

Effect of Cyclic Simulation Cooling and Solidification during High Pressure Die Casting

GVOZDEN B. JOVANOVIĆ, Institute for Technology of Nuclear and
Other Mineral Raw Materials, Belgrade
ORCID: 0000-0002-9754-2230

Original scientific paper
UDC: 621.746.5.044.7:669.715
DOI: 10.5937/tehnika2601033J

ALEN Š. DELIĆ, TTU energetik d.o.o, Tuzla, Bosna i Hercegovina,
VASO D. MANOJLOVIĆ, Univesity of Belgrade,
Faculty of Technology and Metallurgy, Belgrade
ORCID: 0000-0002-3009-2909

STEFAN M. DIKIĆ, Univesity of Belgrade,
Faculty of Technology and Metallurgy, Belgrade
ORCID: 0000-0003-2700-0628

MILICA M. MILETIĆ, Institute for Technology of Nuclear and
Other Mineral Raw Materials, Belgrade

MIROSLAV D. SOKIĆ, Institute for Technology of Nuclear and
Other Mineral Raw MaterialsG, Belgrade
ORCID: 0000-0002-4468-9503

This is a case study on how successive simulation cycles influence the cooling and solidification during high pressure die casting. The casting model is made for a mounting frame for recessed lighting and the material used is aluminum alloy for the casting and the die is made from H11 tool steel. A total of 8 simulations were made with various conditions. Two different die opening criteria were used, first is that the liquid phase of the casting reaches 0%, and second that the casting cools down to 450 °C. After the casting is removed from the mold five different cooling times were simulated (5s, 10s, 30s, 60s, 120s) for the duration of 10 cycles with stationary air of 20°C as a cooling medium. The most optimal cooling time was determined to be 30 seconds, and for this criteria the number of cycles was increased 100. However, 100 cycles were simulated as solidification only with the assumption that the casting cavity was filled to 100%, even if the flow simulations of the 10 cycles showed a maximum of 99.977%. Depending on the cooling time the overall time needed to finish 10 cycles of casting was between 11 and 27 minutes, while 100 cycles took around 3 hours according to the simulations. For the 100 cycles for the first condition the cycle time grew from 74 to 107 seconds, while for the second it grew from 75 to 126 seconds. Once more operating parameters are acquired from the manufacturer, casting failures can be avoided by using simulations to properly maintain equipment.

Key Words: HPD casting, aluminum, manufacturing, Nova Cast, cyclic simulation

1. INTRODUCTION

When it comes to traditional casting technologies optimizing processes can be crucial in reducing costs.

Author's address: Gvozden Jovanović, Institute for
Technology of Nuclear and Other Mineral Raw Materi-
als, Belgrade, Bulevar Franš d'Eperea 86

e-mail: g.jovanovic@itnms.ac.rs

Paper received: 04.02.2026.

Paper accepted: 10.02.2026.

One such casting technology is high pressure die (HPD) casting which is widely practiced in the casting industry for metals such as aluminum and its alloys [1]. Simulation can effectively mimic various casting techniques, including the cyclical nature of high pressure die casting [2].

According to Dou et al. it is common that the poor mechanical properties and significant variability parts that are made by HPD casting can be closely linked to the size and distribution of shrinkage/gas porosities,

large intermetallic phases, and externally solidified crystals that develop in the shot sleeve before injection [3]. Through simulation, the evaluation of different inflow routes and feeding systems effects can be made helping to identify and mitigate defects that can occur during casting.

By gathering experimental or manufacturing data, the precision of simulation can be improved to contribute to enhanced casing quality and lower cost. Norwood et al. [4] measured the die surface temperature during HPD casting of aluminum, with a pouring temperature of 750 °C and a cycle time of 20-24 seconds. The results indicated that the die temperature occasionally exceeded 450 °C, but it generally ranged between 400-450 °C. The primary input for every simulation program is a 3D CAD model used to design the molds, secondary is how said model is integrated with the software infrastructure to simulate operating conditions [5].

The solidification mechanism of casting alloys, including aluminum-silicon alloys, are heavily influenced by the cooling rate, particularly in castings produced using HPD technology. It is widely recognized that the mechanical properties of cast aluminum alloys are significantly affected by the local microstructural features that develop during solidification [6]. The cooling rate reflects the heat transfer conditions of solidification, and it is crucial since it influences the castings microstructure [7]. During manufacturing using the HPD, the mold needs to be cooled down after every cycle so that the equipment can last longer, cooling is done by blowing air, water, or just normalization.

Also, coating are often applied do the contact surfaces of the die before a casting cycle begins. There are all processing parameters that can influence how many casting cycles can be performed before maintenance, that are important to manufacturing economics. For this paper this simulation of HDP will be made on a model of an aluminum mounting frame for recessed lighting.

Due to the layout of the Nova Cast software interface this paper will be mainly focused on the cooling of the mold, but it will also give attention to the solidification of the casting before it is removed from the mold. Unfortunately, if there is a need to simulate what would happen to the casting once dislodged from the mold that would require a different simulation setup for each cycle.

2. MATERIALS AND METHODS

The material used for the mold was the standard H11 tool steel while the casting material was aluminum alloy SS4250. As stated in the Nova Cast database the chemical composition of the aluminum is presented

in Table 1, and other thermal characteristics are presented in Table 2.

Table 1. Chemical composition of aluminum alloy from the Nova Cast database

Element mass (%)	
Al	84.04
Si	10.00
Mg	0.20
Mn	0.30
Cu	3.00
Fe	0.80
Ni	0.15
Zn	1.50
Ti	0.01

Table 2. Nova Cast database characteristics of aluminum alloy described in Table 1

Material parameter	
Liquidus Temperature (°C)	595.56
Eutectic temperature (°C)	534.19
Solidus Temperature (°C)	534.19
Q _{er} (kJ/kg)	339.00
Q _{et} (kJ/kg)	505.58

The model used in this study has four components, that are presented in Figure 1. The casting (dark purple), the pressure chamber (dark orange), and two cooling channels (light green).

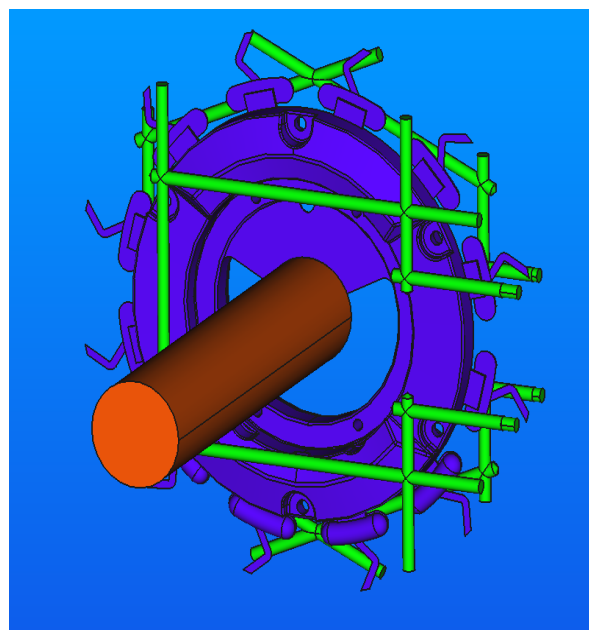


Figure 1 - CAD model of the casting set up

Once input in the Nova Cast software the mold will be made up from the dimensions of the calculation box.

The heat conduction for the steel material of the mold is presented in Figure 2.

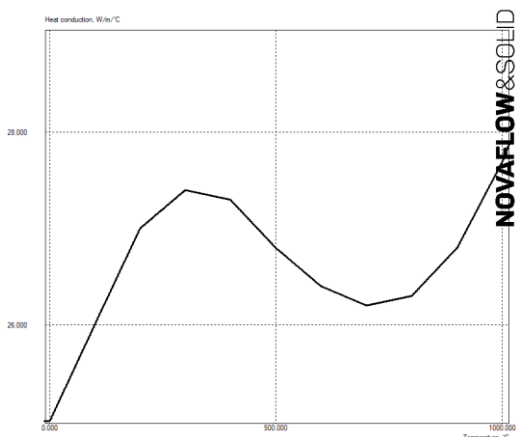


Figure 2 - Nova Cast database heat conduction for the tool steel H11 mold material

2.1. Simulation set up

The software program used for cyclic modeling and casting simulation is the Nova Cast [2]. This program utilizes the finite volume method instead of the common finite element method. This means the model is divided into small cubes and edge cells.

The network is made by altering the size of the cubes in the model to the end of the calculating box. This means the size of the cells can be larger. For this model the cell size was 5.0 mm with a total cell count of 221076 with 22451 casting cells. When building the mesh the Mould thickness option was adjusted so the

calculating box that represents the mold and cuts off most of the pressure chamber and ensures that the cooling channels start at the edge of the box (Low X 25 mm, High X -3 mm; Low Y -270 mm High Y 25 mm; Low Z 10 mm; High Z 25 mm). This is necessary in order to build the beginning and end of the cooling channels in the **Channels** options (Figure 3, left), doing so the temperature of the water was set to 30°C, the flow was 0.3 L/s, and the pressure was 1.05 bar. Additionally, this way the **Gating point** is easier to establish as it is the same as the diameter of the pressure chamber 80 mm (Figure 3, right).

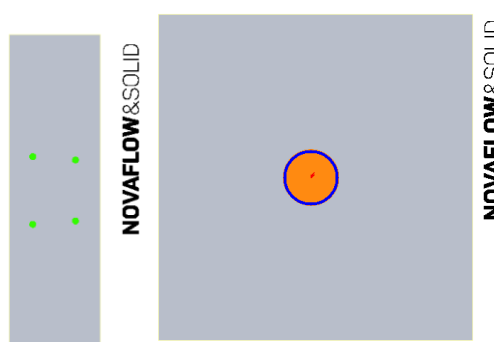


Figure 3 - End of model where the pressure chamber and cooling channels go into the mold

When it comes to high pressure die casting in the Filling parameters there are multiple options, however for this paper HPD with filling chamber was chosen and the following parameters are presented in Figure 4.

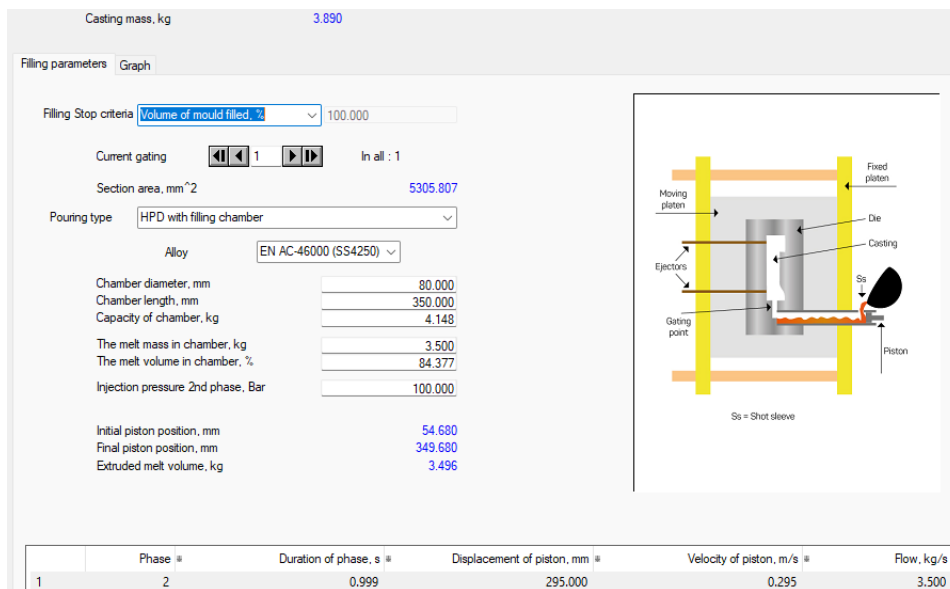


Figure 4 - Filling parameters for high pressure die casting used for all simulations

When choosing the shrinkage model the feeding pressure was set to 300 bar, and the gravity influence was not taken into account. A quasi-equilibrium model calculation without segregation was chosen in the

solver setting option, with all other options turned off. In all cases the heat transfer model was by default set to air gap. The automatic vent on the edge of the top box boundary was turned off. The initial temperature

for the mold material was 250 °C while the air in the mold was 200 °C. Cooling media is air outside of mold set at 20°C. Finally, for cyclic modeling 10 cycles were calculated as Flow and Solid (F&S). At first, the die opening was set to volume of liquid phase at 0% while the cooling phase after the casting is ejected was set at different times: 5s, 10s, 30s, 60s, and 120s. Then one simulation was made where the die opening was set to 450 °C and the cooling phase was 30s.

However, for modeling 100 cycles simulations were set to All Solid (All S) to conserve processing time. In that case pouring phase is not simulated, as for the cooling phase it was set 30s and the two variables were die opening at 0% of liquid phase and die opening at 450°C.

3. RESULTS AND DISCUSSION

The basic operating parameters were extrapolated from the simulation results and presented for every cooling time and each cycle in Table 3. The cooling time is the set parameter in the cyclic modeling while the filling time is the simulated time needed to fill the mold, and the solidification time is the time calculated for the liquid phase to reach 0% after the mold is filled.

The total time needed for each cycle as well as the whole time needed for all the 10 cycles are also presented in Table 3. As expected, the first cycle is the same regardless of cooling time and the filling time is the same for all cycles.

Table 3. Casting simulation results of time needed for filling and solidification

Basic operating parameter	Cooling Time	Cycle										Total	
		1	2	3	4	5	6	7	8	9	10		
Filling Time (s)	5 s	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	12
Solidification Time (s)		45	52	57	62	68	72	74	76	76	78	78	661
Cycle time (s)		51	59	63	69	74	78	81	82	82	84	84	723
Filling Time (s)	10 s	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	12
Solidification Time (s)		45	51	57	61	65	70	72	74	74	75	75	644
Cycle time (s)		56	58	63	67	71	76	78	80	81	82	82	711
Filling Time (s)	30 s	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	12
Solidification Time (s)		45	50	54	57	60	62	63	65	66	66	66	589
Cycle time (s)		76	81	85	88	91	94	95	96	97	97	97	901
Filling Time (s)	60 s	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	12
Solidification Time (s)		45	49	51	53	55	57	58	58	59	60	60	544
Cycle time (s)		106	110	112	114	116	118	119	119	120	121	121	1155
Filling Time (s)	120 s	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	12
Solidification Time (s)		45	46	47	48	49	50	50	51	50	51	51	485
Cycle time (s)		166	167	168	169	170	171	171	172	172	172	172	1697

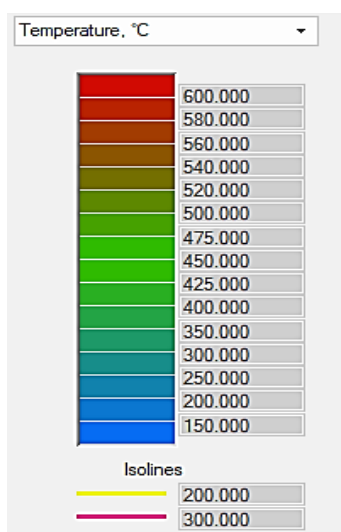


Figure 5 - Temperature scale for all simulations

Naturally the shorter the cooling time is needed for the casting to solidify after each cycle. Therefore, using these types of simulation, it can be determined how much time is optimal for casting a set of products while maintaining proper conditions for tool and equipment maintenance. The most notable drop in solidification time per cycle is found for cooling at 30s. That is why that time was chosen as optimal for comparison for both 10 and 100 cycles. The main difference for All S simulations is that when they are all solid the casting cavity in the mold is filled instantly to a 100% and the cooling starts. In contrast F&S takes 1.2 seconds to fill the mold (Table 3), and the filled volume does not exceed 99.977%. The effect of this difference is illustrated in Figure 6 at the beginning for the solidification in the fifth cycle. The temperature scale is the same for all simulation results and is given in Figure 5. The first simulation comparison for cooling at 30 seconds is

made in the by changing the die opening condition from liquid phase at 0% to die opening at 450 °C. This would add additional time after the casting has solidified further lengthening the overall cycle time. Furthermore, using F&S during the 1.2 seconds of filling time there is significant heat exchange difference that has a cumulative effect as the number of cycles increases. For the purpose of this paper „Eject time“ is defined as the time from the moment the liquid phase reaches 0% until the casting reaches 450°C. If we look how this

time is presented in Table 4 we can also see another effect that stems from the differences between F&S and All S simulations.

The Cycle time (Table 4) is calculated by adding 30 seconds for cooling time and 1.2 seconds for the filling time to the solidification and ejection times. In the All S when the die opening condition is 450 °C for the first cycle the eject time is 1.1 seconds, this is because the mold didn't get to heat up since the was no filling simulation.

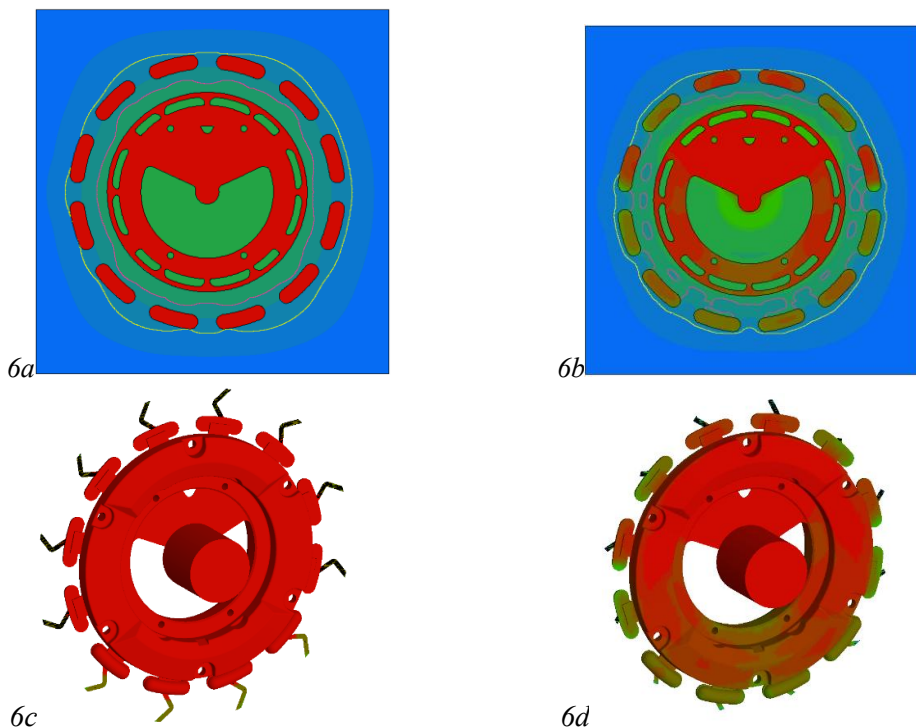


Figure 6 - Temperature distribution at the start of solidification in the fifth cycle: a) mold cross section, 100 cycles simulation; b) mold cross section, 10 cycle simulation; c) casting, 100 cycle simulation; d) casting, 10 cycle simulation

Table 4. Basic operating parameters for the first 10 cycles in F&S and All S simulations

Sim.	Basic operating parameter	Cycle									
		1	2	3	4	5	6	7	8	9	10
F&S 0%	Solid. Time (s)	45.0	49.6	54.2	56.9	59.7	62.5	63.4	65.2	66.2	66.1
	Eject time (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Cycle time (s)	76.17	80.80	85.38	88.14	90.91	93.67	94.59	96.43	97.35	97.35
All S 0%	Solid. Time (s)	42.2	46.8	49.6	52.3	56.0	57.9	59.7	60.6	61.5	62.5
	Eject time (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Cycle time (s)	73.4	78.0	80.8	83.5	87.2	89.1	90.9	91.8	92.7	93.7
F&S 450°C	Solid. Time (s)	45.0	49.6	53.3	56.9	58.8	60.4	61.5	62.5	63.4	63.4
	Eject time (s)	2.3	2.3	6.4	7.5	9.8	10.0	9.8	9.8	9.8	12.5
	Cycle time (s)	78.5	83.1	90.9	95.6	99.8	101.6	102.6	103.5	104.4	107.1
All S 450°C	Solid. Time (s)	42.2	45.9	49.6	52.3	55.1	56.9	58.8	59.6	60.6	60.6
	Eject time (s)	1.1	2.3	2.3	3.8	5.5	5.5	5.5	5.5	5.5	7.5
	Cycle time (s)	74.5	79.4	83.1	87.3	91.8	93.6	95.5	96.3	97.3	99.3

However, All S simulations are necessary in order to estimate the effects if higher number of cycles, which is illustrated in Table 5 that shows how much time was spent for each simulation presented in this paper. Even though most of the simulations were being processed simultaneously, making them take over an hour to complete, All S simulations are much faster and require less processing power.

Therefore, it is beneficial to estimate the filling time on a smaller set of cycles and correlate the cooling

impact. When the 1.2 second of filling time is accounted for it accumulates to 20 minutes, which can be added to the final simulated times for the All S simulations.

The difference in solidification time for the first 10 cycles (Table 4) between F&S and All S simulations does not exceed more than 5 seconds, however when we factor in the ejection time that is needed to cool down the casting to 450 °C this leads to a significant increase in cycle time.

Table 5. Calculation time needed to process all the simulations

Simulation type	Simulated time			Cycles	Die opening	Cooling time	Calculation time		
Flow and Solid	11min	58s		10	Liquid 0%	5s	1h	8min	9s
Flow and Solid	12min	31s		10	Liquid 0%	10 s	1h	31min	39s
Flow and Solid	14min	47s		10	Liquid 0%	30 s	1h	27min	1s
Flow and Solid	18min	56s		10	Liquid 0%	60 s	1h	26min	12s
Flow and Solid	27min	48s		10	Liquid 0%	120 s	1h	27min	44s
Flow and Solid	15min	59s		10	450 °C	30 s		46min	31s
All Solid	2h	46min	38s	100	Liquid 0%	30 s	1h	33min	48s
All Solid	3h	9min	6s	100	450 °C	30 s	1h	34min	22s

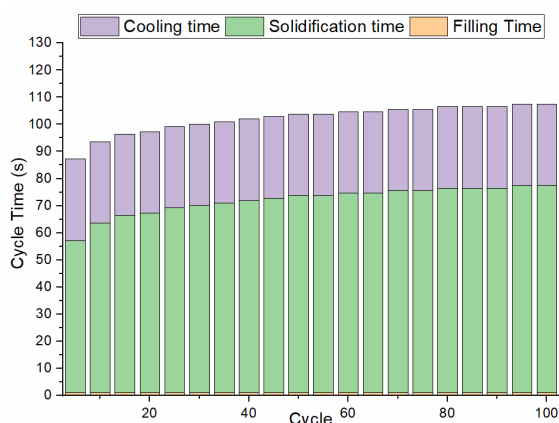


Figure 7 - Cycle time for every 5 cycles when the die opening condition is liquid phase 0%

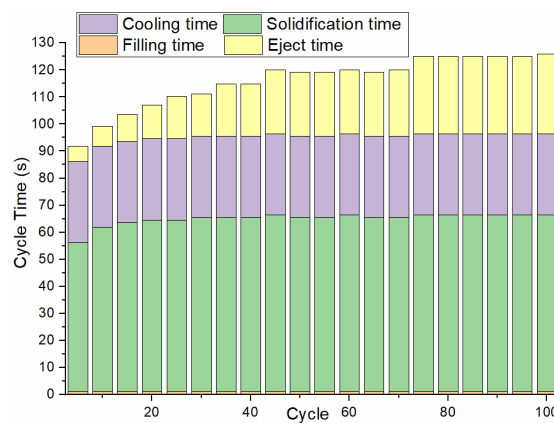


Figure 8 - Cycle time for every 5 cycles when the die opening condition is temperature of 450°C

At higher cycles (Figures 7 and 8) we can see how much the ejection time increases the overall cycle time. Even though the solidification time is lower when the casting is removed from the die at 450 °C, the overall cycle time increases adding up to the final difference in simulated time of about 23 minutes (Table 5).

However, this is just a preliminary case study that demonstrates the benefits of how using simulation to change operating parameters can influence overall casting performance. There are numerous angles on which this model will be improved. The most important thing when doing simulations is realistic information about manufacturing parameters. For example, for this model Filling parameters the gating is in the zone

of the pressure chamber making it shorter for 80 cm, and its overall casting weight is 3.89 kg while the molten mass in chamber is 3.5 kg. That would mean that about 400 kg of casting would be produced from 102 cycles. Furthermore, the cooling channels do not have equivalent heat exchange and have a constant flow and temperature that is not representative of realistic conditions.

Finally, there are other types of HPD casting simulations available in the Nova Cast software that can be contrasted and compared. In the future the plan is to give further attention to the aforementioned issues and get more data from the casting manufacturer so that the simulation accuracy can be further developed.

Also, there is an option for the die opening condition can be fixed at a set time, since it is also one of the possibilities to explore as an operating parameter.

4. CONCLUSION

This paper has demonstrated that cyclic simulation is very important and useful, however also limited when using the Nova Cast software. For cyclical simulations in Nova Cast two options were used Flow and Solid and All Solids. There was a total of 8 simulations for this case study. First five were run for 10 cycles to determine the optimal cooling time after the casting was removed from the die once the liquid phase reaches 0%.

The optimal cooling time was determined to be 30 seconds, and it was used for a different die opening criteria, that was 450 °C. This factored in additional time needed to cool down (eject time) that added to the overall time of each cycle but also lowered the time needed for the solidification of the casting. In all cases the time needed to fill the casting was determined to be about 1.2 seconds. Once the effect of these parameters were established in the first 10 cycles using Flow and Solid the number of cycles was increased to 100 using.

The 100 cycles were simulated using All Solids to save processing time and power. Depending on the cooling time the overall time needed to do 10 cycles was between 11 and 27 minutes, while 100 cycles took around 3 hours according to the simulations. For the 100 cycles if the die opening conditions was 0% liquid phase the cycle time grew from 74 to 107 seconds, while if the conditions was 450 °C it grew from 75 to 126 seconds because of the influence of the eject time.

Once more operating parameters can be acquired from the manufacturer, such as cooling channel temperature and flow changes, time as die opening criteria, piston movement or metal flow a more precise level of correlation between the praxis and simulation will be established. That way the purpose of using software simulations will be fulfilled so money can potentially saved in lowering manufacturing costs by reducing

failed casting and making maintenance more efficient and less frequent.

5. ACKNOWLEDGEMENT

This research was funded by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract No.: 451-03-33/2026-03/200023 and 451-03-33/2026-03/200135).

REFERENCES

- [1] Nandakumar, V. *Process and Tool Design for the High Integrity Die Casting of Aluminum and Magnesium Alloys* (Master's thesis, The Ohio State University), 2014.
- [2] NovaCast Systems A. B: NovaFlow&Solid 6.6, Ronneby, 2015.
- [3] Dou K, Lordan E, Zhang Y. J, Jacot A. and Fan Z. A complete computer aided engineering (CAE) modeling and optimization of high pressure die casting (HPDC) process. *Journal of Manufacturing Processes*, 60, pp.435-446, 2020.
- [4] Norwood A. J, Dickens P. M, Soar R. C. and Harris, R. A. Surface temperature of tools during the high-pressure die casting of aluminium. Proceedings of the Institution of Mechanical Engineers, Part B: *Journal of Engineering Manufacture*, 221(12), pp.1659-1664, 2007.
- [5] Anglada E, Boto F, García de Cortazar, M. and Garmendia I. Metamodels' development for high pressure die casting of Aluminum Alloy. *Metals*, 11(11), p.1747, 2021.
- [6] Kowalczyk W, Dańko R, Górny M, Kawalec M. and Burelko, A. Influence of high-pressure die casting parameters on the cooling rate and the structure of EN-AC 46000 alloy. *Materials*, 15(16), p.5702, 2022.
- [7] Shabestari S. G. and Shahri F. Influence of modification, solidification conditions and heat treatment on the microstructure and mechanical properties of A356 aluminum alloy. *Journal of Materials Science*, 39(6), pp.2023-2032, 2004.

REZIME

UTICAJ CIKLICNE SIMULACIJE HLAĐENJA I OČVRŠĆAVANJA TOKOM LIVENJA POD PRITISKOM

Ovaj rad predstavlja studiju slučaja kako uzastopna ciklična simulacija hlađenja i očvršćavanja utiče na operativne parametre tokom livenja pod pritiskom. Model odlivka napravljen je za montažni okvir za ugradnu rasvetu, a materijal korišćen u simulaciji je aluminijumska legura za odlivak, i alatnog čelika za kalup. Ukupno je izvedeno 8 simulacija sa različitim uslovima. Korišćena su dva različita kriterijuma otvaranja kalupa: prvi je da tečna faza liva dostigne 0%, a drugi da se odlivak ohladi na 450°C. Nakon što je odlivak uklonjen iz kalupa, postavljeno je pet različitih vremena hlađenja (5s, 10s, 30s, 60s, 120s) tokom 10 ciklusa sa stacionarnim vazduhom od 20°C kao sredstvo za hlađenje. Najoptimalnije vreme hlađenja je utvrđeno za 30 sekundi, i za ovaj kriterijum povećan je broj ciklusa na 100. Međutim, 100 ciklusa je simulirano kao čisto očvršćavanje bez ulivanja sa pretpostavkom da je šupljina kalupa bila potpuno popunjena (100%), iako su simulacije ulivanja tokom 10 ciklusa pokazale maksimalno popunjavanje od 99,977%. Prema simulacijama u zavisnosti od vremena hlađenja, ukupno vreme potrebno za završetak 10 ciklusa livenja bilo je između 11 i 27 minuta, dok je za 100 ciklusa to vreme iznosilo oko 3 sata. Pri simulaciji 100 ciklusa, za prvi uslov, vreme jednog ciklusa se povećavalo od 74 do 107 sekundi, dok se za drugi uslov povećalo sa 75 na 126 sekundi. Kada se dobiju dodatni operativni parametri od proizvođača, greške pri livenju mogu se izbeći korišćenjem simulacija uz pravilno održavanje opreme.

Ključne reči: *Livenje pod pritiskom, aluminijum, proizvodnja, Nova Cast, ciklična simulacija*