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Nenehno izboljševanje tlačnega litja s postopkom Šest sigem

Continuous Improvements in Die-Casting Using a Six Sigma Approach

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Prispevek se ukvarja z uporabo metodologije Šest sigem za nenehno izboljševanje procesa tlačnega litja aluminija. Projekt izboljšanja Šest sigem je vpeljan v proces tlačnega litja aluminija z namenom zmanjšati obdelovalni izmeček s povprečnih 4,12 % na manj ko 2 % ter materialni izmeček z 11,43 % na manj ko 4 % v povprečju. Parametri z največjim vplivom na količino izmečka so določeni v diagramu vzrok - posledica, analizirani, izboljšani, ker je to potrebno, in nadzorovani z uporabo orodij in metod Šest sigem. Začetni cilji projekta niso povsem doseženi, narejene so bile večje izboljšave procesa tlačnega litja, ki so dale značilne prihranke.

(Ključne besede: metodologija Šest sigma, tlačno litje, aluminij, nenehne izboljšave)

This paper deals with the application of a Six Sigma methodology to the continuous improvement of an aluminium die-casting process. A Six Sigma improvement project was initiated in an aluminium die-casting process, with the aim to reduce the amount of machining scrap from an average of 4.12% to less than 2%, and the amount of material scrap from 11.43% to an average of less than 4%. The parameters with a major influence on the level of scrap were defined in a cause-and-effect diagram, analyzed, improved where necessary, and put under control using Six Sigma tools and methods. Although the initial project goals were not completely met, major die-casting process improvements were made, resulting in significant savings.

(Keywords: Six Sigma, die-casting, aluminium, continuous improvements)

0 UVOD

Zaradi velike količine izmečka v procesu tlačnega litja aluminija se je pričel izvajati projekt izboljšanja Šest sigem. Glavna namena projekta se nanašata na zmanjšanje ravni odkritega izmečka pri tlačnem litju, ki v povprečju dosega 4,12 %, kakor tudi izmečka pri obdelavi, ki v povprečju znaša 11,43 %. Cilja projekta Šest sigem sta: zmanjašanje izmečka pri tlačnem litju na manj ko 2 % in izmečka pri obdelavi na manj ko 4 %.

Skladno z metodologijo DMAIC, prvi korak je bil merjenje ravni celotnega izmečka in določanje deleža v odstotkih za posamezne vrste izmečka. Poroznost, s svojim deležem več kakor 80 %, je bila ugotovljena kot najizrazitejša vrsta izmečka pri tlačnem litju (sl. 1).

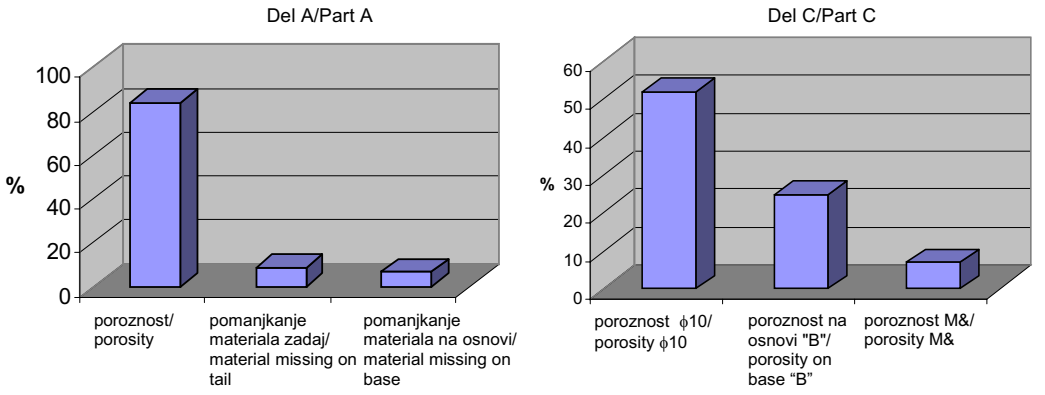
Analiza izmečka pri obdelavi pa je pokazala, da sta izmeček, povzročen s pršenjem kalupov, in

0 INTRODUCTION

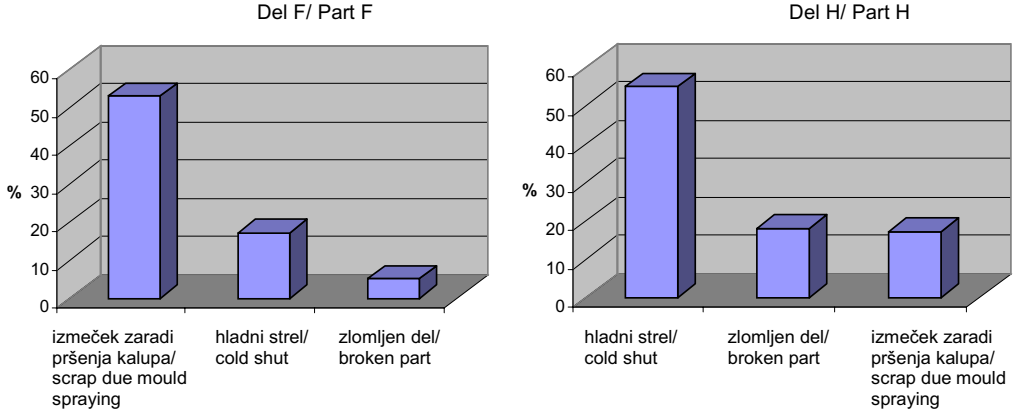
Due to the high level of scrap in the aluminium die-casting process a Six Sigma improvement project was begun. The main project goals were related to a reduction in the amount of scrap during pressure die casting, which on average amounted to 4.12%, as well as a reduction in the amount of scrap during machining, which on average equals 11.43%. The Six Sigma project goals were a reduction of scrap during the die-casting process to less than 2%, and scrap during machining to less than 4%.

In accordance with the *DMAIC* methodology the first step was to measure the current scrap level and to determine the percentage of each type of scrap in the total. Porosity was selected as a major scrap type in die-castings that contributes more than 80% to the total amount of scrap (Fig. 1).

The machining-scrap analysis revealed that the scrap caused by mould spraying and the type of scrap



Sl. 1. *Materialni izmeček za izbrana izdelka*
Fig. 1. *Material scrap for selected types of products*



Sl. 2. *Obdelovalni izmeček za izbrana izdelka*
Fig. 2. *Machining scrap for selected types of products*

izmeček, imenovan *"hladni strel"*, najbolj opazni vrsti izmečkov pri tlačnem litju (sl. 2).

1 ANALIZA PROCESA IN IZBOLJŠAVE

Postopek tlačnega litja je ponazorjen s shemo na sliki 3.

V postopek vstopa surovi material, kateremu je dodan tudi povratni material iz livarne ali obdelovalnice za ponovno pretaljevanje. Po taljenju se raztaljeni material nalije v lonec za litje in prenese v stroj za tlačno litje. Pred nalivanjem v stroj se raztaljeni material izpostavi procesu odplinjevanja, da bi se zmanjšal delež plinov v talini in s tem zmanjšal pojav poroznosti pri litju. Na vsakem stroju za tlačno litje se raztaljeni material nalije v peč, ki omogoča litje pri ustrezni temperaturi. Po tlačnem litju sledi ločevanje dolivkov, nadzor in raziglanje. Po tem so deli pripravljeni za prevoz za nadaljnjo obdelavo.

called *cold shut* represented the two most influenced types of scrap observed during die-casting (Fig. 2).

1 PROCESS ANALYSIS AND IMPROVEMENTS

The die-casting process is represented by the process map shown in Figure 3.

The process involves raw material, to which is added material that is returned from the process to be melted again. After melting, the melted material is poured into the casting vessel and transported to the casting machines. Before pouring into the die-casting machines, the melted material is subjected to a process of out-gassing to reduce the amount of gas in the materials and to prevent the appearance of porosity in the castings. On each die-casting machine melted material is poured into the furnace; this enables casting at the appropriate temperature. After the die-casting, the parts are subjected to trimming, control and deburring. At this point the parts are ready to be transported for further machining.

Kakor je razvidno, določena vrsta izmečka nastane med tlačnim litjem in le manjši del med procesom ločevanja dolivkov. Številni parametri lahko vplivajo na raven izmečka. Razvrščeni so v pet glavnih kategorij: material, osebje, stroji, meritve in okolje ter analizirani z diagramom vzrok – posledica (sl. 4).

Skupine material, osebje in stroji, s podskupino kalupi, so analizirani posebej, medtem ko je skupina meritve analizirana skupaj s skupino osebje, skupina okolje pa skupaj s skupino stroji.

1.1 Material

Da bi zagotovili celoten nadzor nad materialom, so izvedli podrobno analizo sestave in ravnanja s talino med prevozom, odplinjevanja in segrevanja na temperaturo litja. Opravljene dejavnosti izboljšanja, ki se nanašajo na pripravo raztaljenega materiala, so naslednje:

- Zaradi neustrezne čistoče talilne peči sta bila izvedena potrebno popravilo in čiščenje, skladno z ustrezno specifikacijo delovnega postopka; višja raven nadzora in pregleda snažnosti sta definirana.
- Po čiščenju se je delovna zmogljivost peči povečala, kar je pripeljalo do izboljšanja učinkovitosti izrabe energije v peči.

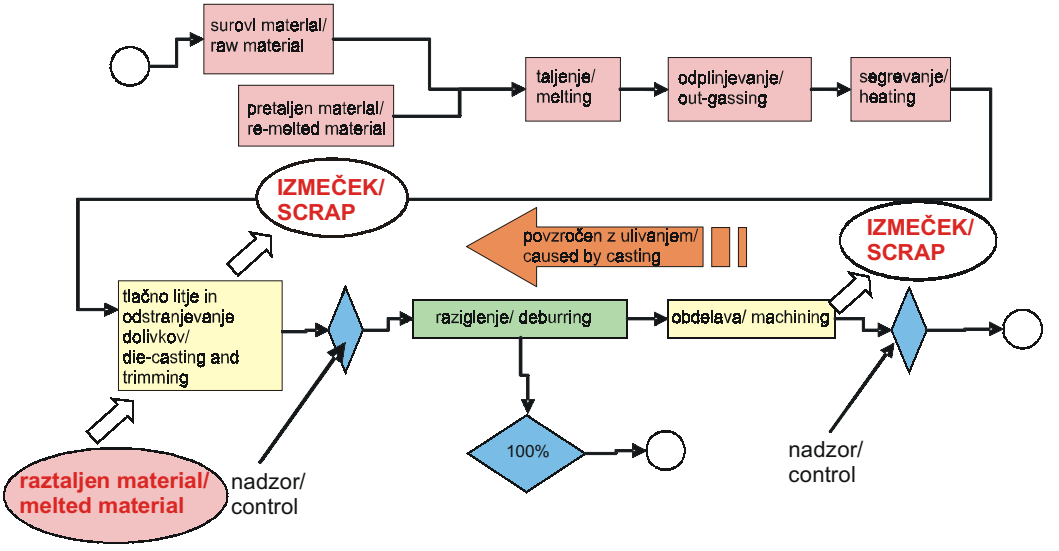
Obviously, scrap is produced during the die-casting and to a smaller extent during the trimming process. There are a large number of parameters that can influence the level of scrap. The parameters are grouped into five main categories: Material, Personnel, Machines, Measurements and Environment, and these are analyzed with a cause-and-effect diagram (Fig. 4).

The groups Material, Personnel and Machines, with the subgroup Moulds, are separately analyzed, while the group Measurement is analyzed together with the group Personnel, and the group Environment is analyzed together with the group Machines.

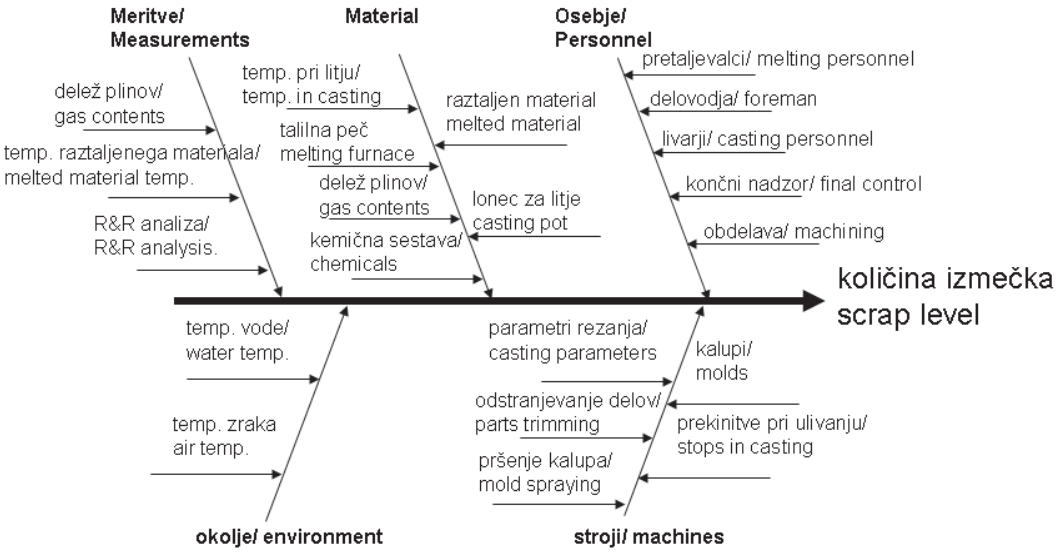
1.1 Material

To ensure that the material is completely under control, a detailed analysis of the composition and the handling with melted material during transportation, out-gassing and heating at the casting temperature, was carried out. The implemented improvement activities that concern the preparation and handling of the melted material are as follows:

- Due to the unsatisfactory cleanliness of the melting furnace, necessary repair and cleaning are carried out and, in accordance with appropriate operating procedure specification, a higher level of control and cleanliness inspections are defined.
- After cleaning, the operating capacity of the furnace is increased, resulting in an improved energy efficiency of the furnace.



Sl. 3. *Poenostavljena shema postopka tlačnega litja*
Fig. 3. *Simplified die-casting process map*



Sl. 4. *Diagram vzrok - posledica za parametre, ki vplivajo na količino izmečka*
Fig. 4. *Cause-and-effect diagram of parameters that influence scrap level*

- Osebje je dodatno usposabljano za izvajanje ustreznega čiščenja povratnega materiala iz procesa tlačnega litja pred taljenjem.
- Sedanja izolacija lonca za litje je zamenjana z izolacijo, ki ima manjšo toplotno prevodnost, kar povzroča neznatno ohlajanje raztaljenega materiala med prevozom. Neposredni rezultat te izboljšave je, da se je temperatura segrevanja v peči za litje lahko znižala za približno 45 °C.
- Metoda "Poka-yoke" je uporabljena na stroju za odplinjevanje, da bi preprečili odplinjevanje s tlakom plina, nižjim od dovoljenega.
- Metoda "Poka-yoke" je tudi uporabljena na strojih za tlačno litje, da bi preprečili litje pri temperaturi raztaljenega materiala zunaj določenega delovnega področja.

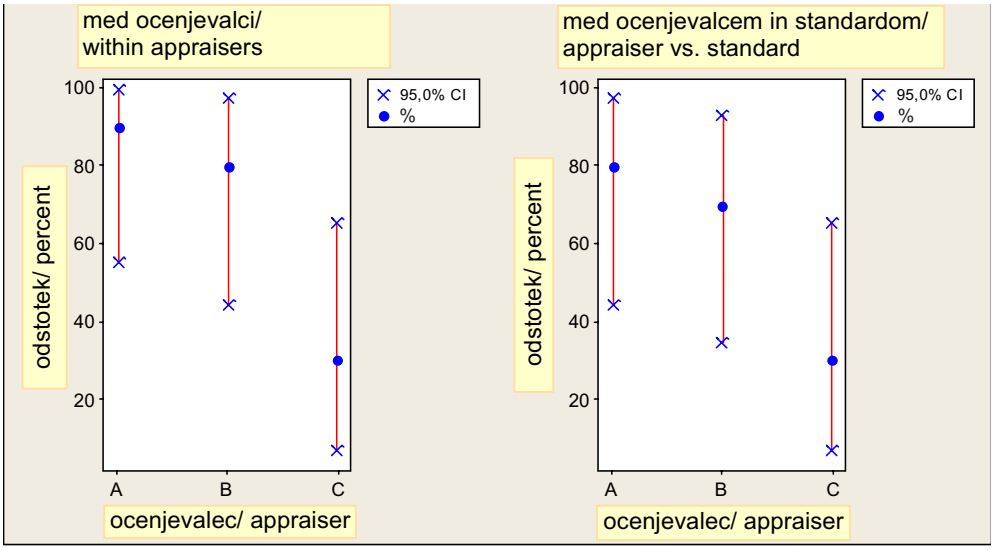
1.2 Osebje

Naslednji pomembni parameter, ki močno vpliva na raven izmečka, je osebje. Ugotovljeno je, da naj bi bil operater, kot dejavni udeleženec v procesu litja, ustrezno usposobljen za čimprejšnje prepoznavanje izmečka in ustrezno ukrepanje. Po tej poti bi lahko preprečili ali se izognili velikim nihanjem procesa, ki se jih včasih odkrije prepozno. Za oceno ravni prepoznavanja izmečka osebja se izvaja analiza R&R. Doseženi rezultati kažejo, da bi morali izpeljati naslednje usposabljanje osebja (sl. 5).

- Personnel are additionally trained to provide adequate cleanliness of the material that is returned from the die-casting process to melting.
- The existing casting vessel's insulation was replaced with insulation that has less thermal conductivity, which results in significantly less cooling of the melted material during the transportation. As a direct result of that improvement, the heating temperature in the melting furnace can be decreased by approximately 45°C.
- A Poka-yoke is applied to the out-gassing machine to prevent out-gassing with a gas pressure lower than that which is allowed.
- A Poka-yoke is also applied on the die-casting machines to prevent casting with a melted-material temperature outside the defined operating window.

1.2 Personnel

The next important parameter that strongly influences the level of scrap is the personnel. We concluded that the operator, as an active participator in the casting process, should be adequately trained to recognize scrap as soon as possible, and to react appropriately. In such a way scrap can be prevented and we can avoid major process discontinuities that are sometimes recognized too late. To assess the level of personnel scrap recognition, an R&R analysis was conducted. The results show that further personnel training should be carried out (Fig. 5).



Sl. 5. *Rezultati R&R analize pri prepoznavanju izmečka pri obdelavi*
Fig. 5. *Results of the R&R analysis for scrap recognition during machining*

Vodeno usposabljanje osebja vpliva na boljše prepoznavanje izmečka pri litju; omogoča uporabo nadzornih načrtov, s katerimi se da zelo zgodaj prepoznati posebne vzroke za spremembe procesa.

1.3 Stroji

V analizi vpliva stroja na raven izmečka, je bil glavni poudarek podan znižanju ravni izmečka zaradi potrebnega pršenja kalupa z oljem. Pri sedanji tehnološki rešitvi je prvi uliti del po pršenju vedno izmeček. Številne tehnološke rešitve so bile analizirane in najbolj obetajoča je bila uporaba avtomatskega pršenja kalupa z različnimi vrstami olja. Po začetnih preizkusih in poskusih je bil nameščen sistem za avtomatsko pršenje kalupa na vseh strojih za tlačno litje. Na sliki 6 so prikazane šobe za pršenje kalupov z oljem.

Analiza vpliva stroja za tlačno litje na količino izmečka je bila izpeljana v številnih smereh. Tako so bili med projektom nadzorovani številni delovni parametri, zamenjani neustrezno delujoči elementi strojev za tlačno litje ipd.

Posebna pozornost je bila namenjena analizi nihanj pri delovanju stroja za tlačno litje ali zaustavitvam. Izkazalo se je, da je bilo veliko število nezabeleženih kratkih prekinitev med delovanjem stroja za tlačno litje. Nihanje pri delovanju stroja za tlačno litje povzroča nepotrebno in

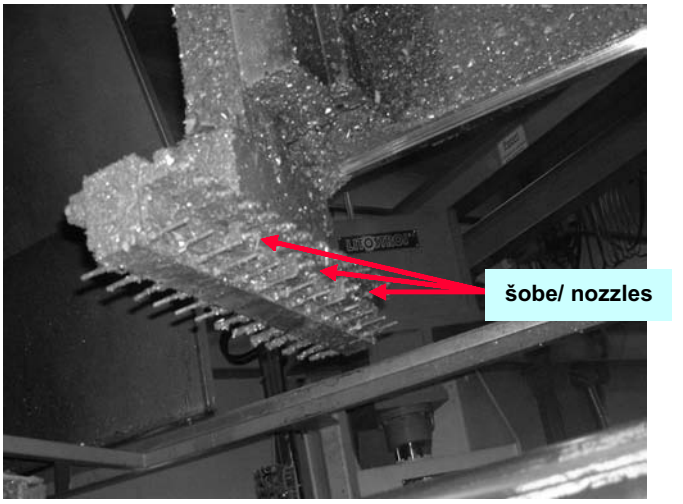
The personnel training resulted in better scrap recognition during casting, enabling the application of control charts, by which special causes of variation in the process are recognized as early as possible.

1.3 Machines

In the analysis of the machine's influence on scrap level, the main focus was on decreasing the level of scrap due to the necessary mould spraying. With the existing technological solution, the first part cast after spraying is always scrapped. Several technological solutions were analyzed, and the most promising was the use of automated mould spraying with different types of oil. After the initial experiments and tests, automated mould spraying was installed on all the die-casting machines in the process. Figure 6 shows the nozzles for spraying the mould with oil.

An analysis of the influence of the die-casting machine on the level of scrap was carried out in several directions. This means that during the work on the project, several operating parameters were controlled, and malfunctioning die-casting machine parts were replaced, etc.

Special attention was given to an analysis of the die-casting machine's operating discontinuities or stops. It was shown that large numbers of undocumented short stops take place during the die-casting machine's operation. The die-casting machine's operating discontinuities cause



Sl. 6. *Šobe za razprševanje olja v kalupu*
Fig. 6. *Nozzles for oil spraying the mould*

nepričakovano ohlajanje kalupov, ki neposredno vpliva na količino izmečka.

Opazovanje stroja za tlačno litje prek krmilne enote stroja in postavljanje doseženih podatkov v povezavo z količino izmečka za določene krajše odmore, pokaže močno povezavo med količino izmečka in številom prekinitev pri delovanju stroja (sl. 7). Zato je treba ločeno analizirati nihanja pri delovanju strojev za tlačno litje, da bi jih zmanjšali na minimum.

1.4 Kalupi

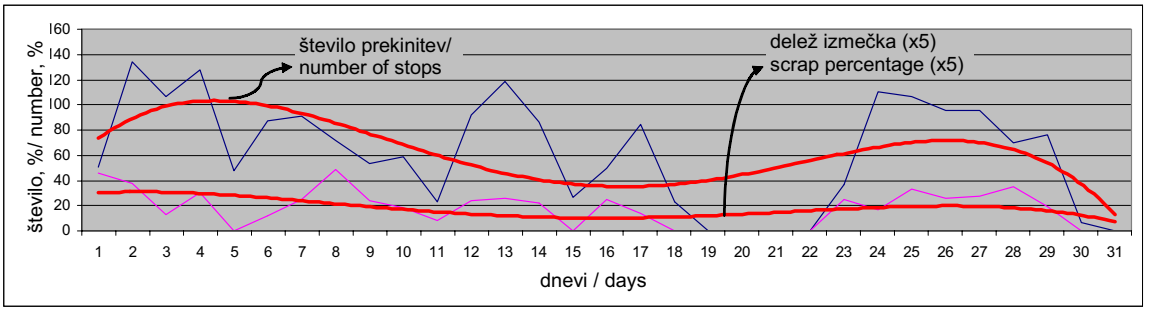
Osrednja karakteristika opazovanega procesa tlačnega litja je hitro spreminjanje. Med projektom so uporabili precejšnje število novih kalupov. Ta usmeritev se nadaljuje. Vsak nov kalup pri procesu je nov vir sprememb. Poseben problem je bilo uvajanje novega kalupa za sedanji liti del. V

unnecessary and unwanted cooling of the moulds, which directly influence the level of scrap.

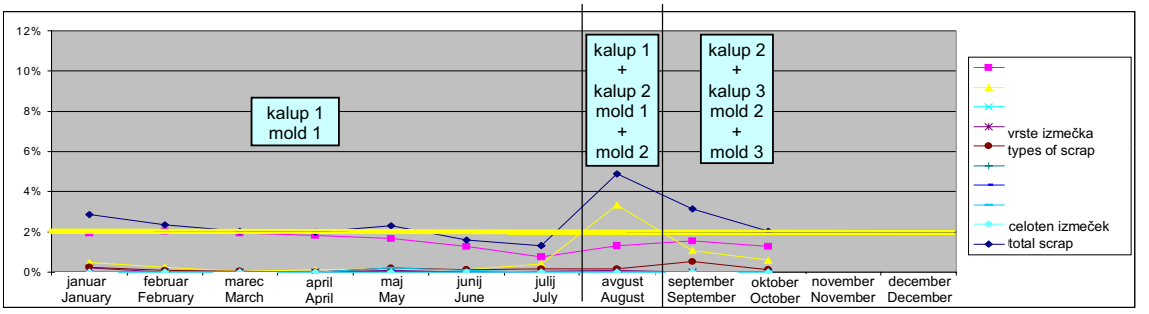
Monitoring the die-casting machine via a machine control unit, and putting the obtained data in correlation with the scrap level for certain shorter intervals showed the strong correlation between the scrap level and the number of stops when a machine is in operation (Fig. 7). Therefore, it is necessary to separately analyze the casting machine's operating discontinuities in order to reduce them to a minimum.

1.4 Moulds

The main characteristic of the observed die-casting process is rapid changing. During the project a significant number of new moulds was introduced, and this trend is continuing. Each new mould in the process represents a new source of variability. A particular problem was the introduction of a new mould for the



Sl. 7. *Analiza količine izmečka ter prekinitev tlačnega litja na stroju, krajših kot 10 minut*
Fig. 7. *Analysis of the level of scrap and the die-casting machine's operating stops that are shorter than 10 minutes*



Sl. 8. *Količina izmečka za del H, za obdobje 10 mesecev*
Fig. 8. *Scrap level for part H, for a 10-month period*

nekaj primerih drugi ali tretji kalup, za enako vrsto litega dela, ni bil dobavljen z uporabljenimi izboljšavami glede na prvi kalup, kar je jasno pri uporabi drugega ali tretjega kalupa povzročilo veliko količino izmečka v procesu. Primer je prikazan na sliki 8.

2 SKLEP

Količina obdelovalnega izmečka, ki je bil na začetku projekta v povprečju 11,43 %, je zmanjšan na povprečje 7,51 %. Upoštevajoč stroške ulitega dela, stroške surovega povratnega materiala, ki se vrača na taljenje, in načrtovanega števila ulitih delov v naslednjem opazovanem obdobju, lahko izračunamo znatne prihranke.

Prihranki so doseženi tudi pri taljenju z večjo učinkovitostjo talilne peči kakor tudi pri procesu tlačnega litja zaradi večje učinkovitosti in izkoristka strojev za tlačno litje.

Čeprav so bili doseženi znatni prihranki in izboljšave je treba povedati, da na začetku postavljeni cilji procesa niso povsem doseženi. Razlogov za to je kar nekaj: npr. velika dinamika proizvodnje, uvajanje velikega števila novih kalupov v proces ipd. Zato je treba predlagati smernice za nadaljnje delo pri stalnem izboljšanju kakovosti procesa tlačnega litja.

Te smernice so:

- stalno izboljšanje discipline pri postopku,
- stalno usposabljanje osebja,
- uvedli naj bi preventivno vzdrževanje kalupov.

Posebno pozornost naj bi posvetili prekinitvam delovnega procesa tlačnega litja, še posebej skozi novi projekt Šest sigem.

Na koncu je v preglednici 1 podana še skupna količina izmečka za določene dele v procesu tlačnega litja aluminija.

existing cast parts. In several cases, the second or the third mould for the same kind of cast part was not delivered with the applied improvement from the first mould. This means that the introduction of the second or the third mould also introduces a higher level of scrap in the process. An example is shown in Figure 8.

2 CONCLUSION

The machining scrap level, which at the beginning of the project was on average 11.43%, was reduced by an average of 7.51%. Taking into account the price of the part, the price of the raw material that is returned during melting, and the planned number of parts in a subsequent control period, significant savings can be achieved.

Savings were also achieved during melting, due to the higher efficiency of the melting furnace and, in the die-casting process, also due to the higher efficiency and utilization of the die-casting machines.

Although significant savings and improvements are achieved, it should be said that the initial process goals were not completely met. There are several reasons for this; for example, the high dynamics of the production, the introduction of a large number of new moulds in the process, etc. For this reason it is necessary to suggest directions for further work in continuous quality improvement in the die-casting process.

These directions are:

- the discipline in the process should be continuously improved,
- the personnel should be continuously trained,
- preventive mould maintenance should be introduced.

Special attention should be given to the die-casting process' operating discontinuities, which are possible with a new Six Sigma project.

In conclusion, a summary of the scrap level for certain parts in the pressure die-casting process and the results of the aluminium die-casting process are shown in Table 1.

Preglednica 1. *Količina izmečka na začetku in na koncu projekta*
Table 1. *Scrap level at the beginning and at the end of the project*

	izmeček zaradi pršenja kalupa **scrap due mould spraying**	**hladni strel** **cold shut**
količina izmečka na začetku projekta scrap level at the beginning of the project	1,92 %	5,75 %
količina izmečka na koncu projekta scrap level at the end of the project	0,55 %	2,89 %
izboljšanje **improvement**	**1,37 %**	**2,86 %**

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