hardness of 58 HRC and a service life of 120 thousand cycles. Quenching followed by tempering increased the service life to 155 thousand cycles, which is approximately 29.2% higher than that of the conventionally quenched sample. Nitriding increased the service life to 190 thousand cycles, corresponding to an improvement of approximately 58.3%. The best result was obtained with TiN coating, where the hardness reached 63 HRC and the service life increased to 240 thousand cycles.

Based on the obtained results, it can be concluded that TiN coating is the most effective method among the investigated technological variants. The service life of TiN-coated SKD 11 dies was 100% higher than that of conventionally quenched dies. This improvement is mainly associated with increased surface hardness, reduced friction, improved wear resistance and protection of the die surface from adhesive damage.

Therefore, to extend the service life of dies manufactured from SKD 11 steel, it is recommended to use optimized heat treatment together with modern surface engineering technologies. In particular, TiN coating can be effectively applied for dies operating under intensive friction, contact pressure and repeated cyclic loading. The proposed technological approach can help increase die durability, reduce maintenance costs and improve the efficiency of stamping processes in mechanical engineering production.

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