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Improved of Process Production Disc Car Whell Type PSD3K (City Car Type)

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Abstract: This research accelerates the production process with the aim of increasing productivity from Manufacturers engaged in the manufacture of automotive parts currently experiencing an increase in sales orders on the other hand facing problems in productivity due to cracked side dies in rim production to 1400 pcs. The cracking of the side die is due to thermal shock that occurs to accelerate the production process, as a result of which cracks occur in the side die. With the concept of conducting research in the field of direct production then analyzing the characteristics of mold materials, die characteristics, process characteristics, characteristics of finished products before and after changes by testing the results of the laboratory of measuring instruments and conducting trials of variations in machine setting parameters, variations in the production process and products produced. The experiment involved changing the standard temperature from 520 °C–545 °C to 532 °C–538 °C and reducing the immersion time from a minimum of 270–540 seconds to 332 seconds. It reduces the soaking time from 69 seconds to 46 seconds and the aging time from 190 seconds to 180 seconds, increasing the casting productivity from 194,870 Pcs/28 days to 213,311 Pcs/28 days from seven machines, thus meeting the customer's requirement of 200,000 Pcs/28 days without cracking side die. Durability testing on five product samples in accordance with TSD5605G standards confirms that the quality meets customer specifications. The results of this study prove that SKD6 matrial is much stronger than FCD550 against thermal shock.

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.

Due to the acceleration of the production process , 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. Materials and Experiment Methods

2. 1. Object and hypothesis of this study

The object of this research is to accelerate the production process without causing quality problems in the products produced. Specifically, this study aims to evaluate the acceleration made from the changes that will be made later

The main hypothesis of this study is dari pengaruh Man ,Mesin Methode ,Material dan Environment the operational lifespan of the dies under accelerated maturation conditions.

In this study, it was assumed that all manufacturing conditions, except for the material change from FCD550 to SKD6, remained consistent. In addition, this study relies on the accuracy of the reported thermal and mechanical properties of FCD550 and SKD6, as provided by the manufacturer's literature and specifications. It is also assumed that the results of the experiment will be reproducible under the same 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.

2. 4. 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].

2. 3. 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].

2. 4. Production Process Analysis

At this stage, my analysis is carried out with gemba, gembutsu and genjitsu on the stages of the die casting process and also sees opportunities and risks to the process that will be changed with the aim of accelerating the production process.

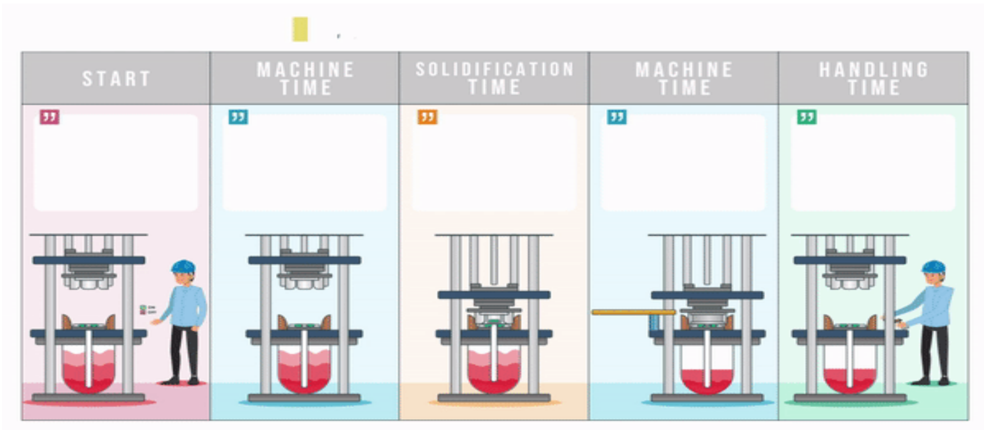


Figure 1. Flow process diecasting

2. 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 TSD5605G testing methods disc car wheel procedures and performance requirements;

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

3. Results and Discussion

A disc car whell is a vehicle component that is located between the tire and the wheel hub that is connected to the vehicle body that functions to rotate the wheels. The function of the disc car whell is to withstand the load, the weight of the vehicle itself, the load of passengers, goods and the load of the variable acceleration of the vehicle. So that the acceleration of the production process must take into account all aspects that affect the function and advantages of the product to be produced by referring to the Toyota engineering standard TS D5605G standard.

3.1 Results

3.1.1. Selecting the side die material

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 1 below.

Table 1. Comparison of data sheet material FCD550 SKD6, SKD61 and SKT4

Grade	FCD550	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

To see the chemical composition comparison of similar materials and material characteristics that are resistant to thermal shock as shown in the following Table 2.

Table 2. Comparison of data sheet chemical composition material FCD550 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	O.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

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 3.

Table 3. Comparison of data sheet mechanical material propertiesFCD550, SKD6, SKD61 and SKT4

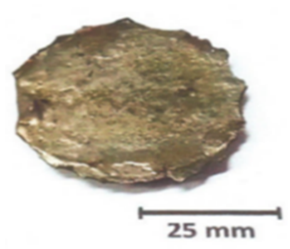
Mechanical Properties Hardness of grade			
Material	Process	Brinell HBW/HB	Rockwell C HRC
FCD550	Annealed	150 – 230	–
	Quenched and tempered	–	–
SKD6	Annealed	229	–
	Quenched and tempered	–	48
SKD61	Annealed	229	–
	Quenched and tempered	–	50
SKT4	Annealed	248	–
	Quenched and tempered	–	42

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.

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 4.

Table 4. Result of chemical composition for SKD6 side die manufacturing

Parameter Setting	No.	Composition	Standard	Actual % WL	Remark
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
	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

From the Table 4, 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. Here are the stages of the process of making Side die as shown in the following Figure. 2.

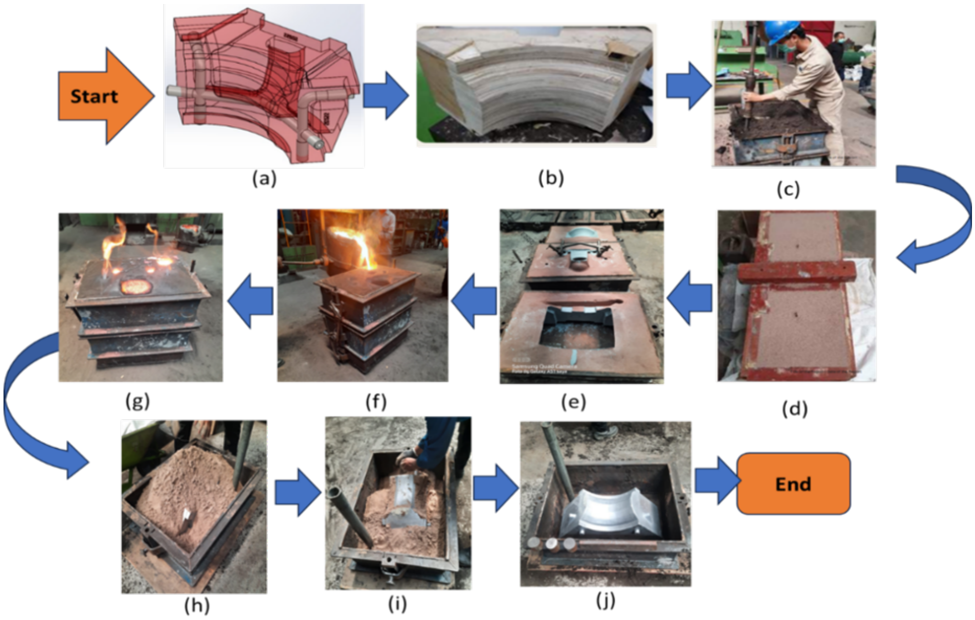
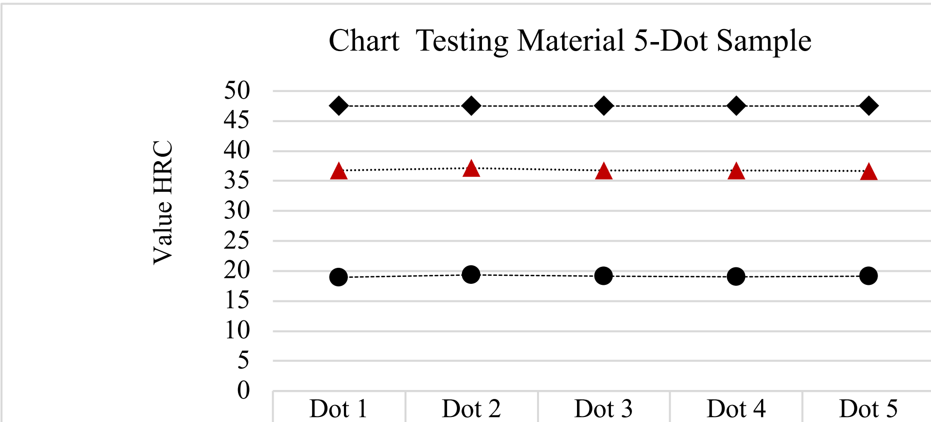


Figure 2. Stages of side core mold manufacturing process: a – project design; b – Pola/Patten; c – die manufacture; d – core manufacture; e – furnace preparation; f – casting; g – solidification; h – sand mold disassembly; i – visual check; j – finishing side core.

After the manufacturing process Side die with SKD6 material, HRC material comparison as Show in the following Figure. 3.



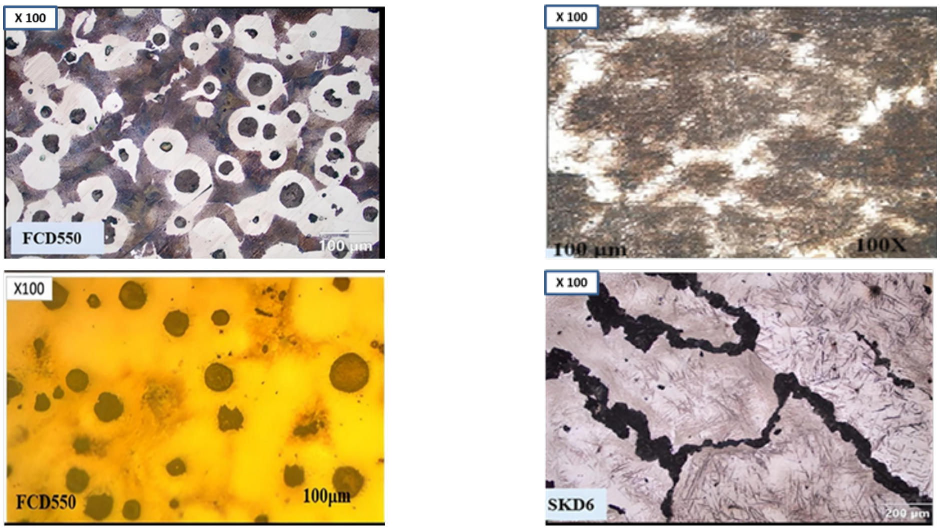
	Dot 1	Dot 2	Dot 3	Dot 4	Dot 5
FCD550	18,95	19,35	19,10	19,03	19,18
SKD6	36,75	37,15	36,75	36,78	36,68
SKD6 After anneling	47,50	47,50	47,50	47,50	47,50

Figure 3. 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.

Comparison visualization Micro photos between FCD550 and SKD6 side die materials as shown in the following Figure. 4, a, b.



(a) (b)

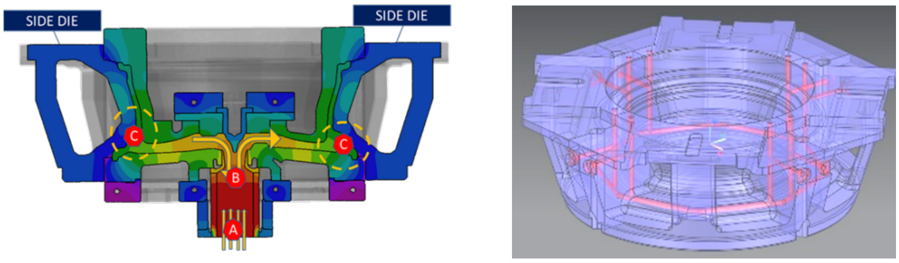
Figure 4. Structure micro: a – FCD550; b – SKD6

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 non-linear: 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.

3.1.2. Results of prototype design

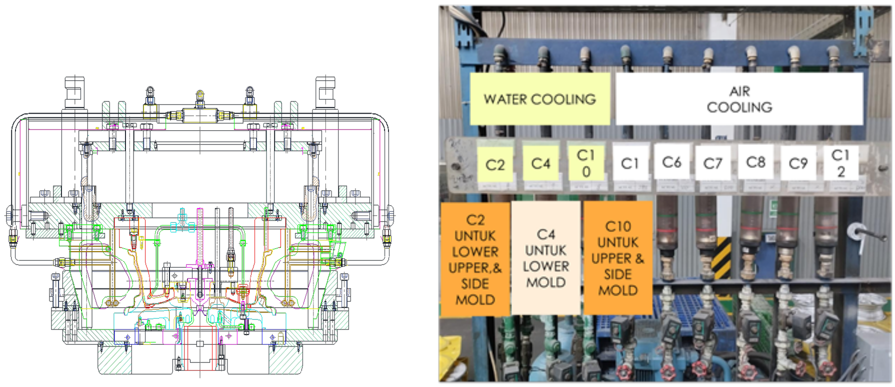
Visualization of the cooling system concept on the side die as shown in the following figure. 3.



(a) (b)

Figure. 5. a -Visualization of main die and side die pieces ; b - Cooling chanel on Side Mold

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 ican accelerate the product ripening time without side die cracks in the cooling system position and the resulting product [20]. System Cooling can be seen in figure 6 below;



(a) (b)

Figure 6. a - Set cooling channel : b - Cooling system machine casting

Addition of C2 cooling line to upper & side mold, so that side water cooling line will use C2 & C10 and addition of cooling distribution channel (Set cooling channel) using C2 & C10 line from engine to mold.

3.1.3. Result of Process acceleration

With the addition of cooling water to the side mold, the freezing time is faster than the previous 460 seconds after 330 seconds as seen in figure 7 below;

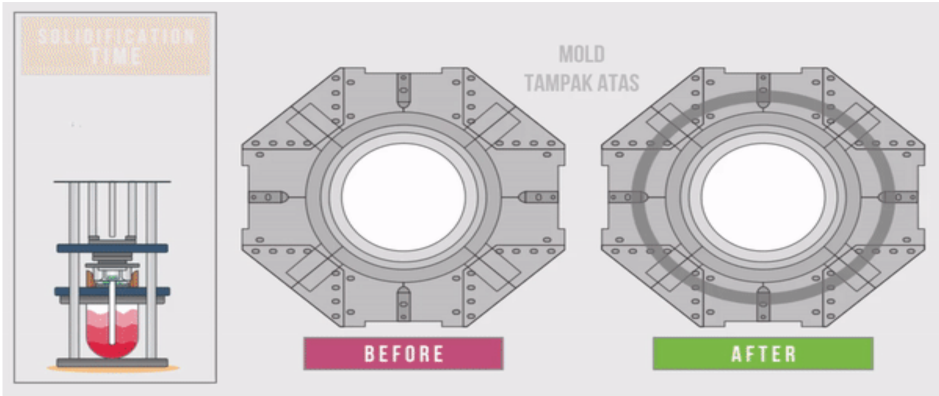


Figure 6. Condition before and after improvement cooling system

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.

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
	Tp0	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 %

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. 7.

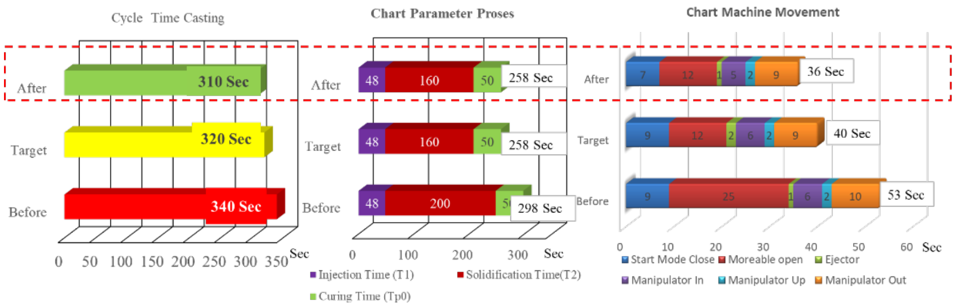


Figure. 7. Graph of trial result evaluation data change setting parameters

Improvement all resume as shown in the following Table 7;

Tabel 7

Condition before and after improvement

Improvement Items		Cycle time improve	
Before	After	Before	After
Without Cooling system side die	Modifying hydraulic pressure control system	53 sec	40 Sec
Without Cooling system inmold design	Addition of cooling media with changes in mold design and casting parameters	460 sec	330 Sec
Material FCD 550	Material SKD6	460 Sec	330 Sec
Manual air blow process	Create automation air blow	7 Sec	3 Sec

From the results of the evaluation of the Improvement that has been carried out 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 has been fulfilled.

Hasil Check Visualisasi dari produk bisa dilihat dari tabel 8

Tabel 8. Condition visual check after product test

No.	Gambar Produk	Product Test Toyota Engineering Standard TS D5605G			
		Drum Test (RFT)	Moment Life (CFT)	Impact 13°	Impact 90°
1		OK	OK	OK	OK
2		OK	OK	OK	OK
3		OK	OK	OK	OK
4		OK	OK	OK	OK
5		OK	OK	OK	OK

100% of the resulting products are free of cracks and declared OK according to customer standards.

3.2. Discussion

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, Tmax=maximum temperature=700 °C, Ttake=40 °C (temperature water cooling), ΔT=Tmax–T(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.

4. 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.

Supplementary Materials: 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.

Author Contributions: 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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Appendix 1. Durability Report Aluminum Alloy Wheel Casting Mold

ALUMINIUM ALLOY WHEEL CASTING MOLD
DURABILITY REPORT

Status — **Trial Masspro**

Product	RUSH (17x6.5J) mold # 1
Mold	Design modification ~~(~~ New mold (circled) Existing type Repaired type
Details	Trial NEW PRODUCT Par 3 CPC

Test Result

Test standard			Test no.	Lot no.	Result	Judge
13° Impact Test	Criteria	Falling position				
W= 606 kg	1. No penetrated crack	0°	1	YEADF	606Kg, no crack	OK
P= 200 kPa	2. No separation		2	YCADR	606Kg, no crack	OK
215 / 60 R17	between rim and disc		3	YCADQ	636Kg, no crack	OK
	3. No air leakage	95°	1	YCADB	606Kg, no crack	OK
	(100% fall in 1 min.)		2	YDHDO	606Kg, no crack	OK
			3	YDADQ	636Kg, no crack	OK
		130°	1	YDADH	606Kg, no crack	OK
			2	YDADH	606Kg, no crack	OK
			3	YDADE	636Kg, no crack	OK
Impact Test 90°		Criteria				
JWL		No crack	1	YDADS	1010Kg. 8" / 0° no crack	OK
			2	YDADQ	1010Kg. 8" / 0° no crack	OK
			3	YEADG	1010Kg. 8" / 0° no crack	OK
M=1010Kg , H=8 inch			4	YEADS	1010Kg. 9" / 0° no crack	OK
Air pressure=254.8kp H=9 inch						
Tire= 215/60 R17						
Nut Seat Test		Criteria				
188.2Nm		No crack				
Bending Moment Fatigue Test		Criteria				
* Standard		No crack	1	YDADM	300.000 cycle, no crack	OK
M= 2.273 kNm (DMC)					600.000 cycle, no crack	OK
N= $100x10^4$ cycles min					1.000.000 cycle, no crack	OK
			2	YDADG	300.000 cycle, no crack	OK
					600.000 cycle, no crack	OK
					1.000.000 cycle, no crack	OK
					2.000.000 cycle, no crack	OK
					3.000.000 cycle, no crack	OK
			3	YDADR	300.000 cycle, no crack	OK
					600.000 cycle, no crack	OK
					1.000.000 cycle, no crack	OK
M= 2.867 kNm (JWL)			1	YEADE	100.000 cycle, no crack	OK
N= $10x10^4$ cycles min						
			1	YBADI	100.000 cycle, no crack	OK
			1	YEADB	100.000 cycle, no crack	OK
					200.000 cycle, no crack	
Dynamic Radial Load Fatigue Test		Criteria				
* Standard		No crack	1	YDADJ	3.000.000 cycle, no crack	OK
M= 18,369 kN (DMC)					6.000.000 cycle, no crack	OK
			1	MBADB	3.000.000 cycle, no crack	OK
N= $150x10^4$ cycles min						
			1	YDADD	3.000.000 cycle, no crack	OK
Tire= 215/60 R17						
M= 15.656 kN (JWL)			1	YDADP	500.000cycles. No crack	OK
N= $50x10^4$ cycles min			2	YEADL	500.000cycles. No crack	OK
			3	YDADN	500.000cycles. No crack	OK
Tire= 215/60 R17					1.000.000cycles. No crack	OK

Note :

Appendix 2. SOP - Parameter Proces Casting SKD6

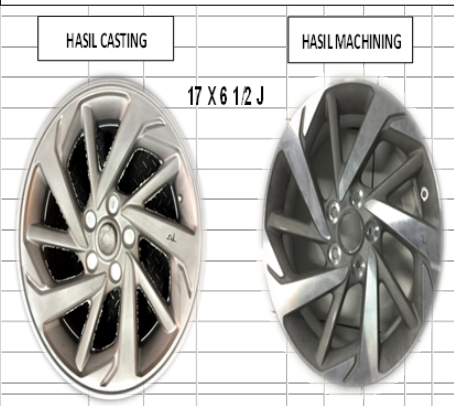
PROCESS	: CASTING CPC	Side Water Cooling System	REVISION : 5

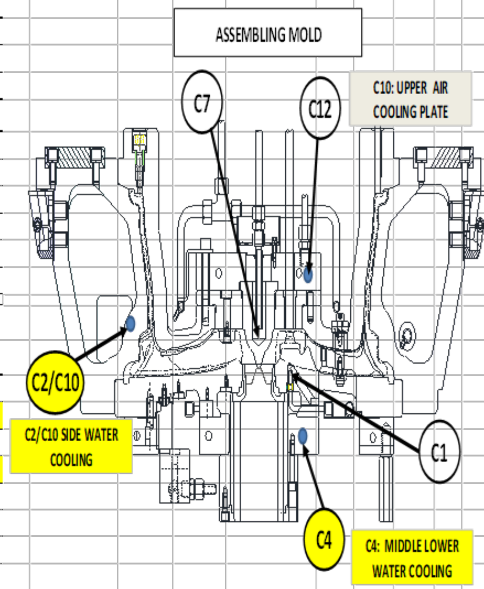
KONDISI CASTING - SW 1		NILAI SETTING	NILAI STANDARD
PREHEAT MOLD	(°C)	480	480 ± 20
TEMPERATUR HEATER METAL	(°C)	720	720 ± 10
TEMPERATUR INJECTION START	(°C)	490	460-490
TEMPERATUR MOLD OPEN	(°C)	510	490-510
SETTING SHOOT MAX./HF	(pcs)	20	20 ± 1
TARGET CYCLE TIME	menit	5:50	5:30-6:20
TYPE STEEL NET (KAWAT KASSA)	Ø mm	54	54
DIAMETER RISER TUBE	Ø mm	70	70
INTERLOCK TEMP. INJECTION	(°C)	30	460-490
INJECTION PRESSURE	P1 (mBar)	300	300-380
	P2 (mBar)	800	800-880
	Add. Pressure	4	4

INJECTION TIME	NILAI SETTING				STANDARD
SHOOT PRODUKSI	START UP 1	START UP 2	START UP 3	START UP 4	MASS PRO
PERSEN COOLING (%)	0	50	75	100	100
DELAY QUENCH (detik)	0	0	0	60	30-60
TEMP. MOLD (°C)	400 - 430	430 - 450	450 - 460	460-490	460-490
TIME SET. T1 (detik)	30	30	30	30	30
TIME SET. T2 (detik)	10	10	10	10	10
TIME SET. T3 (detik)	10	10	10	10	10
TIME SET. T4 (detik)	0	50	100	180	220 ± 20
TIME SET. Tpo (detik)	120	100	90	50	40-50
KAWAT KASSA	TIDAK	TIDAK	TIDAK	YA	YA

COOLING POSITION	PRESSURE (Bar)	FLOW RATE LPM	DELAY TIME (detik)	AIR COOLING (detik)	WATER COOLING (detik)	AIR COOLING (detik)
C1	5 ± 1	320 ± 40	160	140	-	-
C2	6 - 7	10 ± 2	40	40	50	50
C3	-	-	-	-		-
C4	6 - 7	10 ± 1	200	-	30	20
C5	-	-	-	-	-	-
C6	-	-	-	-	-	-
C7	5 ± 1	320 ± 40	80	220	-	-
C8	-	-	-	-	-	-
C9	-	-	-	-	-	-
C10	6 - 7	10 ± 2	40	40	50	50
C11	-	-	-	-	-	-
C12	5 ± 1	280 ± 40	80	220	-	-

ILUSTRASI GAMBAR





REV.	ITEM
2	Setting Flow Rate C1,C4,C7,C10
3	Total shot 20-22
4	Perubahan parameter casting
5	Penambahan Side Water Cooling

QMS	Approved by	Checked by	Prepared by
Abiyansyah	Juhaeri	Dariyono	Rian

Notes:
1. START UP #1, #2, #3 merupakan product TRIAL.
2. Jika Temperature injection start dibawah standard (< 460°C), Lakukan trial shot Start up #3.
3. Jika Injection start dibawah temperature standar (< 460°C), maka produk harus DI-REJECT.
4. Bila terjadi problem produksi segera hubungi SUPERVISOR atau PE MECA.
5. Apabila jumlah shot melebihi nilai maksimal shot, maka produk harus DI-REJECT.
6. Jika cycle time di atas standard (>6:20), setting flowrate C1, C7, C4, C10 pada standard maksimal sampai Standar Cycle Time tercapai. Catat nilai flowrate pada Laporan Harian Produksi Casting.

Appendix 3. Monitoring of production results.

IMPACT 13° TEST REPORT (Impact 1)

Standard Condition for Impact 13° Test

Type	P8D3K [17X8.5J] Mold #8
Load / Height	808kg/230 ± 2 mm
Tire size	215/60 R17
Tire air pressure	200 ± 10 kPa
Part No	42611-BZA80
Drawing no	P-R13-DA
Status pengujian	Trial casting chemco

Requirement

IT 13° = 0°,95°,135° After droping no crack

Test Condition and result for Impact 13° Test

Posisi	0°	95°	135°	
Load / Height	808kg/230 mm	808kg/230 mm	808kg/230 mm	
Testing date	28-Feb-24	28-Feb-24	28-Feb-24	
Lot number	8DW	8DW	8EW	

Picture

0°	95°	135°	
Front View	Front View	Front View	Front View
			
Back View	Back View	Back View	Back View
			
OK, no crack No leakage	OK, no crack No leakage	OK, no crack No leakage	

References

1. Wankhede, V. A., & Vinodh, S. (2022). State of the art review on Industry 4.0 in manufacturing with the focus on automotive sector. International Journal of Lean Six Sigma, 13(3), 692-732.doi.org/10.1108/IJLSS-05-2021-0101
2. Zhao, X., Gao, P., Zhang, Z., Wang, Q., & Yan, F. (2020). Fatigue characteristics of the extruded AZ80 automotive wheel. International Journal of Fatigue, 132, 105393.doi.org/10.1016/j.ijfatigue.2019.105393
3. Klobčar, D., Kosec, L. K. B. T. J., Kosec, B., & Tušek, J. (2012). Thermo fatigue cracking of die casting dies. Engineering failure analysis, 20, 43-53. doi.org/10.1016/j.engfailanal.2011.10.005
4. Schwam, D., Wallace, J., & Birceanu, S. (2002). Die materials for critical applications and increased production rates (No. DOE/ID/13693). Case Western Reserve University/Dept of Materials Science and Engineering (US). doi.org/10.2172/806823
5. Y. Su, G. Fu, C. Liu, C. Liu, and X. Long, "Microelectronics Reliability Fatigue crack evolution and effect analysis of Ag sintering die-attachment in SiC power devices under power cycling

based on phase-field simulation," Microelectron Reliab., vol. 126, no. May, p. 114244, 2021, doi: 10.1016/j.microrel.2021.114244.

6. H. Cai, Z. Wang, L. Liu, Y. Li, and F. Xing, "Crack source and propagation of AZ91-0. 9Gd alloy," J. Mater. Res. Technol., vol. 16, pp. 1571–1577, 2021, doi: 10.1016/j.jmrt.2021.12.065.
7. Schumacher, O., Marvel, C. J., Kelly, M. N., Cantwell, P. R., Vinci, R. P., Rickman, J. M., Harmer, M. P. (2016). Complexion time-temperature-transformation (TTT) diagrams: Opportunities and challenges. Current Opinion in Solid State and Materials Science, 20(5), 316-323. https://www.elsivier.com/open-access/userlicense/1.0/
8. E. Lordan et al., "High-Pressure Die Casting : A Review of Progress from the EPSRC Future LiME Hub," 2022. https://doi.org/10.3390/met12101575
9. S. Luthfiyah, A. Faridh, and B. Soegijono, "The Effect of Vacuum Quenching on Corrosion and Hardness of the Surface of SKD61 Steel," IOP Conf. Ser. Mater. Sci. Eng., vol. 694, no. 1, 2019, doi: 10.1088/1757-899X/694/1/012033.
10. U. Sudjadi and R. V. Sinaga, "Study of the hardness and microstructure profiles of SKD61 steel plunger tip (local material) after plasma nitriding," IOP Conf. Ser. Mater. Sci. Eng., vol. 839, no. 1, 2020, doi: 10.1088/1757-899X/839/1/012019.
11. W. Yi, G. Liu, J. Gao, and L. Zhang, "Boosting for concept design of casting aluminum alloys driven by combining computational thermodynamics and machine learning techniques," J. Mater. Informatics, 2021, doi: 10.20517/jmi.2021.10.
12. E. Walsh et al., "Manufacture of tablets with structurally-controlled drug release using rapid tooling injection moulding," Int. J. Pharm., vol. 624, no. January, p. 121956, 2022, doi: 10.1016/j.ijpharm.2022.121956.
13. Q. Yang, X. Wu, and X. Qiu, "Microstructural Characteristics of High-Pressure Die Casting with High Strength – Ductility Synergy Properties : A Review," 2023. https://doi.org/10.3390/ma16051954
14. Y. ran ZHOU et al., "Mechanism of heterogeneous distribution of Cr-containing dispersoids in DC casting 7475 aluminum alloy," Trans. Nonferrous Met. Soc. China (English Ed., vol. 32, no. 5, pp. 1416–1427, 2022, doi: 10.1016/S1003-6326(22)65883-7.
15. C. Wei et al., "A thermal-stress modelling methodology in ABAQUS for fundamentally describing the die/casting interface behaviour in a cyclic permanent die casting process," J. Mater. Res. Technol., vol. 15, pp. 5252–5264, Nov. 2021, doi: 10.1016/j.jmrt.2021.10.120.
16. D. Campos Neto, A.L. Korenyi-Both, C. Vian, S.P. Midson, M.J. Kaufman, The development of coating selection criteria to minimize die failure by soldering and erosion during aluminum high pressure die casting, Journal of Materials Processing Technology, Volume 316, 2023, 117954, https://doi.org/10.1016/j.jmatprotec.2023.117954.
17. M. Ahmadein, A. H. Elsheikh, and N. A. Alsaleh, "Modeling of cooling and heat conduction in permanent mold casting process," Alexandria Eng. J., vol. 61, no. 2, pp. 1757–1768, 2022, doi: 10.1016/j.aej.2021.06.048.
18. Z. Niu, G. Liu, T. Li, and S. Ji, "Effect of high pressure die casting on the castability, defects and mechanical properties of aluminium alloys in extra-large thin-wall castings," J. Mater. Process. Technol., vol. 303, no. January, p. 117525, 2022, doi: 10.1016/j.jmatprotec.2022.117525.

19. Z. Li et al., "Characterization on the formation of porosity and tensile properties prediction in die casting Mg alloys," vol. 10, pp. 1857–1867, 2022, doi: 10.1016/j.jma.2020.12.006.
20. P. Dudek, J. Białoń, J. Piwowońska, W. Walczak, and K. Wrzała, "The impact on the cost of making high pressure die castings with multi-cavity die and vacuum assistance," Vacuum, vol. 210, Apr. 2023, doi: 10.1016/j.vacuum.2023.111859.