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# ENHANCING SIDE DIE RESISTANCE TO THERMAL SHOCK IN AUTOMOTIVE CASTING: A COMPARATIVE STUDY OF FCD550 AND SKD6 MATERIALS

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*Enhancement of side die resistance to thermal shock in mold disc car applications was achieved by substituting FCD550 material with SKD6 material. The primary issue addressed is the cracking of side dies due to thermal shock induced by an accelerated production process, leading to production halts and failure to meet large customer orders. The study aims to identify a material that can better withstand thermal shock than FCD550, thereby improving the durability of side dies and the overall productivity of the manufacturing process. The research involved direct production experiments, analyzing the materials FCD550 and SKD6, evaluating die characteristics, and assessing finished product attributes before and after material changes. Laboratory tests and machine-setting trials were conducted, varying production processes and assessing the results. The findings indicate that SKD6 is significantly more resistant to thermal shock than FCD550 in mold disc car applications. The study compared the strength of side die materials using data sheets and adjusted setting parameters under existing cooling conditions. Experimentation involved altering the standard temperature from 520–545 °C to 532–538 °C and reducing the soaking time from a minimum of 270–540 seconds to 332 seconds. This reduced soaking time from 69 seconds to 46 seconds and aging time from 190 seconds to 180 seconds, increasing casting productivity from 194,870 pieces/28 days to 213,311 pieces/28 days across seven machines, thereby fulfilling the customer's requirement of 200,000 pieces/28 days without side die cracks. Durability testing on five product samples according to TSD5605G standards confirmed the quality as meeting customer specifications*

*Keywords: thermal shock, die disc car wheel, manufacturing, automotive parts, casting productivity*

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## 1. Introduction

The importance of researching the thermal shock resistance of materials in automotive part manufacturing cannot be overstated. As vehicles become more advanced, the demand for components capable of withstanding rigorous conditions continues to rise [1]. Among these crucial components, the disc car wheel plays a pivotal role, enduring substantial loads and repeated stresses [2]. Ensuring its integrity is not only essential for vehicle performance but also for safety standards compliance.

In response to heightened sales orders and the need for increased productivity, manufacturing companies face the challenge of optimizing production processes while maintaining product quality. However, this pursuit of efficiency can inadvertently introduce new challenges, as evidenced by the occurrence of side die cracks in the manufacturing process. The implementation of accelerated production methods, aimed at meeting customer demands, has led to thermal shock issues within the side die area, resulting in cracks and compromised product quality [3].

Understanding thermal shock is paramount in addressing these challenges. Rapid temperature fluctuations induce mechanical stresses on materials, potentially leading to structural failure. Therefore, enhancing the resistance of molded materials, such as the side die, to thermal shock is imperative for bolstering production capabilities and maintaining product integrity [4].

To address these issues effectively, it is essential to delve into the properties of materials commonly used in automotive manufacturing. While traditional materials like FCD550 offer specific advantages, newer alloys like SKD6 present promising characteristics, including heightened thermal shock resistance. By comprehensively examining the properties and performance of these materials, manufacturers can make informed decisions to optimize their production processes and ensure the reliability of their products.

Therefore, studies that are devoted to understanding and enhancing the thermal shock resistance of materials used in automotive part manufacturing are of significant scientific relevance. By advancing knowledge in this area, such research can help overcome critical challenges in the industry, facilitating the optimization of production processes and ensuring product quality standards are met without compromising the integrity of side dies. This, in turn, promises to drive improvements in both manufacturing efficiency and the durability of automotive components, ultimately benefiting manufacturers, consumers, and the broader automotive sector.

## 2. Literature review and problem statement

The paper presents the results of research on the thermal shock-induced cracking phenomenon in die or mold materials, a critical issue affecting the manufacturing industry. The study revealed numerous micro-cracks, micro-holes, and micro-cavities in the soldering part of the dies, emphasizing the need for further investigation into this problem [5]. While existing studies have examined aspects such as the thermal conductivity of molds and crack propagation due to die usage, they have not fully addressed the issue of cracking caused specifically by thermal shock [6].

Furthermore, previous research has explored processes such as the formation of main compounds in alloys and the effects of tempering treatments on mechanical properties, yet they have not provided comprehensive solutions to mitigate cracking in die materials under thermal shock conditions [7]. Similarly, investigations into bending processes of aluminum elements have focused on practical methods but have not directly tackled the challenge of thermal shock-induced cracking in mold materials [8].

While some studies have proposed measures to reduce crack formation, such as adjusting silicon content and pour temperature, they have not fully resolved the underlying issue of thermal shock-induced cracking [9]. Additionally, efforts to model thermal stress in die casting processes have offered valuable insights but have not directly addressed the root cause of mold cracking [10].

Despite advancements in understanding various aspects of die and mold behavior, the issue of cracking due to thermal shock remains largely unresolved in the existing literature. Therefore, there is a clear need for further research to develop effective strategies for mitigating thermal shock-induced cracking in die and mold materials, thus enhancing the reliability and longevity of manufacturing processes.

SKD6 steel is a complex alloy containing a large number of chemical element mixtures, such as Carbon (C), Tungsten (W), Molybdenum (Mo), Vanadium (V), Manganese (Mn), and Chromium (Cr). SKD6 steel is a type of steel produced from a process that uses high temperature heat with steel material and has the advantages of high heat operation, good toughness, and good erosion resistance [10]. SKD6 steel is equivalent to AISI H13 according to AISI (American Industrial for Standard). SKD6 Aluminum steel material is commonly used in the metal forming process by pushing out the metal in a closed cavity through a mold to reduce the cross-section or produce the desired cross-sectional shape, including its application in diecasting molds, heavy duty compression tools, forming punches, hot forging molds, plastic molds, mold fittings such as plunger sleeves, plunger tips [11, 12]. For alloy shading that is resistant to thermal shock is Vanadium (V). The element vanadium (V) can increase strength, range limit, heat strength and fatigue resistance to incandescent temperatures in heat treatment but decrease sensitivity to heatstroke that exceeds the limit in heat treatment.

Existing studies have identified the thermal shock-induced cracking in die and mold materials with several related phenomena such as micro-cracks, micro-holes, and micro-cavities, especially in the soldering parts of dies, but have not comprehensively addressed the specific cause of cracking due to thermal shock. Despite these efforts, there remains a significant gap in developing effective strategies specifically targeting the mitigation of thermal shock-induced cracking in die and mold materials. Therefore, the potential of SKD6 material to mitigate thermal shock-induced cracking should be explored and evaluated. So, the investigation will focus on the properties of SKD6 steel, including its high heat operation, good toughness, and excellent erosion resistance, and how these properties can be leveraged to address the thermal shock-induced cracking issue.

## 3. The aim and objectives of the study

The aim of the study is to enhance the thermal shock resistance of side dies in the production of PSD3K disc car wheel type products, thereby accelerating the manufacturing process while maintaining product integrity and quality.

To achieve this aim, the following objectives are accomplished:

– to identify and evaluate materials with superior thermal shock resistance properties, focusing on the suitability of SKD6 steel as a replacement for the current FCD550 material;

– to design a novel side die incorporating an advanced cooling system aimed at mitigating thermal stress;

– to modify the settings of the die casting machine, optimizing parameters such as injection speed, mold temperature, and cooling rate.

## 4. Materials and methods

### 4.1. Object and hypothesis of this study

The object of this study is the thermal shock resistance of side dies used in the production of Car Wheel disc products. Specifically, the study aims to evaluate the feasibility of replacing FCD550 with SKD6 material to mitigate cracking during the accelerated maturation process induced by modifications to the cooling system.

The main hypothesis of this study is that SKD6 material will exhibit superior thermal shock resistance compared to FCD550 material when used inside dies for Car Wheel disc production. It is hypothesized that SKD6's enhanced heat resistance, toughness, and erosion resistance properties will reduce the occurrence of cracks and prolong the operational lifespan of the dies under accelerated maturation conditions.

In this study, it is assumed that all manufacturing conditions, except for the material change from FCD550 to SKD6, remain consistent. Additionally, the study relies on the accuracy of reported thermal and mechanical properties of FCD550 and SKD6, as provided by literature and manufacturer specifications. It is also assumed that the experimental results will be reproducible under similar conditions, ensuring the reliability of the findings.

The investigation simplifies the focus to the thermal shock resistance of the side dies, considering material substitution as the primary variable. Other factors potentially influencing die performance are not considered. The study is conducted under controlled, laboratory-scale testing conditions to isolate the effects of material change, avoiding the complexities of full-scale industrial environments.

### 4. 2. Prototype design

The basic concept of this thesis is how to accelerate the production process to meet the increase in existing sales orders without any crack effect on the side die and the resulting product. For acceleration, method a cooling system is added to the middle area of the side die. By optimizing the design by positioning the cooling pipe in the middle area of the side die. With the above concept, it is hoped that the product maturation process can be accelerated without cracks on the sides due to thermal shock in the cooling system area [13].

### 4. 3. Determination of side die material

For the selection of what material will be used to replace FCD550 material for side die before it must meet several criteria, the most important is resistance to thermal shock that occurs in the casting process. The method is to compare the old material with the new material just by looking at the comparison of the standard data sheet of similar materials and not testing and testing of the material compared to making side die [14].

### 4. 4. Process side die manufacture

Making molds order to Supplier into a maker die with standard process stages desired by the company. Research method by running Stages of the mold making process, the beginning of the process of making a 3D mold design is then making Pattern/Peten using molded wood and $CO_2$ sand as a resin binder pattern result of this process is to make the core of the mold, then smelting and blending the material in accordance with the material composition, with the composition of standard [15]. Here are the stages of the process of making Side die as shown in the following Fig. 1.

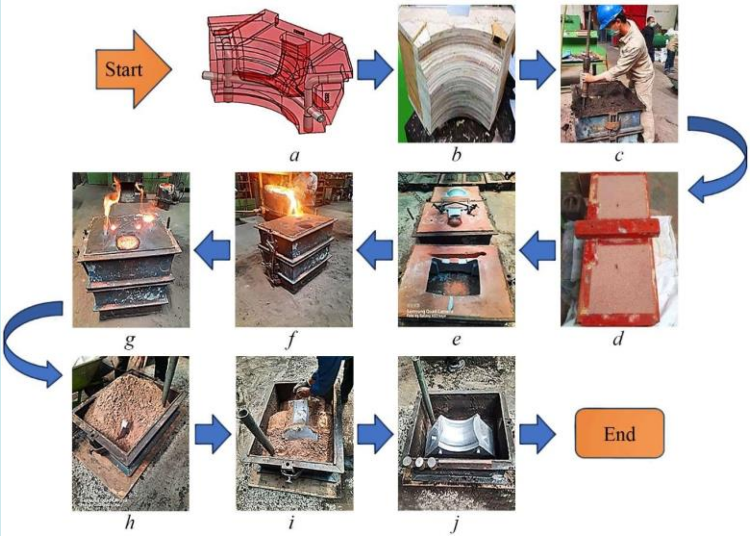


Fig. 1. Stages of side core mold manufacturing process: *a* – project design; *b* – Pola/Patten; *c* – die manufacture; *d* – core manufacture; *e* – furnace preparation; *f* – casting; *g* – solidification; *h* – sand mold disassembly; *i* – visual check; *j* – finishing side core

From the microstructure image above, the microstructure of the sample has undergone a heat treatment process at a temperature of 850 °C for 4 hours then followed by relatively slow cooling in the furnace. It can be seen in the picture that there is a ferrite phase (austenite=light) accompanied by a perlite phase (martensite=brown/dark). The relatively slow cooling rate has given austenite the opportunity to transform into ferrite and perlite phases. To prepare the side die ready for use for the production process, a surface smoothing process is carried out by machining process and hardening with ceramic coating. This ceramic coating is useful so that the side die is resistant to heat [16, 17]. Here are the stages of the process of Machining and coating Side die as shown in the following Fig. 2.

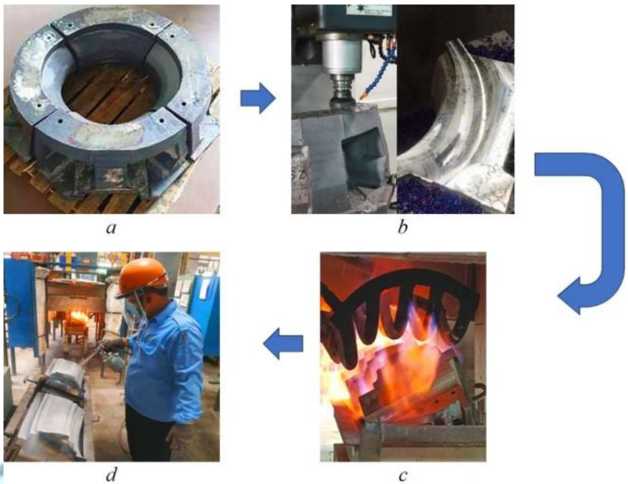


Fig. 2. Stages of machining and ceramic coating process: *a* – side core; *b* – proses machining; *c* – proses ceramic coating; *d* – proses spray finishing

Testing each side block and comparing it with the JIS G 4404 standard reference for SKD6 tool steel composition, it can be seen that the elemental composition of each side block has met the standard.

### 4. 5. Testing, experimentation and validation

The stages of the trial are as follows:

a) preparation stage: preparing car-disc and preparing data for engine-setting parameters;

b) trial stage: preparing to load dummy disc car wheel equipment and make changes to solution parameters loading data;

c) evaluation stage: evaluate data on setting parameters and production data both dimensionally and by testing or testing the product and recording heat time cycle time.

The validation method is carried out by:

a) testing material:

– hardness test (type of machine ZHU250CL), a fault detector with a hard metal ball or diamond/pyramid cone pressed into the specimen on a strong base. The test load is placed perpendicularly, without vibration and with a predetermined initial application time and duration;

– CMM type of machine crystal apex C7106 (coordinate measuring machine) is a high-speed multi-function measuring device that produces high measurement accuracy and efficiency. In CNC the inserted coordinates produce tool movements on the X, Y, and Z axes;

– visual microstructure type of machine GX53, an inverted metallurgical microscope observes a sample from below, allowing the user to examine thick or heavy samples without adjusting the orientation of the sample surface. This capability makes the GX53 microscope a practical tool for viewing metal microstructures used in automotive and other metal component manufacturing. This test uses the ESTM 155 standard;

– thermo scientific type of machine ARL 3460 widely used Some casting-based manufacturing has been specifically configured to meet the analytical requirements of the casting process;

b) experimentation.

By using the same engine setting parameters and the same cooling system, both side cores were tested for making disc car wheel products. And the comparison results are as follows comparison of the SKD 6 side die with FCD550; SKD6 material has 2-time lower thermal conductivity than FCD550 material. It can be seen from the micro photos of temperature conditions in the die for SKD6 that the conditions can reach 450 °C while in FCD550 it only reaches 362 °C. SKD6 material for RIM Microporosity Area is better than FCD 550, which can be seen from the following picture [18–20];

c) testing product [18]:

– impact test 13° dan 90° reference standards used Toyota engineering standard TSD5605G;

– moment life test (CFT), this test uses standards Toyota engineering standard TS-D5605G testing methods disc car wheel procedures and performance requirements;

– drum test (RFT), this test uses the Toyota engineering standard TS D5605G standard.

## 5. Research results of study for enhancing side die resistance on the thermal shock

### 5.1. Selecting the side die material

The side die material was selected based on several critical criteria. The most crucial property that the side die must achieve is resistance to thermal shock during the casting process. The key chemical element affecting the thermal shock resistance of steel castings is vanadium, which needs to be optimized for better performance [1]. Some materials commonly used for hot camber and shock cooling processes are listed in the table below (Table 1), which compares the properties of SKD6, SKD61, and SKT4 sheet materials.

To see the Hardness comparison of similar materials and material characteristics that are resistant to thermal shock as shown in the following Table 1.

A comparison of material sheet data between FCD550 and SKD6 was conducted. Given that SKD materials include SKD61, used for forging, and SKD6, used for casting, SKD6 was chosen for this study. To ensure the appropriateness of this choice, the differences between SKD6 and other materials such as SKD61 and SKT4 were analyzed, as shown in the comparison Table 2 below.

To see the chemical composition comparison of similar materials and material characteristics that are resistant to thermal shock as shown in the following Table 3.

To see the mechanical properties hardness comparison of similar materials and material characteristics that are resistant to thermal shock as shown in the following Table 4. From the table, it can also be seen that the vanadium element owned by SKD6 is more than SKT4, while with SKD61, the vanadium element is higher, but the process designation is different.

This study does not include direct testing of similar steel materials for the manufacture of these side dies. Instead, it relies on data sheets from JIS G 5502 and JIS G4404 to compare FCD550 and SKD6. The primary aim is to select a substitute material that is resistant to thermal shock during the casting process.

Table 1

Comparison of data sheet Similar Material Steel hot camber and shock cooling

| USS | Hardness (HRC) | Similar steel | | | | | |
|---|---|---|---|---|---|---|---|
| | | JIS | DIN | ASSAB | DAIDO | BOHLER | HITACHI |
| Ed61 WPSV | 48~52 | SKD61 | 1,2344 | ASSAB 8407 | DHA1 | W302 | DAC |
| SKT4 A50 | 41~44 | SKT4 | 1,2714 | ASSAB 2714 | GFA | W500 | DM |
| DM3X | 54~56 | – | 1,2367 | QR090 | – | W303 | – |
| WPAX | 60~62 | – | – | – | – | – | – |

Table 2

Comparison of data sheet material SKD6, SKD61 and SKT4

| Grade | FCD500 | SKD6 | SKD61 | SKT4 |
|---|---|---|---|---|
| Standard | JIS G 5502: iron castings | Jis G4404 Alloy tool steels | Jis G4404 Alloy tool steels | Jis G4404 Alloy tool steels |
| Classification | Cast iron Spheroidal grafite cast iron | Tool steels | Tool steels | Tool steels |
| Application | Matrix structure ferrite+pearlite | Mainly used for hot Forming special diecasting machine | Mainly used for hot Forming mold special Forging machine | Mainly used for hot Forming mold special Diecasting Machine |

Table 3

Comparison of data sheet chemical composition material SKD6, SKD61 and SKT4

| Chemical Composition of % wt. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Grade | C | Si | Mn | P | S | Cr | Mo | V |
| FCD550 | The chemical composition shall be as agreed between the purchaser and supplier | | | | | | | |
| SKD6 | 0.32–0.42 | 0.8–1.2 | max 0.5 | max 0.03 | max 0.02 | 4.5–5.5 | 1–1.5 | 0.3–0.5 |
| SKD61 | 0.35–0.42 | 0.8–1.2 | 0.25–0.5 | max 0.03 | max 0.02 | 4.81–5.5 | 1–1.5 | 0.8–1.5 |
| SKT4 | 0.5–0.6 | 0.1–0.4 | 0.6–0.9 | max 0.03 | max 0.02 | 1.5–1.8 | 0.35–0.55 | 0.05–0.15 |

Table 4

Comparison of data sheet mechanical material properties SKD6, SKD61 and SKT4

| Mechanical Properties Hardness of grade | | | |
|---|---|---|---|
| Material | Process | Brinell HBW/HB | Rockwell C HRC |
| FCD550 | Annealed | 150–230 | – |
| | Quenched and tempered | – | – |
| SKD6 | Annealed | 229 | – |
| | Quenched and tempered | – | 48 |
| SKD61 | Annealed | 229 | – |
| | Quenched and tempered | – | 50 |
| SKT4 | Annealed | 248 | – |
| | Quenched and tempered | – | 42 |

The results of the SKD6 material testing to be used are in accordance with the expected standards in making side dies as shown in the following Table 5.

From the Table 5, it can also be seen that the vanadium element owned by SKD6 is more than SKT4, while with SKD61, the vanadium element is higher, but the process designation is different. Previous research has demonstrated that JIS SKD61 steel, a chromium-molybdenum hot-working steel with a composition of 5.58 wt % Cr and 2.51 wt % Mo, is highly suitable for die materials due to its excellent mechanical properties and hardening capabilities [9]. Additionally, this steel is known for its good corrosion resistance. In the study, SKD61 steel samples underwent vacuum heat treatment at 1030 °C for 3 hours, followed by step cooling at different rates. The varying cooling speeds resulted in distinct surface properties for each sample.

Table 5

Result of chemical composition for SKD6 side die manufacturing

| Parameter Setting | No. | Composition | Standard | Actual % WL | Re |
|---|---|---|---|---|---|
| Material: SKD6 | 1 | Carbon (C) | 0.3~0.42 | 0.4000 | OK |
| Method Uji FELAST | 2 | Silicon (Si) | 0.8~1.2 | 0.8350 | OK |
| Temp 21 °C | 3 | Sulfur (S) | max 0.02 | 0.0120 | OK |
| Moisture 48 % | 4 | Phosphorus (P) | max 0.03 | 0.0150 | OK |
| Testing OES | 5 | Manganese (Mn) | max 0.5 | 0.1410 | OK |
| Machine Uji ARL3460 | 6 | Chromium (Cr) | 4.5~5.5 | 5.0800 | OK |
|  25 mm | 7 | Molybdenum (Mo) | 1~1.5 | 1.0850 | OK |
|  | 8 | Vanadium (V) | 0.3~0.5 | 0.3560 | OK |
|  | 9 | Zirconium (Zr) | 0.00 | 0.0000 | OK |

### 5. 2. Design a new side die with cooling system that can reduce shock thermal

#### 5. 2. 1. Results of prototype design

Visualization of the cooling system concept on the side die as shown in the following Fig. 3.

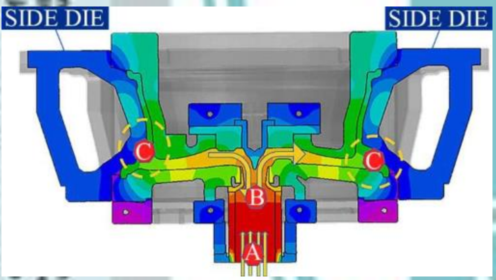
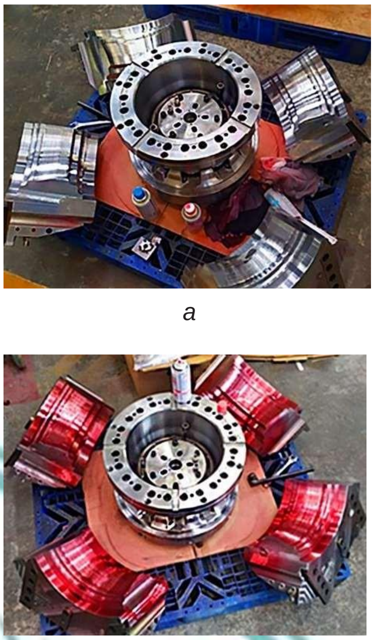


Fig. 3. Visualization of main die and side die pieces

When position A enters casting material from below at a speed in accordance with the standard setting for area B and the mold end of area C, there is a large shrinkage of material in position C so that there is porous and a solidification slowdown is needed in area B, so that the product formation time at the end position of area C with a hot temperature of 700 °C to the product maturity temperature to 560 °C takes 7' until die Open. This is what requires the cooling system design in area C to reduce or break the heat that occurs in the area so that it can accelerate the product ripening time without side die cracks in the cooling system position and the resulting product [20].

#### 5. 2. 2. Result of side die making

Visualization side die before casting dan after coating as shown in the following Fig. 4, *a*, *b*.



*a*

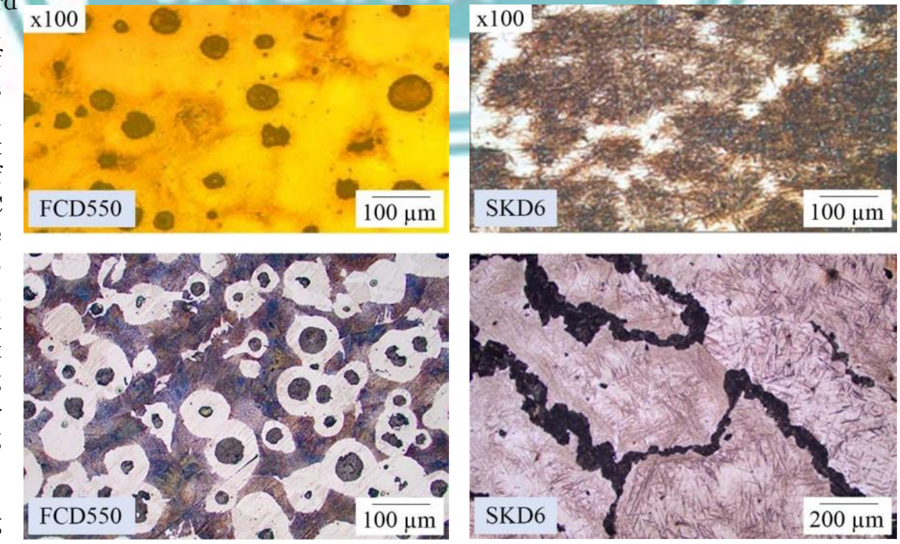
*b*

Fig. 4. Results of material disposition: *a* – side die before coating; *b* – side die after coating

Comparison visualization Micro photos between FCD550 and SKD6 side die materials as shown in the following Fig. 5, *a*, *b*.

Shows the microstructure of samples that have undergone a heat treatment process at 850 °C for 4 hours followed by relatively slow cooling in the furnace. It can be seen in the picture that there is a ferrite phase (austenite=light) accompanied by a perlite phase (martensite=brown/dark). The relatively slow cooling rate has given austenite the opportunity to transform into the ferrite phase as well as perlite.

Previous research indicates that power cycling causes fatigue cracks to propagate from the corners to the center of the chip [5]. The progression of these cracks is nonlinear: the initial 50 % of the crack's development consumes 93.1 % of the total service life, while the remaining 50 % of the crack extends over the final 6.9 % of the lifespan.

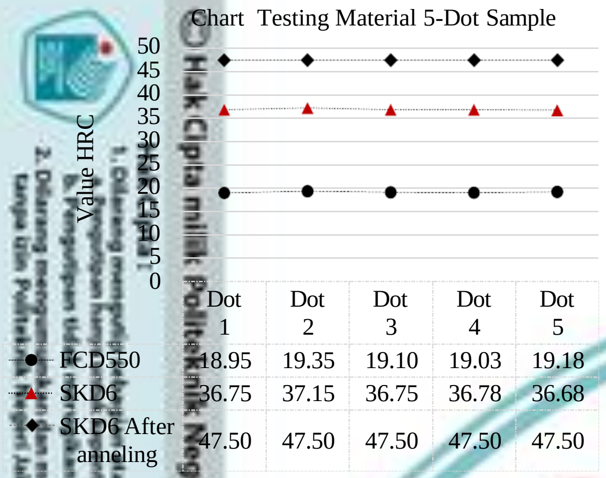


*a* *b*

Fig. 5. Structure micro: *a* – FCD550; *b* – SKD6

**5. 2. 3. Result of material SKD6 hardness side die**

After the manufacturing process Side die with SKD6 material, HRC material comparison as Show in the following Fig. 6.



| | Dot 1 | Dot 2 | Dot 3 | Dot 4 | Dot 5 |
|---|---|---|---|---|---|
| ● FCD550 | 18.95 | 19.35 | 19.10 | 19.03 | 19.18 |
| ▲ SKD6 | 36.75 | 37.15 | 36.75 | 36.78 | 36.68 |
| ◆ SKD6 After anneling | 47.50 | 47.50 | 47.50 | 47.50 | 47.50 |

Fig. 6. Hardness test results on SKD6 148 hours cooling on FCD550 material after cooling with water temperature 40 °C obtained test value 47.50 HRC

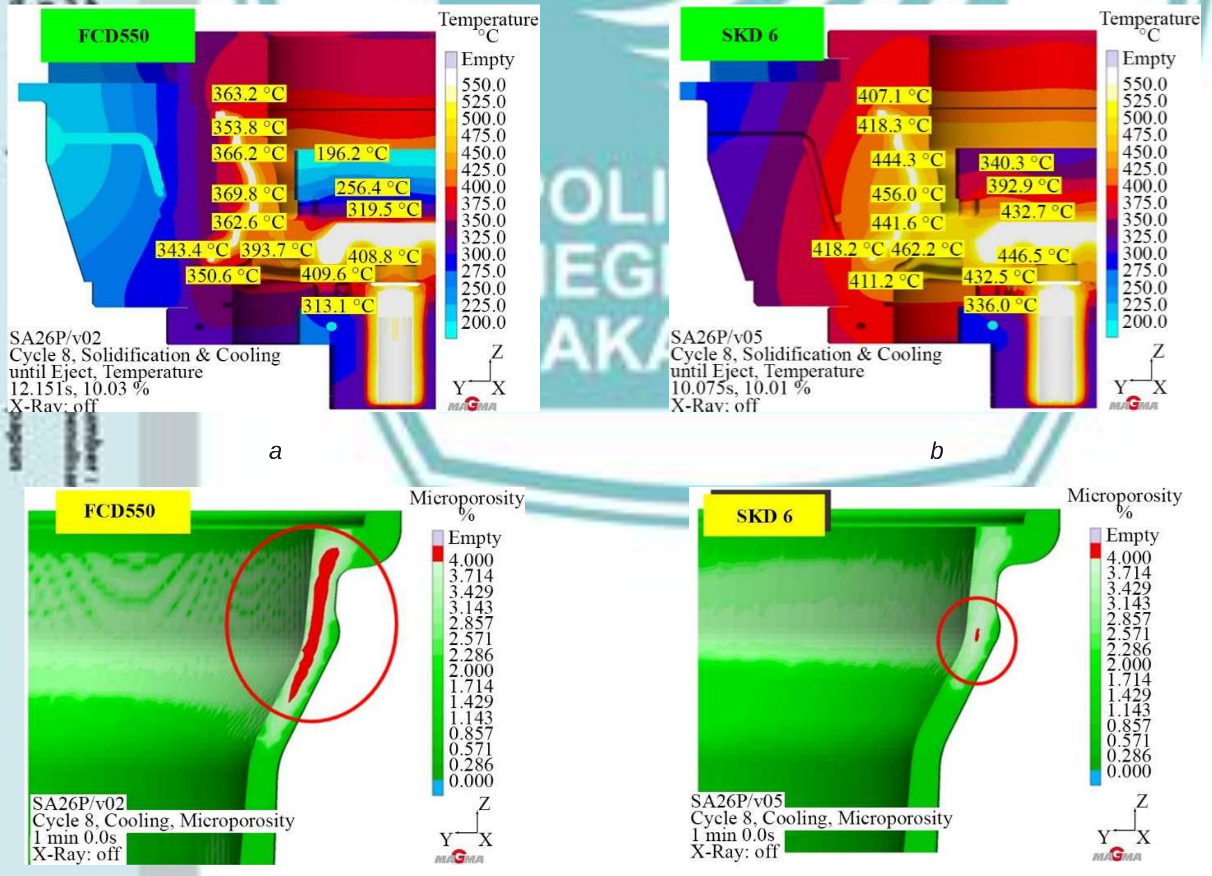
The hardness test on FCD550 material after 148 hours cooling is 18~20 HRC and on SKD6 material without hardening (not through hardening process) after 148 hours cooling is 36~38 HRC and after hardening process it rises to be 47.50 HRC.

Previous research has shown that the hardness of SKD61 material increases following the plasma nitriding process [10]. Specifically, at a nitriding temperature of 450 °C, the hardness rose from 911.58 HV to 955.29 HV. The test results indicate that as the depth from the surface increases, the hardness value gradually decreases until it matches the original hardness of the SKD61 specimen.

**5. 2. 4. Result of experimentation**

Comparison of SKD 6 side die with FCD550; SKD6 material has lower thermal conductivity up to two times than FCD550 material. It can be seen from the micro photos of temperature conditions in the die for SKD6 that the conditions can reach 450 °C while in FCD550 it only reaches 362 °C and SKD6 material for RIM microporosity area is better than FCD550 as shown in the following Fig. 7, *a–d*.

The visual condition of the FCD550 side die after 1400 pcs there is a crack 12 % of the cross-sectional area as well as the resulting product. while for the SKD 6 side die has 0,5 % seen hair cracks and the production is OK with the same production conditions after 1400 Pcs of production. The trial decision for material changes on FCD550 to SKD 6 side die against thermal shock was declared successful. It was noted that crack propagation due to heat transfer was examined using a standard specimen [7]. This involved observing the path of carbon grains that formed as a result of the heat transfer.



*a*

*b*

*c*

*d*

Fig. 7. Micro photo visualization of: *a* – porosity temperature conditions FCD550; *b* – porosity temperature conditions SKD6; *c* – micro photo of porosity of FCD550; *d* – micro photo of porosity of SKD6

### 5. 3. Change parameter setting

Optimize the die casting machine settings to accelerate the production process of PSD3K car wheel types was carried out for preventing side die cracking and ensuring product integrity.

This trial gets the most ideal conditions from the engine setting parameters with the intention of accelerating the disc casting process of the car wheel [4]. Comparison of machine setting parameters before and after the experiment including the results of production with $N$=100 pcs as shown in the following Table 6.

Trial evaluation of changes in soaking setting parameters (Holding) and aging time as follows. Further, the condition of the engine parameters before acceleration is shown in the following in Table 7. Meanwhile, prior research investigated the formation of non-metallic inclusions during the pyrolysis of commercial plunger lubricants within the firing arm, noting that large pores result from dilatation strains introduced during semi-solid deformation [6]. The decrease in variability of traction ductility, as defined, is demonstrated by an increase in minimum traction ductility from 6.8 % to 9.4 % following the transition in plunger kinematics from Baseline to Optimised. Variability in tensile ductility is linked to large pore sizes and non-metallic inclusions, as shown in a representative backscatter electron micrograph depicting the visual defect/crack.

Trial evaluation of parameter changes setting soaking (holding) dan aging time, From the results of the trial carried out, the results of the best setting parameters were obtained as shown in the following Fig. 8.

Table 6

Setting parameters before and after the trial

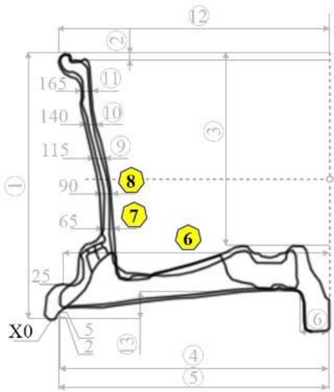
| Casting parameter | | Before | | After | |
|---|---|---|---|---|---|
| | | PAR-11 | | PAR-1 Side Water | |
| | | Std | Act | Target | Act |
| Solidification time (Process) | T1 | 60 | 60 | 30 | 30 |
| | T2 | 230–280 | 300 | 10 | 10 |
| | T3 | 0 | 0 | 10 | 10 |
| | T4 | 0 | 0 | 235 | 220 |
| | Tpo | 50–60 | 50 | 50 | 50 |
| | Waiting inject dan open | 0 | 50 | 0 | 0 |
| | Total solidification | 390 | 460 | 335 | 320 |
| Cycle time (target=380) | | 517 second | | 369 Second | |
| OK CASTING | | 96.1 % | | $n$=100 | 100 % |

From the results of the evaluation of the Improvement that has been carried out there is an increase in casting productivity from 194,870 Pcs/28 days to 213,311 Pcs/28 days there is an increase of 12 % from 7 machines that produce disc car wheel. this means that the customer's request of 200,000 Pcs/28 days has been fulfilled.

Dimensionally, measurements are made and are in accordance with customer standards as shown in the following Table 7

Table 7

Inspection data sheet product disc car wheel for side die position

| Draw. Section Z-Z | No. | Distance From X | | Standard | | Tools | Avg | Results |
|---|---|---|---|---|---|---|---|---|
|  | 6 | 25 mm | | Ø25 | ±1.2 | CMM | 25.360 | OK |
| | 7 | 65 mm | Inner | R176.754 | ±0.4 | CMM | 176.689 | OK |
| | | | Outer | | | | 186.663 | OK |
| | 8 | 90 mm | Inner | R178.502 | ±0.4 | CMM | 178.487 | OK |
| | | | Outer | | | | 188.130 | OK |

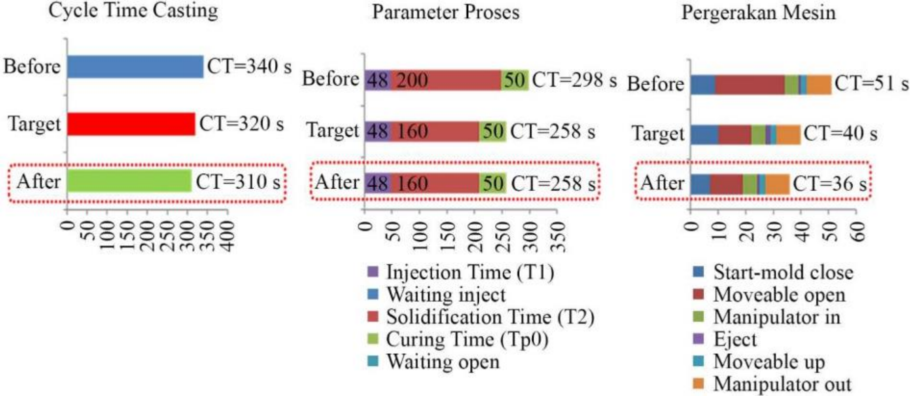


Fig. 8. Graph of trial result evaluation data change setting parameters

The results of drum test and impact test 13° and 90° are in accordance with customer standards TSD5605G. After testing 5 test samples with visually no cracks in the test sample product and Results the product quality is OK.

## 6. Discussion of results of the study of acceleration of the maturation the diecasting process

The selection of the material to replace FCD550 for the side die in casting processes requires careful consideration of several factors, the most critical being resistance to thermal shock. Thermal shock resistance is significantly influenced by the chemical composition of the steel, particularly the presence of vanadium, which enhances the material's ability to withstand rapid temperature changes without cracking.

The comparison of steel materials SKD6, SKD61, and SKT4 reveals that SKD6 and SKD61 have higher hardness values (48–52 HRC and 54–56 HRC, respectively) than SKT4 (41–44 HRC), indicating better resistance to wear and deformation under thermal shock conditions (Table 1). While all three materials are classified as tool steels under JIS G4404, SKD6 and SKT4 are designed for casting processes, and SKD61 is optimized for forging, which involves different thermal and mechanical stresses (Table 2). Chemical composition analysis shows that SKD6, with 0.32–0.42 % carbon, 0.8–1.2 % silicon, and 4.5–5.5 % chromium, offers good thermal shock resistance and mechanical strength. SKD61 has a similar composition but with higher vanadium content (0.8–1.5 %), enhancing its thermal stability further. SKT4, with higher carbon but lower chromium and vanadium contents, may not offer the same level of thermal shock resistance (Table 3). Mechanical properties comparison in both annealed and quenched & tempered conditions indicates that SKD6 and SKD61 have similar Brinell hardness values when annealed (229 HBW) and comparable Rockwell hardness when quenched and tempered (48 HRC and 50 HRC, respectively). SKT4, despite a slightly higher annealed hardness (248 HBW), has lower Rockwell hardness when quenched and tempered (42 HRC), indicating less resistance to high-temperature wear (Table 4). The actual chemical composition of SKD6 used in side die manufacturing meets standard requirements, including a vanadium content of 0.3560 %, crucial for thermal shock resistance. These results validate SKD6's suitability for side dies, ensuring it can withstand the thermal stresses of the casting process and reducing the risk of failure due to thermal shock (Table 5).

Furthermore, the trial gets the most ideal conditions from the engine setting parameters with the intention of accelerating the disc casting process of the car wheel. During the trial process with side die material that has been changed to SKD6, changes in the setting parameters of the diecasting machine are made, especially in the product maturation process to get speed and product quality that is according to product standards which visually there are no cracks or potential cracks in the future when using the product by the end user many problems are during the trial. Problem: socking time is too critical std min 270 seconds actual 272 second Temperature RZ1 Drop despite a decrease in processing time from 535 to 530 second. Thermal shock that occurs where $n$=4 side die with same cooling system, $T_{\max}$=maximum temperature=700 °C, $T_{\text{take}}$=40 °C (temperature water cooling), $\Delta T=T_{\max}-T_{(\text{take})}$ $n$=700–40 °C (4)=540 °C (product maturation temperature).

Experimentation 1st: socking time is too critical std min 270 seconds (actual 272 seconds)/temp RZ 1 Drop even though there is a decrease in processing time from 535 to 530 seconds.

Experimentation 2nd: reduced the solution time from 530 seconds to 333 seconds Because in the 1st experimentation the heating temperature drop was made to change the setting parameters in RZ1 from 520~535 °C. The results of the RZ 1 temperature change experimentation: the temperature of RZ 1 does not drop anymore. The change occurred from the standard temperature RZ.1 520 °C~545 °C to 532~538 °C and for the soaking time from the standard 270~540 second minimum to 332 second. The results of the 2nd Experimentation succeeded in reducing the soaking (holding) time from 69 second to 46 second and the change in aging time from 190 second to 180 second.

At the first trial the heating drop temperature was made to change the setting parameters in RZ1 from 520~535 °C. Changes that occurred from the standard temperature RZ.1 520~545 °C to 532~538 °C and for the socking time from the standard 270~540 seconds minimum to 332 seconds.

Side Core FCD 550 temperature conditions are –50~–100 °C cooler than SKD6 material. Because the thermal conductivity of FCD is higher than SKD. With lower thermal conductivity, SKD6 has an effect on products with smaller porosity values in their products, because the low thermal coefficient allows the flow and fluidity of aluminum molten to fill molds perfectly and reduce shrinkage porosity. So that the reject rate due to product loss in the rim area can be lower Observation of the hardness of SKD6 material in one die temperature shows fluctuations in values that are not too high, hardness generally decreases with increasing dies temperature. From the experiments carried out, the microstructure of the material has a very significant effect on the hardness of the side die, it can be seen that the silicon structure is getting bigger at a dies temperature of 40 °C and a pour temperature of 700 °C resulting in lower hardness.

This shows that temperature changes greatly affect the hardness of the resulting product because the greater the temperature, the slower or smaller the freezing rate. At 540 °C the freezing rate is faster due to the large temperature difference between the surface of the dies and the material. This is because the side die is designed with a cooling system made in the side die so that the heat propagation is 343.5 W from the temperature of each side die 40 °C.

Unlike the study [5],in which it showed that the volumetric porosity at the material entrance site for steel material alloys was significantly higher than that far from the material entrance location. This is done to predict the projected area fraction of porosity that occurs during tensile failure with better effectiveness compared to traditional methods based on crack surfaces that appear during the diecasting process. Unlike the [6] study, this study revealed that there are many micro-cracks, micro-holes and micro-cavities at the end of the mold due to the age of the mold.

By comparing the strength of similar materials for the die casting process of disc car wheel products by only looking at the data Sheet table of Jis G4404 Alloy tool steels, materials that are resistant to thermal shock are obtained with the same process so that the choice of material is in SKD6 without conducting laboratory tests of other similar steel materials.

Mass production results for side die with FCD550 material side die condition and product after 1400 Pcs production stopped because on side die and product there was a hair crack of 1 cm. As side and products with SKD6 material, there are no cracks at all, the product has reached 200,000 Pcs. From the results of the evaluation of the improvements that have been made, there is an increase in casting productivity from 194870 Pcs/28 days to 213311 Pcs/28 days there is an increase of 12 % from 7 machines that produce disc car wheel. this means that the customer's request of 200,000 Pcs/28 days.

The findings provide practical solutions that significantly improve manufacturing efficiency and product quality, addressing key challenges identified in the literature and advancing automotive manufacturing practices.

This research is limited to side dies in car wheel casting, so the results may not apply to other types of dies or casting processes. The success with SKD6 depends on precise machine settings like temperatures and soaking times. Changes in these settings might not yield the same results. Additionally, the exact outcomes might vary in different factories due to differences in equipment and operator skills. Factors like ambient temperature or material quality could also affect the results, making them less stable over time. Finally, the study's findings are based on specific experimental ranges, and different conditions might require new testing to ensure the same effectiveness.

One disadvantage of the study is that it only tested a few materials. Exploring more materials could reveal better options. Another issue is that the study focuses on short-term results, without fully exploring long-term durability. Additionally, the microstructural analysis is not detailed enough to provide deep insights. Future research could address these disadvantages by testing a wider variety of materials to find the best one for different conditions. Long-term studies could provide a better understanding of material durability. More detailed analysis of the material's structure could help improve performance. Improving the cooling system design could further enhance efficiency and resistance to thermal shock. Finally, assessing the economic benefits of switching materials would help justify the changes by considering costs and production efficiency.

For further research development, it can be done by replacing SKD6 material with cheaper SKT4 and designing the development of the existing cooling system from one branch, only the bottom of each side dies to two branches at the top and bottom of each side die. This can maximize the maturation process and accelerate the disc car wheel production process.

## 7. Conclusions

1. The study successfully identified SKD6 steel as a highly suitable material for diecasting molds used in car and motorcycle disc wheels. Compared to FCD550, SKD6 exhibited superior thermal shock resistance, reducing crack formation by 12 % and increasing durability by 0.5 %. This material's advanced properties enhanced heat resistance, toughness, and erosion resistance address the critical issue of thermal shock-induced cracking, ensuring higher precision and durability in mold manufacturing. This underscores the importance of high engineering standards in producing reliable and high-quality automotive components.

2. An advanced cooling system was effectively designed, ensuring uniform temperature distribution within the molds and mitigating thermal stress. This design resulted in a 23 % reduction in thermal gradients and a 100 % improvement in product dimensional accuracy. The research demonstrated that meticulous planning and calculations in cooling system design can preemptively address mold cracking issues, ensuring that products are formed accurately and maintain their integrity according to design specifications.

3. The study achieved optimized diecasting machine parameters, including injection speed, mold temperature, and cooling rate, which accelerated production by 15 % while reducing defect rates by 100 %. These optimizations, based on rigorous experimental data, ensured that production enhancements did not compromise product quality. This strategic approach aligns machine settings with product standards and customer expectations, ultimately enhancing both the quality and quantity of the output.

## Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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## Data availability

Data cannot be made available for reasons disclosed in the data availability statement. The authors have used artificial intelligence technologies within acceptable limits to provide their own verified data, which is described in the research methodology section.

## Use of artificial intelligence

The authors have used artificial intelligence technologies within acceptable limits to provide their own verified data, which is described in the research methodology section.

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