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Prihodnost lahkih kovinskih delov: postopek MAXImolding®, stroj MAXImolding®, stiskalnica Multi-Shot-Multi-Injectors-Press (TERApress™ majhnih dimenzij) v pametnih digitalnih livarnah

The Future of Lightweight Metal Parts: The MAXImolding® Process, the MAXImolding® Machine, Multi-Shot-Multi-Injectors-Press (TERApress™ at small size) in Smart Digital Foundries

1 Postopek brizganja poltrdne lahke kovinske zlitine

Brizganje poltrdne kovine je postopek brizganja, ki vključuje polnjenje forme s kovino v delno staljenem stanju, pri katerem so kroglice trdne snovi homogeno razpršene v talini. Štirje postopki, ki se trenutno uporabljajo za litje poltrdnih kovin, in sicer Thixomolding®, Thixocasting®, Rheocasting® in postopek z napetostno inducirano aktivacijo taline (SIMA), so na začetku zapleteni in izredno zahtevni za vzdrževanje. Postopki tlačnega litja v hladno ali toplo komoro ali vakuumskega tlačnega litja ne izpolnjujejo pričakovanj končnega uporabnika glede kakovosti, enostavnosti, prihranka energije, varnosti, ekonomičnosti in okoljske odgovornosti. Tu nastopi postopek MAXImolding®, ki še dodatno poenostavi in izboljša postopek Thixomolding®. Postopek MAXImolding® deluje na podlagi mehansko obremenjenih drobcev oz. drobcev z želeno metalurško konfiguracijo. Izbrani drobci se dovajajo v enoto za predpripravo, ki se imenuje izpiralnik. V našem vertikalnem stroju za brizganje se drobci segrevajo z natančnim nadzorom temperature v argonski atmosferi. Temu postopku pravimo »solid-to-semisolid-

1 Semisolid Light Metal Alloy Injection Molding Process

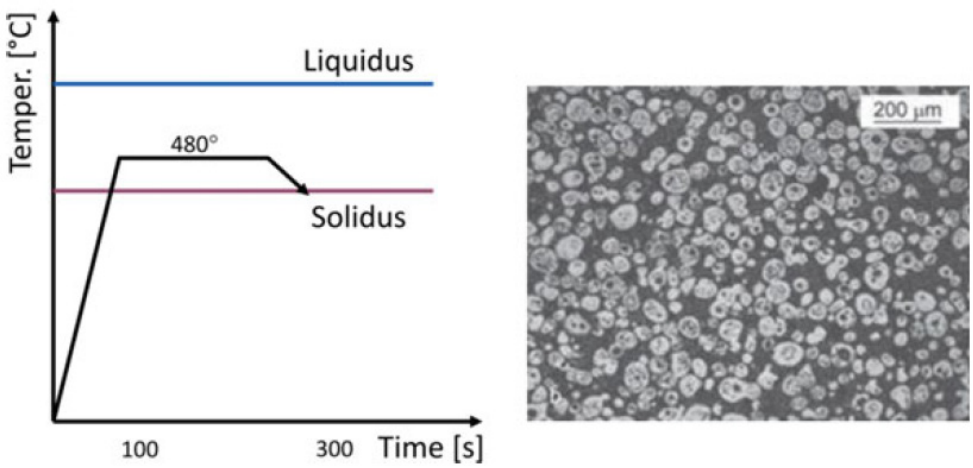
Semisolid metal injection molding is a molding process that involves filling a mold with metal in a partially molten state in which globules of solid are homogeneously dispersed in the liquid. The four currently used semisolid metal casting processes, Thixomolding®, Thixocasting®, Rheocasting®, and stress-induced melt activation (SIMA), are complex to start and very highly maintenance intensive. The processes, cold or hot chamber die-casting or vacuum die-casting, do not fulfill end-user expectations for quality, simplicity, energy savings, safety, economy, and environmental responsibility. This is where the MAXImolding® process comes in and further simplifies and improves the Thixomolding® process. MAXImolding® process involves mechanically stressed chips or chips in preferred metallurgical configurations. The selected chips are fed into a pre-conditioning unit called a scrubber. The chips are heated with precise temperature control under an atmosphere of Argon in our vertical injection molding machine. We call this process “solid-to-semisolid-to-solid” molding because we

to-solid«, saj začnemo s trdnimi drobci, proizvedemo poltrdno kašo in končamo s trdnimi deli kompleksnih geometrij iz forme. Postopek se v celoti izvaja v stroju MAXImolding®. Za preprečevanje oksidacije drobcev uporabljamo zelo majhno količino argona.

Dr. Frank Czerwinski se že desetletja ukvarja z raziskavami na področju poltrdne metalurgije in izboljšavami strojev za brizganje magnezija. Zapisal je, da je mogoče tiksotropno brozgo, talina katere vsebuje okrogle trdne delce, ustvariti v toplotnem masnem reaktorju pod izključno uporabo toplote: Slika 1 prikazuje postopek in mikrostrukturo zlitine. Uvedeni postopek ne predvideva vrtenja vijaka. Za proizvodnjo poltrdne brozge s kroglastimi trdnimi delci v talini striženje drobcev ni potrebno. Potrebno je zgolj natančno upravljanje temperature gravitacijskega dovajanja drobcev z vrha na dno reaktorja. Odprava strižnega vijaka

start with solid chips, produce a semisolid slurry, and end with solid net-shape parts out of the mold. The process is fully enclosed in the MAXImolding® machine. We use a very small amount of Argon to prevent chip oxidation.

Dr. Frank Czerwinski has been working for decades in the research fields of “Semisolid Metallurgy” and improvements of Magnesium Injection Molding Machines. He wrote that the thixotropic slurry containing spherical solid particles in the melt could be obtained in the thermal mass reactor under the sole influence of heat. Figure 1 shows the process and the microstructure of the alloy. The adopted process does not require screw rotation. It is not necessary to shear the chips to produce a semisolid slurry that contains spherical solid particles in the melt. Precise temperature control of chips fed under gravitation from the top to the bottom of the reactor is only what is



Slika 1. Stroj MAXImolding® deluje v poltrdnem temperaturnem območju med 480 in 580 °C za zlitino AZ91. Mikrostruktura zlitine ima kroglaste, nedendritske značilnosti s 50 % trdnih snovi (dr. Frank Czerwinski). Tako se prepreči nastanek napak

Figure 1. MAXImolding® works in the semisolid temperature range between 480 and 580°C for the AZ91 alloy. The microstructure of the alloy has spherical, non-dendritic features with 50% solids (Dr. Frank Czerwinski). This avoids the formation of defects

močno poenostavi postopek. Ustvarjanje tiksotropne suspenzije, ki vsebuje sferične trdne delce v talini, se lahko izvede v reaktorju s toplotno maso pod vplivom samo toplote.

Potrebno je zgolj natančno upravljanje temperature med dovajanjem drobcev z vrha na dno reaktorja.

2 MAXImolding®: vertikalni stroj za brizganje poltrdnih kovinskih zlitin

Srž zamisli se začne z vprašanjem: kako lahko izdelamo hibridni stroj, s katerim bomo z malo energije in materiala, zelo hitro in brez okolju škodljivih emisij plinov izdelovali visoko integrirane dele, ki so skoraj brez napak? Stroj, ki združuje prednosti postopka Thixomolding® ter strojev za visokotlačno litje (HPDC) s toplo in hladno komoro in nima njihovih pomanjkljivosti? Odgovor na to je brizganje poltrdnih (poltekočih) kovin. Gre za postopek brizganja, pri katerem se forma napolni s kovino v delno staljenem stanju.

Prednosti tega postopka so naslednje:

- manjša poraba energije,
- daljša življenjska doba forme,
- brez ustvarjanja tekoče kovine,
- brez rokovanja s tekočo kovino,
- manjše krčenje pri strjevanju,
- manjša dovzetnost za plinske vključke ali napake,
- boljši izkoristek surovin,
- veliko večja varnost.

Stroj MAXImolding® je rezultat naprednega razvoja stroja za brizganje magnezija. Napredek v tehnologiji Thixomolding® z odpravo ekstruderja z vijakom, ki je bil glavna pomanjkljivost tehnologije Thixomolding®, je privedel do razvoja vertikalnega stroja MAXImolding®.

required. Elimination of screws for shearing is a major simplification of the process. The generation of thixotropic slurry that contains spherical solid particles in the melt can be done in the thermal mass reactor under the sole influence of heat.

Precise temperature control of chips fed under gravitation from the top to the bottom of the reactor is only what is required.

2 MAXImolding®: Vertical Semisolid Metal Alloy Injection Molding Machine

The core of the idea starts with the question: How can we build a hybrid machine that can produce high-integrated parts that are nearly defect-free with little energy and material, very quickly, and without environmentally harmful gas emissions? A machine that combines the advantages of Thixomolding® and Hot and Cold Chamber high-pressure die-casting machines (HPDC) and avoids their disadvantages? The answer to this is offered by semisolid (semi-liquid) metal injection molding. A molding process in which a mold is filled with metal in a partially molten state.

The advantages of this procedure are as follows:

- lower energy consumption,
- increased mold life,
- no generation of liquid metal,
- no handling of liquid metal,
- less solidification shrinkage,
- less susceptible to gas inclusions or defects,
- better yield from the raw material,
- and much safer

The MAXImolding® machine is the result of advanced development of the magnesium injection molding machine. Advancing Thixomolding® technology by

Ta postopek zagotavlja številne izboljšave v primerjavi z okolju neprijaznimi stroji za visokotlačno litje (HPDC) s toplo ali hladno komoro, ki porabijo veliko energije. Kolikor nam je znano, se dandanes večina izdelkov iz magnezija izdeluje s tlačnim litjem. Litje magnezija tako zaostaja za tehnološkim stanjem? Mogoče napredkom? Razdvojem? Vendar pa novi stroji za brizganje poltrdnih kovin omogočajo bistveno boljše možnosti obdelave. Na primer novi patentirani stroj ne predvideva talilnega lonca s pregretim taljenim magnezijem med litjem, zaradi katerega je potrebna uporaba zaščitnega plina SF_6 ali R134a (toplogredni plin) in prav tako ne potrebuje energije za ohranjanje staljene kovine v pregretem tekočem stanju. Namesto tega je mogoče uporabiti trdne magnezijeve delce. Uporabijo se drobci z želenimi metalurškimi lastnostmi in dovedejo v glavni procesor za magnezij, ki (z dodajanjem toplote) pretvori trdni magnezij v poltrdno brozgo, zelo podobno drobljenemu ledu pri temperaturi tik nad 0 °C.

Ta poltrdna struktura deluje pri temperaturah, ki so pogosto za 200 °C nižje od trenutnih temperatur pri predelavi magnezija za tlačno litje, kar omogoča velike prihranke pri energiji. Poltrdna magnezijeva zlitina se nato podobno kot pri postopku injekcijskega brizganja plastičnih mas vbrizga v trajno formo. Postopek MAXImolding® se v celoti izvaja v stroju; gre za postopek oblikovanja delov »solid-to-semisolid-to-solid«, ki se lahko uporablja v običajnih proizvodnih obratih.

Postopek je preprost, zato ga je mogoče uporabljati v vseh regijah sveta, za njegovo izvajanje pa obsežno usposabljanje ni potrebno. Navpična usmeritev stroja MAXImolding® pomaga prihraniti prostor in izboljša pretok materiala. Popolnoma avtomatizirano odstranjevanje delov je

eliminating the extruder with a screw as a major disadvantage of Thixomolding®, resulted in MAXImolding® vertical oriented machine.

This process offers many improvements compared to the environmentally unfriendly, high-energy consumption hot and cold chamber high-pressure die-castings (HPDC) machines. As we understand, most products made from magnesium today are being made by die-casting. The magnesium casting was left behind in the technology curve. However new semisolid metal injection molding machines offer much improved processing capability. For example, the new machine does not require a melting pot of overheated molten magnesium during casting that requires the SF_6, SO_2, or R134a cover gas (greenhouse gas pollutant) and does not need the energy to maintain the molten metal in an overheated molten state. Rather, solid magnesium particulates can be used. The chips, with preferred metallurgy, is used and fed into the magnesium main processor that (by adding heat) converts the solid magnesium into a semisolid slush of material, very similar to crushed ice at a temperature just above 0 °C.

This semisolid structure operates at temperatures often 200°C below the current Magnesium die-casting processing temperatures resulting in significant energy advantages. This semisolid magnesium alloy is then injected into a permanent mold, very similar to the plastic injection molding process. The MAXImolding® process is a fully enclosed; “solid-to-semisolid-to-solid”, part-shaping process that can be operated in ordinary manufacturing plants.

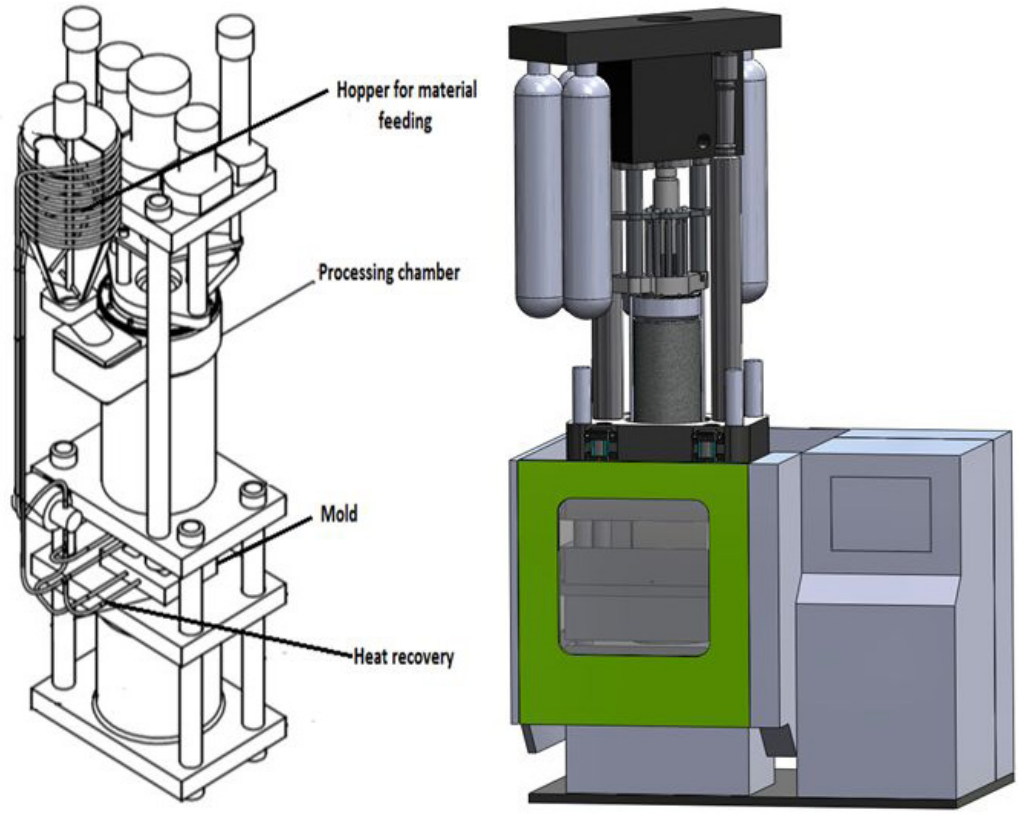
The simplicity of the process makes it easy to operate in any region of the world without the need for extensive training. The MAXImolding® vertical orientation saves floor space and improves material flow. Fully

enostavno vključeno in se izvaja s pomočjo robotskih naprav. Pri strjevanju magnezija v formi se z inovativnim postopkom segrevanja/hlajenja zajeta toplota iz taljenja sprošča za ponovno uporabo.

Stroj MAXImolding® reciklira to toploto taljenja in predhodno ogreje vhodne magnezijeve drobce. Že zaradi prihrankov energije so z deli povezani stroški konkurenčni na trgu v primerjavi s katerim koli drugim danes poznanim postopkom ven. Emisijske kupone, ustvarjene s to tehnologijo, bi bilo mogoče ustrezno tržiti in prodajati kot deleže ogljika na odprtem trgu tistim, ki upravljajo obrate z visoko proizvodnjo CO_2. Da bi optimizirali porabo energije, zmanjšali obseg vzdrževanja in izboljšali kakovost proizvodnje, smo valj in vijak zamenjali z novim reaktorjem v obliki valja z visoko toplotno maso. Simetrično maso valja je veliko lažje nadzorovati z vidika toplote in vzdrževati stabilno temperaturo poltrdne taline. Obdelovalni valj vsebuje osem manjših obdelovalnih komor, v katere z vrha vstopajo drobci AZ91D, po štiri na levi in desni strani, ter večjo odprtino na sredini valja za vbrizgalni bat. Grelniki so nameščeni okoli valja in se segrevajo od vrha proti dnu, kar zagotavlja enakomerno in natančno segrevanje. Spodnja plošča s formo se odpira navzdol, kar omogoča varen dostop za pobiranje delov. Ko je forma zaprta, je delilna ravnina forme v celoti za trdnimi varovali, zato je ta postopek v primerjavi s strojem za horizontalno vpenjanje veliko varnejši. Odstranjevanje delov se preprosto izvede s katero koli stransko napravo za izmet. Zamenjava ekstruderja z reaktorjem z visoko toplotno maso je omogočila natančen nadzor temperature in posledično učinkovitejši postopek, ki predvideva manj vzdrževanja. Slika 2 spodaj prikazuje shemo stroja MAXImolding®.

automated part removal is easily integrated by simple robotic devices. Magnesium solidification in the mold releases captured heat of fusion via an innovative heating/cooling process for re-use.

MAXImolding® recycles this heat of fusion, by pre-heating the input magnesium chips. The energy savings alone allow the costs of parts to be competitive in the market compared to any other magnesium process known today. Carbon credits generated by this technology could be suitably marketed and sold as carbon shares on the open market to those who need to operate plants with high CO_2 output. To be able to improve on energy, reduce maintenance and improve output quality, we replaced the barrel and screw with a new high thermal mass reactor in the form of a cylinder. Symmetrical cylindrical mass is much easier to control heat and maintain a stable temperature of the semisolid melt. The processing cylinder contains eight smaller processing cavities for AZ91D chips entering from the top, four on each left and right side, and a larger bore in the middle of the cylinder for the injection piston. Heaters are placed around the cylinder and nuzzle from top to bottom for uniform and precise heating. Lower platen with mold opens downwards creating safe part pickup access. When the mold is closed, the parting line of the mold is completely behind solid guards, making this process much safer when compared to the horizontal clamping machine. The removal of parts is simply done by any side entry device. Replacing the extruder with a high thermal mass reactor led to precise temperature control and thus a more efficient and less maintenance-intensive process is accomplished. Figure 2 below shows the schematic of the MAXImolding® machine.



Slika 2. Stroj MAXImolding® z zalogovnikom in enoto za predobdelavo, predelovalno komoro in formo z rekuperacijo toplote

Figure 2. MAXImolding® machine with hopper and pre-processing unit, processing chamber, and mold with heat recovery

3 Magnezij za predelavo v stroju

Začnimo z izvornim materialom in pripravo v stroju MAXImolding®. Kovinski ostružki, magnezijevi delci velikosti 2x5 mm, ki jih imenujemo tudi drobci, se dovajajo v zalogovnik s predprocesorjem za čiščenje drobcev z levitacijo, napolnjenim z argonom ali katerim koli drugim primernim medijem za čiščenje. Drobci Mg se segrejejo do 200 °C z natančnim nadzorom temperature. Oksidacijo preprečimo z dovajanjem argona. Drobce nato neprekinjeno

3 Magnesium Machine Feedstock

Let us start with the source material, and preparation in the MAXImolding® machine. Metal shavings, the magnesium particles in sizes 2x5 mm, also called chips, feeds to a hopper with a chip levitation scrubber preprocessor flooded with argon or any other suitable cleaning medium. The Mg chips heat up to 200 °C with precise temperature control. The oxidation is prevented by flooding with argon. The chips are then continuously dosed into the vertical

odmerjamo v vertikalni stroj za brizganje in jih od zgoraj navzdol počasi segrevamo v osmih komorah, ki jih ogrevajo posebni uporovni koaksialni grelniki. Toplota, ki se vrača iz forme, se uporabi za predogrevanje začetnega materiala (drobcev). Drobci Mg iz predobdelave se segrejejo na približno 200 °C. Nato poteka segrevanje v argonski atmosferi v termičnem reaktorju v obliki revolverja. Na zunanji steni valja je nameščenih več ogrevalnih območij. V spodnji komori se zbira poltrdna brozga. Viskozna brozga se nato natančno odmeri pod sredinskim vbrizgalnim batom.

Brozgo se v formo vbrizgava pod visokim tlakom 1.000 barov in z visoko hitrostjo do 10 m/s. Za celoten postopek je potrebna homogena navpična pot, dolga samo 1,5 m, kar pomeni, da se celotna livarska linija skrajša na 4,5 m. Tako je postopek lažje obvladljiv. Alternativna surovina so lahko posebej oblikovani drobci z želeno konfiguracijo zlitine, ki se nato ponovno segrejejo na želeno temperaturo za oblikovanje in se vbrizgajo v formo v poltrdnem stanju. Poltrdna kovinska zmes (brozga) se proizvede po potrebi in vbrizga neposredno v formo. Ogrevane magnezijeve poti in izklop šobe močno skrajšajo skupni čas cikla in izboljšajo kakovost dela, hkrati pa ohranjajo nizko porabo energije. Na enak način je mogoče obdelati tudi aluminijeve zlitine.

4 Več strojev, več injektorjev za stroj TERApress™ majhnih dimenzij

Elon Musk iz podjetja Tesla je leta 2021 povedal: »Z našimi ogromnimi stroji za litje poskušamo avtomobile izdelati dobesedno na enak način, kot izdelujemo modelčke avtomobilov.« Leta 2020 je podjetje IDRA Italy tovarni podjetja Tesla (stroj št. 1) v Fremontu v Kaliforniji, ZDA, dobavilo prvi

injection molding machine and slowly heated from top to bottom in eight cavities heated by special resistive coaxial heaters. The heat returned from the mold is used to preheat the starting material (chips). The Mg chips coming from the preprocessor are preheated to approx. 200 °C. Further heating happens with argon in the thermal reactor in the form of a revolver. Several heating zones attach to the outside wall of the cylinder. The semisolid slurry collects in a lower chamber. This viscous mass is then precisely metered under the centrally positioned injection piston.

The high melt pressure of 1.000 bar and high speed of up to 10 m/s are used to inject the slurry into a mold. The whole process requires a unified, vertical path of only 1.5 m, which means that the whole foundry line is shrinking to 4,5 m only. This makes the process more manageable. Alternative feedstock could be the specially formulated chips with the preferred alloys configuration, then re-heated to desired forming temperature and injected into the mold while in the semisolid state. The semisolid metal mixture (slurry) is produced on demand and injected directly into the mold. The heated magnesium pathways and nozzle shutoff greatly reduces the total cycle time and improve part quality while keeping energy consumption low. Similarly, the processing of aluminum alloys is possible in the same way.

4 Multi-machines, Multi-injectors for TERApress™ at Small Size

In 2021, Elon Musk from Tesla said, “With our giant casting machines, we are trying to make full-size cars in the same way that toy cars are made”. In 2020 IDRA Italy delivered the first OL 5500 CS (5.500 ton-force) Giga press (giant house-sized

giga livni stroj OL 5500 CS (sila 5.500 ton) (ogromen stroj za tlačno litje). Enodelni ulitek avtomobila Model 3 bo nadomestilo približno 70 postopkov stiskanja, iztiskanja in litja. Skupna teža tega giga livnega stroja je bila 410 ton. Švicarsko podjetje Buhler je sledilo s še večjim giga livnim strojem z 9.200 tonami sile stiska. Izdelovati je mogoče vedno večje stroje za izdelavo avtomobilov na način igrač, vendar ni nujno, da so večji stroji hkrati prijaznejši do okolja in energetsko učinkovitejši!

Leta 2017 je avtor (AS) izjavil: »Mogoče bo ulivati dele iz lahke zlitine velikih dimenzij, ki bodo primerni za proizvodnjo avtomobilov polne velikosti, brez uporabe pločevine, stiskanja, varjenja itd.“ Kako? Z uporabo sistema MAXImolding® TERApress™ majhnih dimenzij, s kombinacijo strojev za oblikovanje poltrdnih kovinskih zlitin namesto velikanskih strojev za litje, imenovanih giga livni stroji. Veliki strukturni deli, velikost katerih je omejena samo z velikostjo forme, pridejo iz velike forme tako, da je več injektorjev za dovajanje poltrdne taline postavljenih navpično nad zelo veliko formo ali okoli nje.

Poleg samega stroja za tlačno litje potrebuje celotna giga celica za litje za proizvodnjo tekoče taline dodatno opremo, kot so: talilna peč, zadrževalna peč, dozirni sistem, vakuumski sistem, enojna ali dvojna brizgalna enota(-e), robot(-i) za odstranjevanje delov, rentgenski aparat, sistem za kaljenje, stiskalnica za odstranjevanje razdelilnih kanalov in vakuumskih kanalov, drobilnik povratnega materiala, roboti za ravnanje z deli in druga oprema za sekundarne postopke, kot so obrezovanje, ravnanje, strojna obdelava, montaža, čiščenje itd.

»Manj je več« tako postane »več je veliko več, in čim več, tem bolje«. Kdaj je velika celica za litje dovolj velika? Takšni stroji za vbrizgavanje tekoče taline, “DCM”–Die-casting Machine) for the Tesla factory (machine #1) in Fremont, California. The single-piece casting for Model 3 will replace around 70 stampings, extrusions, and castings. The total weight of this Giga press was 410 tons. Swiss Buhler follows with an even bigger Giga press with 9.200 tons of clamping force. While making bigger and bigger machines to make cars like toys is possible, bigger is not necessarily better for the environment and energy efficiency!

In 2017, the author (AS) said, “It will be possible to cast large size light alloy parts to suit full-size cars production without the usage of metal sheet, stamping, welding, etc.” How? By usage of MAXImolding® TERApress™ at a small size, by combining semisolid metal alloy molding machines instead of giant casting machines called Giga press. The large structural parts, limited in size by mold size only, come out of a large mold by placing the multi semisolid melt delivery injectors, vertically, above or around a very large mold.

Apart from the die-casting machine itself, the complete Giga casting cell for fluidized melt production needs further equipment like: a melting furnace, holding furnace, dosing system, vacuum system, single or twin spraying unit(s), part removal robot(s), x-ray machine, quenching system, trim press for removal of runners and vacuum channels, return material shredder, part handling robots and other equipment for secondary operations like deburring, straightening, machining, assembly, cleaning, etc.

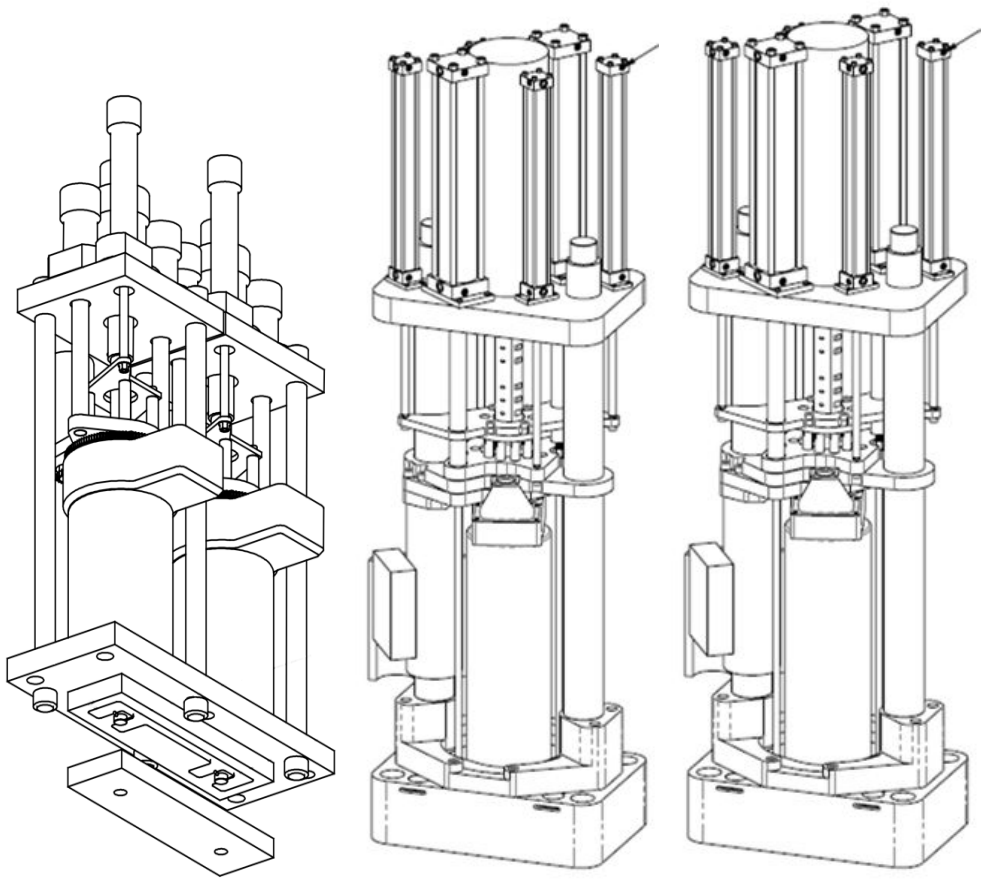
Instead of “less is more” we have here “more is much more, and the bigger, the better”. When is a large casting cell large enough? These machines for the injection of fluidized melt, designed according to the principle “the bigger, the better” are an environmentally unsustainable solution. A Giga press requires large castings and

zasnovani po načelu »čim večji, tem boljši«, so okoljsko netrajnostna rešitev. Za giga livni stroj je treba izdelati velike ulitke in strukturne dele, izdelane iz velikih kosov jekla, ki se obdelujejo na zgolj nekaj razpoložljivih strojih CNC na svetu na oddaljenih lokacijah, kar ima velik vpliv na okolje. Težke dele je treba prepeljati na končno lokacijo, jih sestaviti s posebnimi stroji in na koncu morda okoli giga livnega stroja zgraditi še tovarno.

Za izdelavo zelo velikih strukturnih ulitkov ali izredno velikih površin predlagamo več razširljivih modulov injektorjev (Slika

structural parts made from large steel pieces, machined on only a few available CNC machines in the world in faraway locations, which have a big environmental footprint. You need to transport heavy parts to the final location, assemble them with special machinery, and finally, perhaps even build a factory around the Giga press.

We suggest multiple, scalable, injector modules (see Fig. 3) for semisolid, non-fluidized melt, injecting simultaneously or sequentially to produce very large structural castings or very large surface, thin wall castings. This is a better approach



Slika 3. Več vbrizgalnikov za TERApress™ majhnih dimenzij

Figure 3. Multi-Injectors for TERApress™ at small size

3) za poltrdno, nefluidizirano talino, ki vbrizgavajo sočasno ali zaporedno. Takšen pristop je boljši za litje velikih delov. Na veliko površino kalupa nameravamo namestiti več manjših injektorjev in vbrizgati poltrdno suspenzijo za izdelavo ulitkov velikih delov, kot so bočni paneli ali strehe avtomobilov. Tako je mogoče uliti bistveno boljše dele z veliko boljšimi lastnostmi. Zato izdelujemo več injektorjev za dele z veliko površino iz magnezijevih ali zlitin.

Postopek MAXImolding® manjšim tovarnam omogoča izdelavo katerega koli dela za avtomobil in ohranjanje konkurenčnosti. Poltrdna, nefluidizirana talina je sestavljena iz trdnih drobcev »na zahtevo«, obdelava poltrdne brozge pa v celoti poteka v stroju, ki ne zahteva ločenega pridobivanja in ravnanja s talino. Menimo, da je pristop z giga livnimi stroji pretirano zapleten in okoljsko nevzdržen.

5 Pametna digitalna livarna

Nov postopek, ki temelji na natančnem nadzoru temperature in se izvaja s strojem za oblikovanje poltrdnih kovin MAXImolding® s sistemom za hlajenje forme z vodno meglico in sistemom za električno ogrevanje kalupa, je patentiran in je na voljo za podelitev licenc in komercialno uporabo. Patentiran sistem za nadzor proizvodnje s povratnimi podatki iz rentgenske naprave nam končno omogoča gradnjo popolnoma avtomatiziranega obrata za izdelavo ulitkov za 21. stoletje. Upamo, da nam bo to pomagalo pri izvajanju naprednega postopka tlačnega litja. Model popolnoma avtomatiziranega postopka tlačnega litja/oblikovanja kovin je prikazan na spodnji Sliki 4. Upravljavec mora zgolj vklopiti stroj in poskrbeti, da je material na voljo in da se del po koncu cikla odstrani. Če vzamemo primer tlačno litega platišča za avtomobil,

to casting big parts. We envision placing multiple smaller injectors over a large surface of the mold and injecting a semisolid slurry to create castings of any large parts, like car side panels or rooftops. This way, it is possible to cast much better parts with better part characteristics. That is why we are building multiple injectors for large surface parts made of Magnesium or Aluminum alloys.

The MAXImolding® process allows smaller, cost-effective factories, to produce any part of the car and stay competitive. Semisolid, non-fluidized melt originates from solid chips “on-demand” and the processing semisolid slurry is fully contained within the machine, which does not require separate generation and handling of the melt. We believe that the Giga press approach is prohibitively complex and environmentally unsustainable.

5 Smart Digital Foundry

A novel „solid-to-semisolid-to-solid“ (from chips to parts) precise temperature control-based process incorporating the MAXImolding® semisolid metal molding machine with mold water mist cooling system and mold electrical heating system has been patented and is available for licensing and commercialization. Additionally, a patented manufacturing control system with data feedback coming from an x-ray machine finally allows us to build a fully automated casting factory for the 21st century. We hope that this will help us move in the direction of an advanced die-casting process. A model of a fully automated die-casting/metal molding process is depicted in Fig. 4 below. The operator is only required to power up the machine and ensure material is available and taken away. For example,

sledi postopek naslednjemu osnovnemu zaporedju:

Upravljavec mora zagotoviti napajanje stroja za litje/oblikovanje poltrdnih kovin, imenovan MAXImolding®, upoštevati osnovni kontrolni seznam, povezan z dobavo materiala, začetnimi parametri in preverjanjem varnosti, nato pa na zaslonu na dotik pritisniti gumb »3D Wheel Type« in nato še gumb »Start«. Stroj MAXImolding® začne z litjem prvega platišča v formo v skladu s predlaganimi parametri litja, ki jih določi inteligentni sistem v oblaku (ML, AI, NN, SPC itd.), po zaključku pa kolo izstopi iz stroja za litje/oblikovanje in se prepelje do sistema za rentgenski pregled. Popolnoma avtomatiziran sistem za rentgensko pregledovanje določi kakovost platišča. Če je izdelek izpraven, se vse informacije o tem izpravnem kolesu shranijo v zbirki podatkov o izpravnem platišču. Enak postopek lahko uporabimo za nabor podatkov o prvotni proizvodnji (postopku) kot tudi nabor podatkov o oblikovnem 3D-modelu. Če je kolo neizpravno, se informacije shranijo v podatkovno zbirko podatkov o neizpravnem kolesu.

Ob predpostavki, da je platišče neizpravno, bo sistem znanja določil, kateri niz parametrov je treba iterativno prilagoditi za izboljšanje pomanjkljivih lastnosti platišča, v generatorju parametrov pa se bo ustvaril nov niz vhodnih podatkov. Pregled lahko na primer pokaže, da platišče ni v celoti oblikovano, kar pomeni, da je bilo v formo vbrizgano premalo surovine, kar se običajno imenuje delni vbrizg. Sistem znanja ugotovi, da je primerno daljše obdobje vbrizgavanja, in iterativno ukaže generatorju parametrov, naj zakasni zapiranje šobe in vbrizga več materiala. Serijsko se izvede naslednji strojni cikel in se posreduje sistemu za pregledovanje. Več podatkov iz sistema za pregledovanje ustvarja več informacij in omogoča hitrejše približevanje naboru

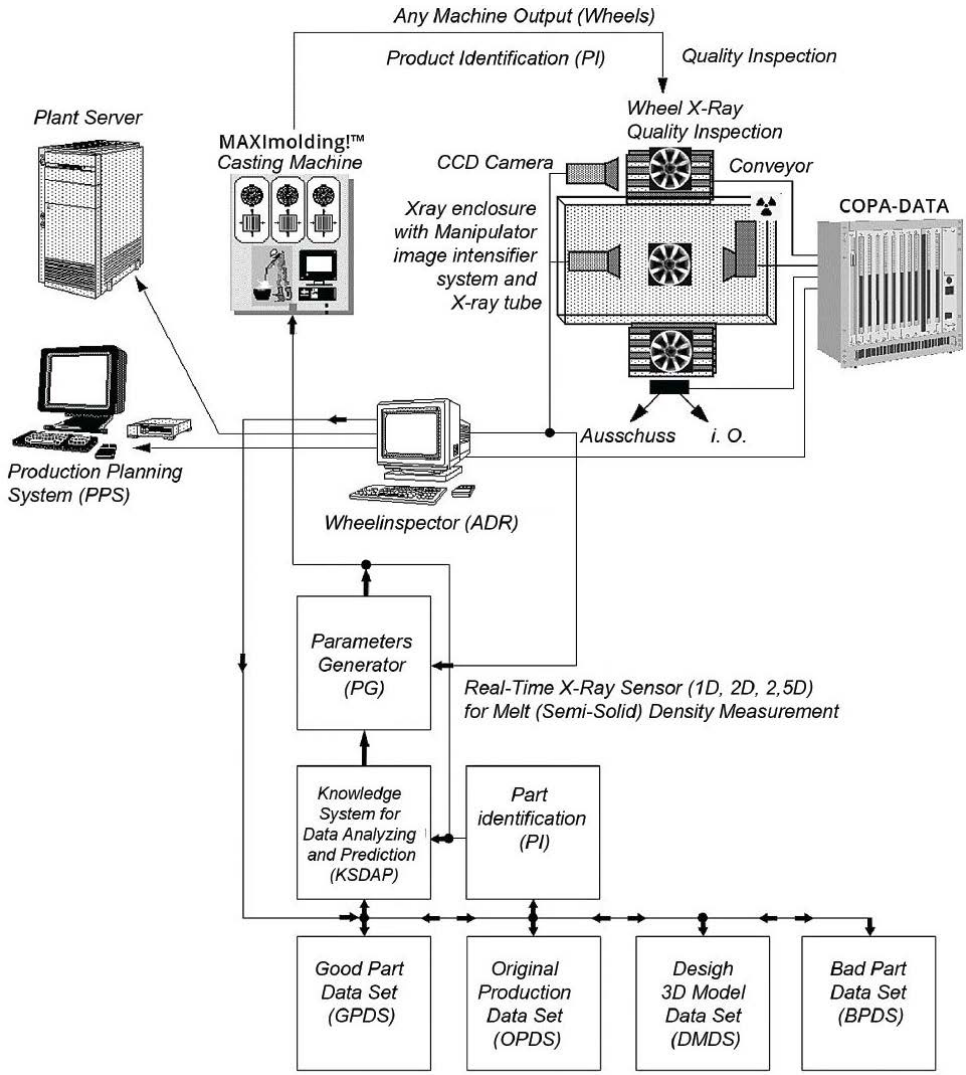
the die-casting wheel for a car would follow a basic sequence like this:

The operator would provide power to the semisolid casting/molding machine called MAXImolding®, follow an initial checklist related to the supply of the material, initial parameters, and safety verification, and then press the „3D Wheel Type“ button on a touch screen, followed by the „Start“ button. The MAXImolding® machine would start casting/molding the first wheel according to the proposed casting parameters by an intelligent, cloud-based system (ML, AI, NN, SPC, etc.), and, upon completion, the wheel would be outputted from the casting/molding machine and transported to the x-ray inspection system. The fully automated X-ray inspection system would determine the quality of the wheel. If the part is good, all information about this good wheel will be stored in a good wheel data set database. The same process would be followed for the original production (process) data set, as well as the design 3D model data set. If the wheel is bad, information will be stored in a bad wheel data set database.

Assuming that the wheel is bad, the knowledge system will determine which set of parameters needs to be adjusted iteratively to improve wheel-deficient characteristics, and a new set of inputs will be generated in the parameter generator. By way of a hypothetical example, the inspection may indicate that the wheel is not completely formed, indicating insufficient feedstock has been injected into the mold, commonly referred to as a short shot. The knowledge system determines a longer injection period is appropriate, and iteratively instructs the parameter generator to delay the closing of the nozzle and inject more material. The next machine cycle is executed, serialized, and passed on to the inspection system. More data from the inspection system generates more information and allows for

parametrov, ki zagotavljajo kakovostna platišča. Ta postopek za proizvodnjo magnezijevih platišč z zapiranjem zanke s podatki iz sistema za pregledovanje in

faster convergence to a set of parameters that yields good quality wheels. This process for producing magnesium wheels by closing the loop with data from an inspection system



Slika 4. Shema pametne livarne platišč iz lahke zlitine, ki se sama uči in obsega stroj MAXImolding® s povratno rentgensko kontrolno zanko, vključno s programsko opremo ADR in sistemom znanja za analiziranje podatkov in napovedovanje parametrov procesa

Figure 4. Schematic of light alloy wheels self-learning smart foundry incorporating MAXImolding® machine with feedback x-ray control loop incl. ADR software and knowledge system for data analysis and prediction of process parameters

pospeševanjem konvergence z naborom podatkov iz izpravnih in neizpravnih koles ter 3D-modelom izvirne zasnove bo omogočil proizvodnjo koles visoke integritete s kar najmanjši izmetom.

Gre za vitko, varno, energetsko učinkovito in okolju prijazno livarno magnezija, ki v ozračje ne izpušča plinov. Vsi stroji za litje/oblikovanje in naprave za rentgensko pregledovanje ter lastni linearni roboti in sistemi strojnega vida, vključeni v ta postopek litja/oblikovanja poltrdnih zlitin, zagotavljajo hitro proizvodnjo izpravnih delov in vzdržujejo stabilen samodejni nadzor procesa v zaprti zanki.

6 Sklepi

Ta novi postopek »solid-to-semisolid-to-solid« v kombinaciji z rentgensko povratno kontrolno zanko in uporabno matematiko (umetna inteligenca, NN, strojno učenje, rudarjenje velepodatkov itd.) ter uporabo samostojnih popolnoma delujočih modulov na podlagi koncepta HyperComMachinery™ podjetja Jacobsen Real-Time X-Ray Machinery Inc. iz Kanade lahko revolucionarno spremeni klasično industrijo tlačnega litja in brizganja kovin. Stroj za brizganje poltrdne magnezijeve kovinske zlitine lahko deluje in ustvari popolnoma avtomatizirano tovarno za litje/oblikovanje. Omogoča hitro proizvodnjo izpravnih delov in vzdržuje stabilen samodejni nadzor procesa v zaprti zanki. Gre za varno, energetsko in snovno učinkovita in okolju prijazno livarno magnezija (sledi še livarna aluminija), ki v ozračje ne izpušča plinov. Vsi stroji za litje/oblikovanje in naprave za rentgensko pregledovanje ter lastni linearni roboti in sistemi strojnega vida, vključeni v ta postopek brizganja poltrdnih zlitin, zagotavljajo hitro proizvodnjo izpravnih delov in vzdržujejo stabilen samodejni

and accelerating convergence with data sets from good wheels and bad wheels as well as a 3D model of the original design will allow the production of high integrity wheels with minimal rejects.

This is a lean, intrinsically safe, energy-efficient, environmentally sound magnesium casting/molding foundry with no emission of gases outside of foundry parameters. All casting/molding machines and x-ray inspection machines, as well as proprietary linear robotics and machine vision systems integrated into this semisolid casting/molding process, will ensure the fast production of good parts, and maintain stable automatic closed loop process control.

6 Conclusion

This new “solid-to-semisolid-to-solid” process, combined with an x-ray feedback control loop and applied mathematics (AI, NN, ML-machine learning, big data mining, etc.) as well as the use of self-contained fully operated modules based on the HyperComMachinery™ concept from Jacobsen Real-Time X-Ray Machinery Inc. Canada, it can revolutionize the classical die-casting and injection metal molding industry. The semisolid magnesium metal alloy injection-molding machine can operate and create a fully automated casting/molding factory. It will ensure the fast production of good parts and maintain a stable automatic closed-loop process control. This is an intrinsically safe, energy and material-efficient, environmentally sound magnesium-molding factory (aluminum foundry follows) with no emission of gases outside of factory parameters. All metal alloy molding machines and x-ray inspection machines, as well as proprietary linear robotics and machine vision systems

nadzor procesa v zaprti zanki ne glede na lokacijo. Zbiranje podatkov o postopkih za enake ali podobne dele po vsem svetu (planetno litje) bo dostopno prek oblaka in vsakdo jih bo lahko uporabil za začetek in izboljšanje postopkov litja magnezija in aluminijevih zlitin.

integrated into this semisolid injection molding process, will ensure the fast production of good parts, and maintain stable automatic closed-loop process control wherever you are on this planet Earth. The collection of process data for the same or similar parts worldwide (planetary molding) will be accessible via the cloud and everybody can use it to start up and improve their processes of magnesium and aluminum metal alloy casting/molding.