Delivery of Engineering Processes Safely as a Team

Engineering processes and human factors

2022

The following report goes over different manufacturing methods utilized to create a product and which of them might be the most suitable, with said product being motor housings. After which, the report discusses process and necessary measures to be taken in the workplace in order to ensure a safe work environment with the chosen manufacturing processes while also talking about potential human factor defects that would have to be taken into consideration and different methods of eliminating or decreasing the possibility of the aforementioned defects causing complications within the workforce.

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Contents table

The product

Motor housing

Motor housings are the enclosure in which a DC motor is stored. The main function of a motor housing is to be able to protect the motor from possible damages that could occur to it such as dust encountering the motor while it's rotating or even from possible physical damage that could be dealt upon the motor itself from either a direct hit or from the motor being dropped.

Product requirements

Strength

Due to the product being an enclosure for a constantly rotating part, the housing itself would have to be relatively sturdy and strong to contain DC motor even if a possible failure arises that causes the motor to come out of place. In addition to that, as stated earlier, one of the main functions of the product is to protect the motor from possible impact, and with that, strength and sturdiness is a necessity.

Long lifespan

The life expectancy from the consumer end of components such as DC motors are generally high, especially ones that are used in heavy workload related application, with examples of said applications being portable power tools such as drills or jigsaws, and for these products to break easily or to only last for a few months or a year only represents bad manufacturing and an overall poor-quality product, and since the motor housing being the main component protecting the DC motor, the lifespan should be one of the main areas of consideration when choosing the material of choice for the motor housing.

Relative cheapness

Although the motor housing is an important part of the DC motor, it is not the main component itself, and as such the product is expected to be relatively cheap. However, the product being cheap does not excuse poor quality, and thus the product should maintain a good standard while keeping the overall expenditures of the production process relatively cheap, with the main areas that should be taken into consideration are the manufacturing process itself, the material of choice, and the finishing process that is going to be used to enhance the product.

Material of choice

Unfit materials

Relative to the requirements of the product, some of the main materials that can be considered are ones such as carbon steel, stainless steel, cast iron, copper, brass, carbon fiber, and aluminum alloys. However, although stainless steel and carbon fiber are ideal in terms of properties, they are too expensive, with stainless steel costing 6 USD per kg, and carbon fiber at around 26 USD per kg as stated by (Wallace, 2018) and (SMITeam, 2021). Brass and Carbon steel being materials that easily corrode, and thus do not meet the requirement of the product long lifespan expectancy. Finally, cast iron and copper are both materials that do not sufficiently meet the strength requirements of the product, with copper being relatively weak and cast iron being brittle, making them both unable to withstand strong impacts that could very likely occur with the type of applications that the DC motor within the motor housing is going to be used in. And thus, it concluded that out of all the aforementioned materials, aluminum alloy would be more suitable for the product, and although aluminum is known for being a generally soft material, certain types of aluminum alloys could counteract that, and as such when considering that, the type of aluminum allow that is going to be utilized is of huge importance and vital care should be taken when choosing the optimal aluminum alloy for the product.

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Potential alloys

As stated by (Montijo, 2021), some of the most utilized aluminum alloys in the industry are alloys 1100, 3003, 5052, and 6061. In addition, aluminum alloy 7075 is also a relatively popular alloy that could be taken into consideration for the product. As such, all the stated alloys would be analyzed in order to find the one that would be most suitable for the stated requirements of the product.

Alloy 1100

As stated by (Montijo, 2021), aluminum alloy 1100 is known for being one of the purest aluminum alloys that is commercially utilized with it being made up of 99% aluminum with certain types being even higher than that, and due to this aspect of aluminum 1100, it shares many similarities to that of pure aluminum, in that it has great corrosion resistance, it can be easily weldable, it is relatively cheap, and it has good thermally conductivity although that is not necessarily relevant to the product. In addition to what was mentioned, aluminum 1100 is easily machinable, however that property comes from it also being soft, and thus also being easily bendable and relatively weak in terms of overall strength.

Yield strength: 34Mpa	***Tensile strength:*** 89.6Mpa

Alloy 3003

Aluminum 3003 is as of 2022, the most widely utilized aluminum alloy in the market. In terms of properties, this aluminum is a moderately strong material and is approximately 20% stronger than that of pure aluminum which can be attributed to the utilized manganese within the alloying elements of the metal as mentioned by (Montijo, 2021). In addition to its strength, the material is easily to work with in that it can be machined and welded with relative ease and therefore less stress would be applied to the material if a machining process were to be utilized when manufacturing the product. The material also has good corrosion resistance and is relatively inexpensive in comparison to some of other metals on the market.

Yield strength: 34Mpa	***Tensile strength:*** 89.6Mpa

Alloy 5052

As stated by (Montijo, 2021), aluminum alloy 5052 is known for being a relatively very strong material and has great corrosion resistance from saltwater, and therefore the material is generally utilized for a variety of aquatic-based applications. In addition to that the material is easily weldable, and therefore less strain would be imparted onto the material if welding was to ever be required throughout the manufacturing process. This alloy is also generally on the cheaper end in comparison to 6xxx or 7xxx aluminum alloys. However, with all that was stated, one of the major disadvantages to alloy 5052 is the fact that it does not react to heat treatment processes, which could cause many issues to arise in terms of residual stress or base strength especially after the conclusion of the primary and secondary processes.

Yield strength: 193Mpa	***Tensile strength:*** 228Mpa

Alloy 6061

Aluminum 6061 is one of the most utilized aluminum alloys on the market alongside alloy 3003, which is the cause due it being known for being one of the most flexible aluminum alloys especially when seeing the wide number of applications that it can be utilized and seen in. That is the case as the alloy is relatively strong and is characterized by its great weight-strength ratio especially when compared to some of the other alloys that can be seen on the market. In addition to that, due to the hardness and the tensile strength of aluminum 6061 being at a point where it is not too hard, making it a great choice if the production process necessitates machining or forming, this aluminum alloy is also capable of being heat treated, which would allow for an increase in the product's overall strength and mechanical properties. In addition to all that was mentioned, Alloy 6061 is also cheap especially when considering all the properties that come with the material. Credit to (Montijo, 2021) for the information stated in this paragraph.

Yield strength: 276Mpa	***Tensile strength:*** 310Mpa

Alloy 7075

As mentioned by (Huang, 2021), alloy 7075 is very strong, even stronger than that of aluminum 6061, which is the case due to the strong metals that is are utilized in the alloying elements. In addition to that, aluminum 7075 has a lower melting point of 477 – 635 degrees Celsius, which is lower compared to that of other aluminum alloys that are utilized in the market, although this attribute might not help relative to the product alone, it would decrease the production cost by a lot since less energy would be required to produce the melting point of the material if a melting production process were to be used, in addition to that, just like aluminum 6061, aluminum 7075 can also heat treated in order to enhance the material's mechanical properties.. However, with all that has been mentioned, aluminum 7075 is generally harder to weld and form and is also much more expensive compared to other alloys that could be utilized.

Yield strength: 503Mpa	***Tensile strength:*** 572Mpa

Verdict

When the product's requirements are taken into account, aluminum 6061 is the metal that seems to suit them the most, that is the case since it can provide strength that aluminum 3003 and 1100 cannot, and although it might be more expensive than them, that property is one of the main requirements of the product. When it comes to aluminum 7075, the increase in price could be detrimental to the longevity of the production process and is most likely going to be replaced due to the increase in price of the base material, it should also be noted that although it is stronger, - as stated earlier – that means that it is going to be harder to work if the product require to go through a machining process. Finally, in terms of aluminum 5052, although it is relatively cheaper in comparison to alloy 6061 as stated earlier, its properties of saltwater corrosion resistance would not be of any use for the application that the material is going to be to utilized in. In addition, the fact that heat treatment processes do not cause any significant effect to alloy 5052 could cause various issues in terms of the overall stress and residual stress, and in contrast, aluminum 6061's microstructure does go through a significant change due to heat treatment processes which would be of extreme importance if it was deemed preferrable or necessary. As such, the material that is going to be utilized for the production of the motor housings is aluminum 6061.

Primary process

What is a primary process?

When talking about manufacturing, the primary process is when resourced material that has not yet been processed is converted into the basic or fundamental shape of the required product. After the primary process is executed, the product should be at a stage where it is either almost done with a few fundamental aspects missing that would be detrimental to the function of the product if they are not added, or the product is done and is theoretically finished but it still has room for potential improvements that could be added to enhance or entirely remove certain flaws.

Processes to rule out

Unfit processes

Although there are a multitude of different processes that could be utilized as primary ones, there are ones that can be deemed inefficient or at least unsuitable for the long-term production of a product such as motor housings. There around three major processes that could be placed into the aforementioned category, with them being forming processes, machining, or also known as subtractive manufacturing, and metal 3D printing processes such as SLM or DMLS printing.

When it comes to forming process, such as rolling, extruding, and drawing, they aren't suitable since they cannot produce the required shape of the product, and as such they can be immediately ruled out. On the other hand, when it comes to forming a product using forging, although accuracy and the overall shape of the product could possibly be achieved, the product would be solid, with the required cavities and holes for the motor housings being machined, which would result in a lot of wasted material which would severely affect the sustainability of the product as expenditures generated from material waste would relatively high.

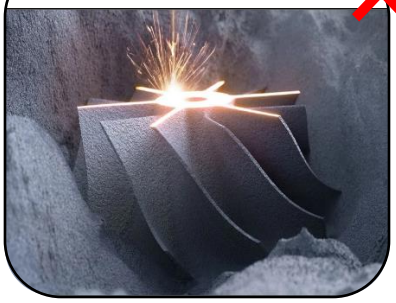
In terms of subtractive manufacturing, and more specifically CNC machining, the same argument said about forging could be said here, in that machining the product from the very beginning would generate a lot of waste and therefore hurt the long-term sustainability of the production process, not to mention the initial machining that would also have to done to get the blocks of material to an appropriate size for them to later be machined to the required shape. Although waste generated from forging and machining could be recycled, the recycling process itself would be both extremely costly and time consuming especially if done at scale as big as this.

Finally, concerning metal 3D printing, the process itself in terms of specifications and the overall quality of the final product is as close as possible to ideal, in that the product would be almost immediately ready for usage right after the printing process due to the fact that metal 3D printers are extremely accurate and would also be able to print any complex geometries such as cavities or threads that the product might be in need of, however, the major drawback to the process is the production time. According to (V, 2020), even some of the fastest metal printers have a print speed of around 100cm³/hour, which is relatively bad if the product being manufactured required a process that is capable of mass production, with 3D printers generally specializing in limited to low production products.

Forging

Machining

Metal 3D printing



Processes that require further analysis

After all that was mentioned, the main production processes that should be taken into consideration to be utilized as the primary process to produce motor housings and the ones that should analyzed in further detail are castings processes and powder metallurgy due to both of them not having clear drawbacks that could cause them to be immediately ruled out and they both could be utilized as serious and efficient long-term processes for the high volume production requirements of motor housings.

Casting

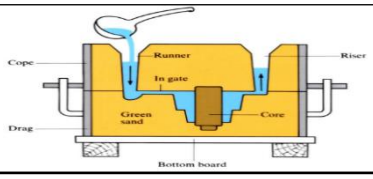
What is casting

Although there are several types of casting processes, the main idea or theory behind the process itself remains the same throughout all of them, which is that the process initially starts by creating a mold, with that mold following the same geometry as that of the product, the mold itself could be created out of different types of materials depending on material that is going to be molded and the casting process that is utilized. The mold creation process on its own is rather time consuming and costly, however it is only a one-time expenditure since the shape of the product would remain the same, and unless it were to be revised, the mold would remain unchanged. After the mold creation process has concluded, the next step of the production process begins by heating the material to its melting point, after which the molten material is poured into the mold and is extracted only after the metal has solidified.

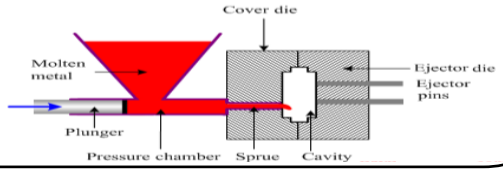
Types

As stated earlier, are multiple types of casting processes that could be utilized, with the main two that are most widely used being Sand Casting and Pressure Die Casting. The difference between the two mostly stems from the material of the mold, with the Sand-Casting mold being created with sand particles that have been compacted together with the use of a binding agent as stated by (Reliance Foundry, 2022), and the metal is simply poured into the mold. While on the other hand Die casting being made from metal with the molten material being pushed into the mold with the use of a high-speed piston at high pressure points. Although the main difference between the two is the material used for the mold, the outcome and product quality does differ. As of 2022, Sand casting is currently the most utilized casting process on the report of (Foundry, 2021), however in terms suitability, die casting would be superior to produce motor housings. That is the case since the main reason sand casting is popular is due to the low tooling cost of the process according to (Olsen, 2020), but when it comes to the overall product quality, die casting is far superior since – as stated by (Tanfel, 2022) and (Haworth Castings, 2017) – it provides a better surface finish, that is the case since the casted materials inherits the sand's texture in sand casting processes which causes a relatively rough surface finish. In addition, die casting does not create porous material which can be seen in much greater numbers in sand casting processes, which would impact the mechanical properties of the product. And therefore, die casting is superior for mass production, which is what is required when producing motor housings, and thus die casting would be the one considered when comparing casting to powder metallurgy.

Sand casting



Pressure die casting



Strengths

One of the main advantage die casting has over many other production processes is that it can produce an entire product within a matter of seconds to only one minute as mentioned by (Premier Engineering Products, 2015), which is the main reason die casting processes are utilized widely for mass production. In addition to that die casting has extremely good tolerances at around ±0.05mm according to (NADCA, 2009), and due to the astounding tolerances, secondary machining for tolerance dimensional accuracy adjustment would most likely not be required due to the already great dimensional accuracy that the product would have from the primary process. The entire die casting process is also environmentally friendly due to it being waste efficient, with the produced waste mostly being due to failed casting attempts which can be avoided as long as proper care and maintenance is taken. Finally, as mentioned by (Cavallo, 2022), die casting processes can create very complex shape, and as such very little secondary work would have to be done on the product since the main frame or shape of the motor housing would already be made with the die casting process.

Weaknesses

Generally, the major drawbacks to die casting processes is the fact that the requirements to get the process working are very costly and time consuming, with the capital expenditures of tooling required being around 15,000 for the low-end and 150,000 USD for high-end casting machinery as mentioned by (Lakeshore Die Cast, 2022), said price range could cause serious issues to small companies starting out, in that they potentially would not have the funds to acquire the adequate machinery. In the case of motor housings, the product doesn't necessarily require high-end machinery however utilizing cheap ones could be very detrimental to the longevity of the production process and could possibly cause serious issues in the long-term. In addition to cost, the lead time required to set-up the tooling is quite lengthy, with the mold creation process taking around 2 to 4 weeks depending on the complexity of the shape as stated by (edmo, 2022), and although the geometry of motor housings is not very complex, the lead time would nevertheless be relatively long.

he aforementioned disadvantages were ones that can be negligible if the necessary means are available and if a strict deadline isn't set. However, there are still some issues relating to the product itself when it comes to die casting, with them being porosity and threading issues. As stated by (Marin, 2018), porosity is when trapped gas from the molten metal expands and forms voids within the cast itself, this is one of the primary issues that occur with casting processes and it could lead to defects and deformations in the mechanical properties and overall shape of the product, this issue could be avoided or reduced if strict care and attention were to be taken to ensure porosity does not happen, and as stated by (Dynacast, 2019), this can be done by designing and placing vents, water lines, overflows and cooling channels within appropriate places. Moreover, the combination of the temperature difference from when the material is melted and when it cools down and the high amounts of pressure the process utilizes, a significant amount of stress and strain would be generated, and if not dealt with, it could cause the product to break easily. issue that die casting must face is the fact that although it can create complex geometries, it cannot form satisfactory threads, which are needed for making motor housings, and as such if the casting process were to be used, a secondary process to machine the thread in would be necessary. Finally, it should also be noted that die casting utilized a lot of energy at around 6 kWh/kg as stated in the (PM-11 International Conference, 2011), which is mostly due to it having to provide a lot of heat and pressure for the casting process to be done, and therefore could cause serious financial issues.

Powder Metallurgy

The process

The powder metallurgy process has been used for centuries and is still being utilized for mass product which is the case due to its reliability and consistent production quality. As stated in (IQS Directory, 2022), for a product to be made using the Powder Metallurgy production process (can be abbreviated as PM), the raw material must go through 4 different stages, with them being powder preparation, mixing and blending, compacting, and sintering.

Powder preparation – atomization

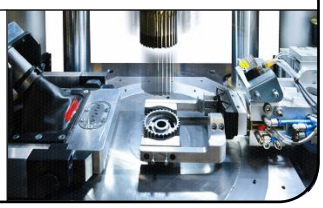
The first of which – powder preparation – is the stage in which the raw solid material is turned into a powder, although there are multiple methods to turn solid metal into, with examples being electrolysis and grinding, with the most common one that is being utilized in the industry being atomization, which is when the molten metal is poured into a chamber, and while it is falling towards the chamber, the liquid metal is hit by either water or inert gas as mentioned by (Chen & Liu, 2014), which thus causes the metal liquid to separate into extremely small particles, after which said liquid particles are left to solidify, and therefore forming very tiny powdered particles of solid metal.

Mixing and blending

Although the metal has been turned into powder after the atomization process, the powder is not yet ready to be utilized for the main manufacturing process due to it being too and unable to be held together. To counteract this issue, the second process – mixing and blending – it utilized, and as mentioned in (IQS Directory, 2022), this process is done by mixing the powdered material with binding agents including wax or thermo-plastics as stated by (M.K.Agrawal, 2022). In addition to that it is also mixed with other powders and lubricants, which assists the powder in having appropriate compaction which would greatly assist in keeping the powder together especially when said powder is later on compacted during the compacting stage of the powder metallurgy process. The entire mixing and blending process is usually done by rotating a drum or a cone that is filled with the powder and all the stated necessary components which would help in achieving a suitable powder mixture. This process can either be done dry or wet depending on the utilized powder and the requirements of the product.

Compacting

After the two stated processes have concluded, the compacting stage initializes. Within this the stage, the powder material is pressed through a die which is done with the use of a specialize powder metallurgy compacting machine, which presses the powder into the die at relatively high pressure points that could reach 1600 MPa depending on the powder mixture. As stated in (IQS Directory, 2022), in addition to forming the powder and giving it the required shape of the product – which in this case is the motor housing – it also helps in decreasing potential voids within the powder, that if not resolved before the sintering stage, could cause deformation to the end result.



Sintering

During the final stage of the powder metallurgy process, the powdered material is sintered, which is a process where the material is heated to a temperature that is below its melting point, which causes fusion between the powder particles, and therefore causing the powdered material to join and solidify without having to go through a liquification process that general melting processes such as casting must go through. The reason to which the sintering process functions is due to the temperature point in which sintering occurs causing the material's powder particles to diffuse, which – as stated by (Cliffs Notes, 2021) – causes the material to move from an area of high concentration to a low one, which accordingly causes the powder particles to fuse together, and thus create the finished product.

Strength

Powder metallurgy is known for being a net-shape production process, meaning that it is able to create products with the end result being very close to that of the ideal product given in the dimensions sheet or 3D model, and it has gained that reputation due the complex geometry that the production process is able to work with and due it having both extremely high accuracy that is even greater than die casting at around ±0.038mm as stated by (Smith Metal Products, 2022), in addition, it is also able to produce products with great surfaces finishes, and when working with a relatively small component such as DC motor housings, these attributes come in play a lot, and would provide great assistance in ensuring no defects occur and that the motor housings would be able to work as intended for each piece produced. Another great advantage of powder metallurgy is that the process is able to use a wide variety of material since most materials could be turned into a powder, and therefore most materials could be utilized in this process, although this isn't necessary relevant as powder metallurgy could be utilized for the production of the aluminum alloy 7075 – which is the material that is going to be used for the production of the motor housings – the property would still be useful if the manufacturer wanted to employ a different material later on in the life cycle of the manufacturing process.

It should also be said that is extremely waste-efficient, with very little to no material waste being produced from the initial powder preparation stage to the sintering stage, and therefore also making the process relatively environmentally friendly and decreasing potential monetary loses that would usually stem from wasted material in other production processes. Another major advantage of powder metallurgy over die casting is the tooling cost, with it being at around 5,000 to 15,000 USD according to (PSM Industries, 2022), which is relatively cheap in contrast to die casting's 15,000 to 150,000 USD.

Weaknesses

In comparison to die casting, the main downside to powder metallurgy is the time consumption, in the entire process from start to finish could take a significant amount of time, however, even when considering the sintering time on its own, depending on the material and the powder mixture it could take around 10 minutes as stated by (Lemoisson & Froyen, 2005), which – in comparison to die casting – is extremely slow and could cause serious issues especially on tight deadlines. It is also worth bearing in mind that the process of converting the solid raw material to powder is rather costly, and since the process utilizes powdered material only, this would only increase the price of sourcing and converting the material, which is an expenditure that would have to be done regularly and therefore it could possibly hurt the longevity of the manufacturing process, not to mention the energy that powder metallurgy processes consume, which is around 5kWh/kg as stated in the (PM-11 International Conference, 2011), and although it is lower in contrast to die casting, it is nonetheless high and would lead to high power related expenditures.

When it comes to the produced part itself, two major issues arise from utilizing powder metallurgy, with them being porosity and threading. Just like die casting, although powder metallurgy is able to create geometrical complex product, its inability to create threads makes it so a secondary process would be necessary to create the threads seen within motor housings. In terms of the porosity issue, due to powder metallurgy utilizing sintering as its method of fusing the powder particles together, the main issue with this is that even though the particles are compacted, small gaps between them known as pores or voids could be seen on a microscopic level which occurs due to several particles not fusing properly, which consequently worsens the material's mechanical properties which is unfavorable for products such as motor housings that need qualities such as strength and sturdiness

Verdict

When it comes to the overall quality of the product, it can be said without a doubt that powder metallurgy is superior to die casting with its higher accuracy and an overall better porosity control which would improve the material's the motor housing's mechanical properties. Powder metallurgy tooling is also much cheaper, especially when trying to obtain high quality powder metallurgy machinery as the difference between PM and die casting in terms of capital expenditures is certainly significant. However, although powder metallurgy has greater tolerances, the difference between the ±0.038mm that it provides to that of the ±0.05mm that die casting does, it wouldn't necessarily cause any significant issues especially to a noncomplex product such as motor housings.

It should also be noted that sustaining die casting processes would be far easier than that of powder metallurgy, since in spite the fact that the energy consumption of die casting processes being higher, the difference between the two isn't very detrimental with it being only 1kWh/kg, however, the expense of converting solid material to powder on a regular basis would result in overall higher and more significant disbursements when it comes to the required machinery if the conversion process is going to be done locally. Potential expenditures for the necessary additives that are going to be used in the mixing and blending process should also be taken into account and would also increase the overall cost of running the process. Although not stated earlier, working with powdered material also raises major health risks due to potential inhalation of the dust metal, which in the case of aluminum it could cause a condition known as "metal fume fever" which could cause various issues, namely chest tightness, fevers, and coughing as stated by (New Jersey Department of Health and Senior Services, 2007), and in the case that the dust were fine it could potentially cause lung scarring and therefore extra safety measures would have to be taken.

However, with all that has been mentioned, the major determining factor between the two processes is the production speed especially since a product such as motor housing would have to be mass produced and speed in that regard is an absolute necessity, and when comparing die casting's speed of seconds to powder metallurgy's 10 minute long sintering process, die casting is far superior, which consequently justifies the capital expenditures and lead time that comes with the process mainly because of the advantages that come with powder metallurgy not being of any necessity for producing motor housings, and therefore die casting would be the primary process that is going to be utilized for the manufacturing of the motor housings.

Secondary process

What is a secondary process?

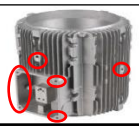
In manufacturing the secondary process– as the name might suggest – is the process that is done after the primary manufacturing process has concluded. It is generally done via machining to either rectify any errors that could potentially occur in the primary process, enhance the product by adjusting the dimensions, or to add necessary aspects of the product that could not be added in the primary process.

Flash removal

The first step after every casting process is the removal of excess material that is formed on the body of the product known as flashing. This material is formed due to the molten material solidifying on the pathway that pushes it towards the mold that is found in pressure die casting processes. As stated by (Pacific die casting, 2022), one of the most optimal methods of removing flashes in an industrial format is to utilize something known as a Trim Die, which is the process that is going to be utilized for removing flashes from the motor housings. The process involved using a tool that contains the same shape as that found in the mold used for casting the material. During the trimming process, the product is placed on the bottom half of the trim die, with the top half afterwards closing onto it and in the process removing any material that is on the edges of the product at relatively high tolerances. After the process has concluded, the excess material can then be recycled and utilized for subsequent production. However, due to the Trim Die would needing to follow the same shape of the casting mold, it would have to be tailored and would also require long lead times.

Threading

In addition to the removal of flashes, threads would also have to be done separately during the secondary processes since – as stated earlier – the initial casting process is unable to create threads in a manner that is deemed adequate. In terms of the tools or processes that could be utilized for the stated job, the main ones would be thread tapping and thread milling, and therefore said processes would be the ones to be analyzed and compared.

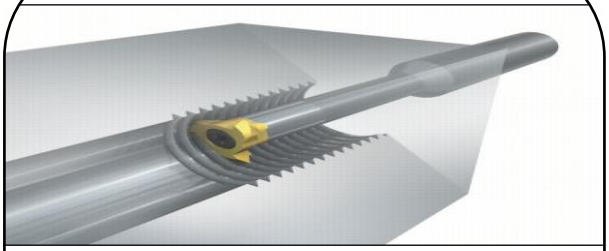


Thread tapping

Thread tapping is the most traditional method of creating an internal thread within an object. The process involved the high-speed rotation of a component known as tap. The tap is a type of drill bit that contains a threading pattern on its surface that – when drilled with – forms internal threads that could be used for any appropriate sized screw. As mentioned by (Zelinsk, 2005), the process can be done with hand or with the use of almost any appropriate machine such as lathes, pillar drills, and a CNC tapping machine, which is the most effective if automation was needed.

As stated by (sansmachining, 2021), the main advantages that comes with thread tapping is the speed, in that a thread tapping process could create a thread hole in much faster intervals in comparison to thread milling. In addition to that thread tapping is capable of threading much harder material and drill deeper holes in a much faster pace. However, the major drawbacks to thread tapping is that the process is utilized for specific diameters only since the tap itself would need to be changed each time if multiple diameters were to be required, and generally speaking taps are expensive components and manufacturing them required long lead times, which would be required if an extremely specific diameter was necessitated to achieve function for the product

Thread milling



The thread milling process is done by inserting and performing a circular motion with the use of a thread milling cutter. The way that the thread milling works is that the thread milling cutter would be inserted into an already drilled hole, after which the thread milling cutter would move in a circular motion within said hole and consequently shape the desired thread. Due to the way that thread milling works the hole would have to be bigger than the milling cutter itself and unlike thread tapping, a traditional a machine would not suffice, and as stated by (sansmachining, 2021), a CNC machine would have to be utilized for the process to control the circular motion required for the process t.

The main area of strength that thread milling provides is that you can thread holes of a variety of diameters without having to worry about the size of the milling cutter since its size determine the size of the hole but rather it only creates the threading pattern within an already made hole. As well, due to the process using a CNC mill, this gives the manufacturer greater control over the threading process in comparison to thread tapping, however, CNC machines possess an overall higher capital cost in comparison. Finally, as stated earlier, thread milling is also much slower when compared to thread tapping.

Verdict

When the product – motor housing – is taken into account, then thread tapping would be the optimal choice for creating the threads within the component. That is the case since most of – if not all – the threads within the component would be identical, and therefore thread milling's strong suit would not be of any use, however the greater threading speed that thread tapping provides would certainly be useful especially since – as stated earlier – the product does require mass production speeds. Although thread milling processes have proven to provide better threading quality, speed of production is more required compared to the quality factor. With all that was mentioned, it can be deduced that thread tapping would be the optimal threading process for adding the necessary threads when manufacturing motor housings, in terms of the machine, a CNC tapping machine would be utilized in order to automate the manufacturing process.

Post-processing

What is post-processing?

Post-processing is the procedure done after a product has finished being manufactured that is used to improve either the aesthetic appeal of the product or enhance its physical or chemical properties. It is known for being a crucial section of the manufacturing since the initial manufacturing process generally have many drawbacks to them that if not treated well during the post-processing or finishing stage, said issues could hurt the overall quality of the product.

Areas of potential enhancement

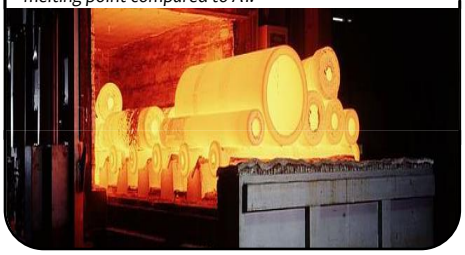
The main issue that the products still possess after the secondary process is the potential residual stress that has been imparted upon the material from both the primary processes as well the secondary process. That is the case due to the thermal stress generated from the temperature change during the casting process as well as the mechanical load caused from the machining done in the secondary process. If this issue were not to be treated, cracking of the material and deformation could potentially occur either in the short or long-term. No heat treatment process that specialize in strengthening the material would be employed in the post-processing stage since the chosen material – aluminum 6061 – already possesses the sufficient strength required for the product.

In terms of the possible processes that could be utilized to counteract the residual stress caused upon the material, heat treatment is the one that is usually used for said applications or jobs, and therefore different heat-treating processes that specialize in decreasing residual stress are the ones that are going to be analyzed and compared within this section.

Heat treating

Heat treating is a process where the material is heated to a certain temperature point below the melting point that is dependent on the material composition as well as the type of heat treatment process that is desired, this initial heating process is known as the heating stage. After the material has reached said point it is held there for a period in a stage called the soaking stage. afterwards it is cooled down at a specific rate in the cooling stage, which is the stage that causes the most significant effect on the material's properties. Overall, depending on the used parameters for all the aforementioned stages, the heat treatment process could impart a multitude of mechanical properties onto the material.

Although heat treatment sounds relatively noncomplex, the process on a microstructural level, this process causes a consequential change in the material's crystalline structure which is the reason that such a significant change occurs to the material. Important terms that should be noted are the A1 and A3 temperature points, points describe a certain temperature in which the material undergo a change in their microstructure, with A3 being closer to the melting point compared to A1.



Annealing

As stated by (Clifton Steel, 2022), the annealing process is one where the material is heated to right above the A3 point and is then cooled down at a relatively very slow and controlled pace which is done by decreasing the temperature of the oven that the material is residing in a calculate manner. The reason to which the annealing process is done slowly as using the approach produces finer and purer microstructure. In terms of properties, annealing causes the material to be much more ductile and softer, allowing for the material to be easily machined and worked with again if the production process ever necessitates, although this could also be used as the final process depending on the requirements of the product.

Normalizing

The normalizing heat treatment process is very similar to that of annealing according to (Clifton Steel, 2022), in that the maximum temperature point that is reached in the heating stage being very similar in both processes, with the same being said about the soaking stage with. However, the variability between the two namely comes from the cooling down stage, while the annealing process is allowed to cool down in a controlled manner within the oven, the material in the normalizing process is taken out of the oven and is simply left to cool at room temperature. The result of the normalizing process is a decrease in the overall residual stress, in addition normalizing also toughens up the material and causes it to be stronger.

Stress relieving

According to (Clifton Steel, 2022), the stress relieving process is done by heating up the material slowly, however, the material is not allowed to reach any of the primary critical points during the heating process. After which it is soaked for a period that allows for the required amount of residual stress to be removed and then temperature is then decrease at a faster rate compared to annealing until it has reached a suitable temperature to be worked with again. However, on the report of (Gale & Totemeier, 2004), one of the main issues with stress relieving is that it decreases the overall yield strength of the material by a relatively notable margin especially in comparison to processes such as annealing or normalizing.

Verdict

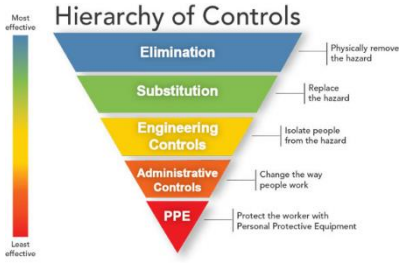
Out of the three heat treatment processes that were compared, normalizing is the one that would be the most suitable for the production process of the motor housings. That is the case since annealing causes the process to be softer which goes against the requirements of the product, in addition, added time that the material remains in the oven during the annealing process would result in the overall increase of the energy expenditures. When it comes to stress reliving, although it would be the foremost process in terms of the overall cost, it does significantly decrease the strength of the material which would not suffice for a product such as motor housings. Therefore, due to all of the stated issues that the other processes possess, normalizing is the heat treatment procedure that is going to be taken during the post-processing stage of the manufacturing process due to it being able to toughen the material while also decrease the residual stress caused by the primary and secondary processes.

Health and safety

H&S Brief

Health and safety procedures and regulations are one of the most important matters discussed in the manufacturing industry as the work environment the employees are situated in being generally surrounded by potentially harmful substances and machinery that could bring about serious health issues and concerns, and due to that said regulation have recently started being more strict to ensure that the worker maintains his human rights and is able to work with relative ease knowing that their work environment has minimal risk to his short or long term health, with this concern increasing especially with the introduction of more technologically advanced equipment. In addition to the worker's personal wellbeing, another major concern that companies face in the matter of health and safety is legal issues, with any injury or medical issue that is inflicted onto the employee while they are within the workplace leading to serious lawsuits and even potentially the closing down of the company if the government sees fit, and therefore the following section will also be referencing certain health and safety legislations documented by the Omani government.

In terms of the process of procedure that is done to maintain health and safety regulation, three steps are usually followed, with them being the identification of any potential hazards that could cause the harm to the user, evaluation of the risk-factor involved with said hazard in terms of both the seriousness of the imparted symptoms or injuries as well as analyzing the likeliness of the hazard occurring. Finally, after the two stated procedures have concluded, finding an adequate solution to the hazard is the subsequent step, which can be done in a variety of way, some of which being eliminating the hazard by entirely removing it from the work environment and the manufacturing process, substitute the hazard with something that would have less overall risk on the worker, or controlling the hazard by isolating the employees from it.



Casting H&S

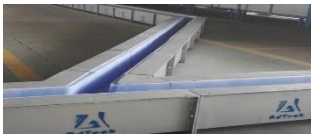
General concerns: *Although there are a multitude of potential health issues that could occur in a manufacturing-based workplace, the majority of which are relatively minute, with some of the apparent ones being issues such as not keeping any unnecessary tools or items near the furnace to ensure nothing accidently falls into the furnace and causes to the furnace due to it being traps under the molten metal, regularly maintaining the tools utilized throughout the entire facility especially ones that are related to the casting machine or furnace in order to ensure to failure occur while the machine is running, and also ensuring the workers don't touch come close to potentially hot parts while working near the furnace or the die casting machine, finally, the die casting machine should also be fenced to make sure that only capable personnel enter the proximity of the machine, said safety measure goes in accordance to article (32) of the Omani Ministerial decree no 286/2008 which states "Any rotating wheel, movable part, or part of the transmission machinery and any hazardous parts of the other machinery shall be fenced." The reason to which said issues are considered minute is the combination of utilizing common sense from the employees side as well as the solution to all of them being relatively easy, with it being having supervision on the workers to ensure their safety and that none of the aforementioned safety regulations are violated, in addition to that, providing a full safety course to all of the workers will assist in informing them of basic safety precautions that they should be aware of.*

Transporting and pouring molten material:

Identification: *A safety issue that could potentially occur during the workplace – especially if the employee's work is in relation to that of the furnace – is molten material spillage caused during the transporting stage to the casting machine. This is the case since the melting process is done separately to that of the casting during aluminum alloy casting with the material later being transported to the die cast, which is done due to heat requirements not allowing the alloy to be melted within the die casting machine itself. As stated by (Cast-Rite corporations, 2022), transporting the material has traditionally been done with the use of a ladle, or a process lip pour, which is a huge container that can hold molten material and is tilted using a wheel to pour the material out of it, and if the transporting of the material is not done in an ensured and safe way while using the aforementioned processes, potential spillages could easily occur and the processes are not considered to be very good in terms of employee safety according to (Striko Westofen, 2022). If the stated issue were to not be taken care of, said hazard would be breaking rule 22 documented in article (15) of the Omani Ministerial decree no 286/2008 which states "Workers must be protected from the hazards of falling, dropping objects, flying chips, sharp objects, caustic or hot liquids or any harmful materials."*

Lip pouring

Risk evaluation: *The risk involving the stated process is relatively high which is the case due to the seriousness of the injury unquestionably causing third degree burns if miniscule number of materials were to get in contact with the employee's skin, and potentially killing them if high amounts of material were to be spilled on the person's body. In addition, although the harm caused by the hazard would not generally occur if the person working with the material were to follow safety procedures, absolutely guaranteeing that that would be the case is not adequate to ensure the safety of the worker, in addition potential failures with the tool used to transport the material if it were to be done manually could occur.*



Launders

Taken measure: *Due to the seriousness of the issue, the optimal procedure to be taken with the process is to replace the main issue that the hazard would generally occur, which is the process that is utilized to transport the material, with it being the use of a ladle or a lip pour due to the poor worker safety that comes when utilizing either of them as stated earlier. The way in which said processes would be replaced is with the use of a launder system, which is a series of connected tubes made out of extremely heat resistant material that are used to that transfer the molten material with the use of gravity, which is done by having said launders tilted downward, causing the material to flow in a downwards stream until it reached a storing container that will then also utilize a launder system to transfer the material to the casting machine. Said landers would be separate from the workers by having them covered and in an isolated location, in addition to safety, as stated by (Striko Westofen, 2022), this process of transferring ensures that materials are in overall better quality due to the smoother flow of material from the furnace to the casting machine, as well as that, the process requires less labor and thus also resulting in lower labor expenditures.*

Gas fumes:

Identification: *As mentioned by (Pacific Die Casting, 2015), a lubricating oil is sprayed onto several parts of a pressure die casting machine such as the cavities of the die itself and the piston that pushes molten material into the die. Said lubricants serve multiple functions, among many of which being assisting moving parts of the machine to move more smoothly such as the aforementioned piston and to also assist in removing the part from the die when the material has solidified. However, the major issue with this is the fact that the lubricant is utilized in areas of the machine that would generally be at extremely high temperature, and consequently it would evaporate and fill the proximate area with fumes and submicronic smoke, that – if breathed in – would potentially cause serious health concerns even if the person were to breathe the fumes for a short period of time.*

Risk evaluation: *The risk that the stated hazard carries is relatively immense, that is the case since – as stated earlier – breathing in fumes produced by lubricating oils for short period could potentially cause serious health concerns, with that issue being significantly amplified if an employee were to be inhaling said fumes for an average of 8 hours per day, as such if the issue were to no be treated, the likeliness of a worker being affected by the hazard is almost – if not – 100%. Additionally, the dangers posed by the hazard are very serious, with them being lung irritation, shortness of breath, and potentially chocking. Moreover, even greater medical concerns such as irregular heartbeats or even sudden death could be seen if a person were to be exposed to the fumes for prolonged periods of time as stated by (McNally Institute, 2021), with all the stated issue being even more prominent to those that have a history of medical respiratory problems.*

Taken measure: *Since there are many employees that would be stationed in the area of the casting station, it would be inefficient in terms of expenditure management to provide them all with respirators, asides from that, it would also be relatively uncomfortable from the employee's standpoint to be wearing a respirator for upwards of six to eight hours, as such the solution to the stated hazard should be done by diverting the gases with the use of ventilation systems. According to (Pacific Die Casting, 2015), one of the most known and effective process to deal with the issue known as source capturing, which is done with the use of a fixed hood that is placed in very close proximity to the main emissions source, said hood afterwards pulls in any emissions formed from the burning lubricating oils or even from the molten metal and releases them to a place isolated of any people that might be harmed due to the fumes. Said solution also assists in following the ventilation section in article (16) of the Omani Ministerial decree no 286/2008 which mentions the following: "Avoid polluted air by providing a natural or artificial ventilation system that provides fresh air in workplaces and use local ventilation where sources of pollutions exist. This system must effectively suck the polluted air out."*

Moisture getting in contact with molten material:

Identification: *According to (Tabatabei & Turner, 2009), if water or any form of moisture were to get in contact with molten material during the melting process, said moisture would evaporate and rapidly turn to steam due to the extremely high amounts of temperature and in the process expand to around 1600 the original volume. Due to the swift manner in which the expansion occurs, the steam emitted would form in high volumes in a relatively quick time and be trapped under the molten material, which would consequently result in an unexpected and instantaneous explosion occurring within he furnace the steam is trapped in. Said liquids could be anything from water bottles or any other liquid containers being placed next to the furnace due a lack of care and supervision to even moisture remnants that could be found in minute quantities on the surface of raw materials.*

Risk evaluation: *The stated hazard is one of – if not the most – dangerous hazards when melting materials in any manufacturing process due the amount of risk attributed to it being extremely high as both the seriousness as well as the likeliness of extreme harm being done by the hazard. That is the case since the cause of the issue can be easily overlooked by an employee that might be unknowledgeable in the regard of the specific hazard and its causes. In addition, the seriousness of the hazard and the potential harm it would cause if it were to occur is extremely severe. As stated by (NADCA, 2009), there was once an incident where a filled liquid container got pushed into a molten material pit with the use of the hopper used for pushing the raw materials in, the result of said incident resulted in the death of 2 people, with 14 being severely injured.*

Taken measure: *As stated by (NADCA, 2009), the method in which potential surface moisture from on the surface of a material could be removed is to simply preheat the material to a temperature of around 150°C until moisture from the surface of the metal evaporated, which would assist in ensuring that no moisture is inserted into the die or the molten material. Additionally, extreme care should be taken in not allowing any liquid containers near sections of the facility that may contain molten metal, which could be done by entirely prohibiting unnecessary liquids in said sections, and even with ones that may be needed, proper supervision should be done.*

PPE: *The Personal Protective Equipment requirements vary a lot from employee depending on the hazards that they are generally facing and what part of their body would be affected the most if said hazards were to harm them. However, in accordance with the (Health and Safety Executive, 2022), people working in sections that operate in environments in which molten material would be dealt with such as the furnace and cupola men as well casters of large dies should always wear safety jackets and trousers, the reason to which coveralls are not utilized instead is that if molten material were to be spilled on their outfit, removing coveralls from their body would take much longer in comparison to removing a jacket and trousers. In addition, the material that should be utilized for said outfit should be entirely made of natural fibers, namely cotton or wool, that is the case since if molten material or any hot tools were to come in contact with clothing made out of synthetic material, said clothing would melt rather than burn and would consequently stick to the wearer's skin as stated by (NADCA, 2009). In addition to the stated jackets and trouser, other safety equipment such as safety boots, helmets, and earmuffs to prevent the possibility of permanent ear damage must be worn all the time. Besides that, heat resistant gloves and safety glasses would have to be worn if the employee is going to be working with hot tools and molten material.*

H&S jacket and trousers

Machining H&S

General concerns: *There are a host of potential health hazard that a worker might run into when working in a machining environment, which is mainly due to the machines utilized all working at extreme speeds, some of which even being sharp and would easily penetrate through the skin, and easily cause severe injuries to the worker which could likely lead to death. However, most of the general safety precautions are ones that could be easily followed. However, although they are easily followed, if the employee were to not be informed properly of them prior to them starting their work, said hazards could easily harm them.*

Some of the most prominent – and basic – safety risks and concerns that involve machining jobs, specifically ones that involve the machine operators are ones such as that they should not wear any loose clothing or gloves to avoid the risk of potential entanglement of the said items with rotating sections of the machine, and following that, the operator should also never work or handle anything involving the cutter or its proximate area unless the machine has fully ceased operating.. Finally, each person that works in the proximate area of the machine should be notified of the emergency switch of the machine and the facility in the case an injury due to the stated causes or others did occur. Finally, the work environment should also be kept clean by the employees to ensure that no one gets hurt due to small fragments of metal produced by the machining process.

In terms of machine safety checks and percussions, excessive cutter force should never be utilized under any circumstances due to the likelihood of the cutter breaking while doing so, which would consequently cause the shattered pieces to go through the air at high speeds which would cause extremely severe injuries, in addition to this, taps should be replaced regularly to ensure they still maintain their quality and that they would not break easily. It should also be noted that although CNC tapping machines can carry the work automatically, the machine should never run without a certified operator supervising it. Other basic safety regulations that should be followed in terms of machine safety are that the security of guards as well as machine vice should always be checked before running the machine. Additionally to all that was mentioned, the CNC machine should be fenced or placed in a separate room that prevents uncapable personnel of entering the proximity of the machine, the fencing process follows article (32) of the Omani Ministerial decree no 286/2008 which stated that "Any rotating wheel, movable part, or part of the transmission machinery and any hazardous parts of the other machinery shall be fenced."

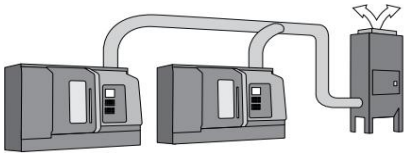
MWF handling:

Identification: *Machine working fluid (abbreviated as MWF) are oil or water-based oil fluids that are sprayed on the machined piece at high pressures while the CNC is working on it which assists in preventing potential overheating of the piece which could cause deformations to utilized material as well as also cause fires due to thermal energy produced by the friction between the tap and the piece. Additionally, MWF is also used to remove dust and fragments from the piece to keep the piece clean and to make sure that said fragments do not enter tiny gaps that might be seen on the design of the product. However, the major concern with MWF is the mist which is formed due to the disturbance occurring to the fluid's stream caused by the fluid hitting the piece at relatively high pressures, which consequently causes the fluid to become airborne and easily inhaled as stated by (CCOHS, 2022). As stated earlier, MWF usually constitutes of an arrange of oils which are generally made up of petroleum and fossils fuels, therefore breathing in said mist would result in serious medical issues.*

Metal working fluids

Risk evaluation: *The risk attributed to false handling of MWF mist is extremely high, in that if not handled with the utmost care, employees could easily spend long working period of up to six or eight hours exposed to the mist, therefore the likelihood of harm is really high, in addition, prolonged exposure has –according to (CCOHS, 2022) – the possible resulting symptoms of dermatitis which causes burning, itching, and blistery skin. In addition to that it could also cause asthma, lung irritation, and potentially more serious medical issues such as defective lung functionality and chronic bronchitis. Furthermore, as stated by (CCOHS, 2022), further research has deduced that inhalation of MWF has contributed to forming certain cancer types such as skin, bladder, pancreas, and more. As such, the risk being taken if the issue relating to MWF mist is not resolved is tremendously high especially due to both the extreme seriousness and likelihood of harm resulting from the hazard.*

Taken measure: *The most optimal measure to be taken to ensure that MWF mist is not breathed in by workers in the proximate area of the machine is to utilize a device known as a Local Exhaust Ventilation (abbreviated as LEV) as stated by (COSHH, 2022), which is device that is utilized for extracting dust and fumes from a specific machine in the workplace. The way the system works is that the LEV is stationed on the vent that would emit MWF mist from the machine, after which the LEV would extract all the emitted particles to a location isolated from people. This can also be done with multiple CNC machines by connecting tubes to the emitting vent, thenceforth said tunes would all catenate to one centralized LEV. It should also be noted that, if possible, MWFs with a lower supply of harmful oils and elements should be used to decrease the severity of the harm that would be imparted onto the employees if the MWF were to be breathed in. Utilizing a ventilation system such as an LEV in areas of airborne harmful substances follows article (16) of the Omani Ministerial decree no 286/2008 which states: "Avoid polluted air by providing a natural or artificial ventilation system that provides fresh air in workplaces and use local ventilation where sources of pollutions exist. This system must effectively suck the polluted air out."*



CNC machines connected to a centralized LEV system

Furthermore, it should also be noted that proper care should be taken when disposing of any remains stemming from liquid MWF due to the fluid being dangerous even If it were to only get in contact with the skin. As such, cleaning machines that contain MWF within them should be done with a specialized system cleaner according to (United Kingdom Lubricants Association, 2021). After which, all the collected MWF should be given to the competent authorities for them to dispose of rather than attempting to dispose of the fluids inhouse as that would add unnecessary risk to the workforce at the facility. However, if inhouse disposal were to be necessary for certain reasons, the manufacturing firm would initially have to get a permission from related authorities stating that they are permitted to doing so, said rule can be seen in article (37) of the Omani Ministerial decree no 286/2008 which mention the following: "Not to produce, use, circulate, store, or dispose of any chemical substances inside the establishment, before obtaining a permit from the concerned authorities."

PPE: *Although the operator or worker would not have to work with tools themselves due to the automation that stems from utilizing CNC machines, however, a lot of potential risk is taken just by working withing a manufacturing environment, and therefore PPE should nevertheless be worn no matter the position that the employee is in as long as they are ever going to operate or work with machines. The basic PPE should be worn are overalls to protect the worker from potential liquid splatter encountering their skin, safety boots to protect them from any harmful tools that could have fallen onto the floor, safety goggles should also be worn whenever the operator opens the CNC guard to prevent dust from flowing into their eyes. Besides, workers should also wear cut resistant gloves that offer back-hand protection – as stated by (Rockford Systems, 2022) – as they would potentially help in the case that cutter spins while the operator's hands are in close proximity. In addition to all that was mentioned earmuffs should be always worn if the machine is running as the high volume generated by CNC machines could potentially cause permanent ear damage.*

Normalizing H&S

General concerns: *There are a multitude of safety protocols that should be followed when working with heat treatment processes. Some of the main ones that should be mentioned are that the temperature of anything around the furnace or any material that comes out of it should*

always be measured before any physical interaction is made. In addition, if an operator or employee were to ever go into the furnace chamber, someone should always be supervising them outside, with a harness connected to both the supervisor as well as the operator within, moreover, every employee working in facility should be informed of the emergency stop for both individual furnaces as well the entire facility. In terms of maintenance, exhaust and heat ventilation of the furnace should always be checked before lighting it and it should be maintained by competent companies on regular basis, which help ensure that no possible fires occur. Finally, all furnace doors should be made so that they can be opened from both the outside and the inside in the case that a maintenance worker working within the furnace gets stuck.

Heat stress:

Identification: *According to (BetterHealth, 2015), heat stress is a condition caused when the body is exposed to high temperatures for prolonged periods of times to a point that it is unable to cool itself back to stable temperatures with the use of sweating alone. This could lead to varying medical conditions that range from nonserious to potentially even life-threatening. This issue is even more prominent in heat treatment processes in comparison to Die casting due to the consistency at which workers would be exposed to extremely high temperatures being much higher, especially to those operating the furnaces. Thankfully, however, the normalizing process requires less operating time in the furnaces in comparison to some other heat treatment processes such as annealing or precipitation treating, nevertheless, the issue should still be taken with the utmost seriousness due to the high risk that it could carry.*

Risk evaluation: *Symptoms that could arise from heat stress are all relatively serious. As stated by (NIOSH, 2020) some of the most prominent ones are the development of heat rashes, which are a skin condition that could cause itchiness and a burning sensation on the affected area, heat stress could cause muscle spasms known as heat cramps which could impart severe pain. In addition to what was mentioned, heat stress could lead to heat strokes, a very serious medical condition that causes the body's temperature to promptly rise at a rapid rate, which consequently causes the body to fail by damaging both the body organs as well as the brain and could easily cause the person experiencing the condition to die unless medical emergency were to be called immediately.*

Taken measure: *Although a very big part of the taken measure does depend on the employee themselves and on human factor which unfortunately cannot be controlled, certain steps could be taken in order to lessen the chance of heat strokes occurring, the first of which is to isolate the furnaces from the employee's proximity unless said employee had to interact with the furnace, which follows the Heat and Cold section of article (16) in the Omani Ministerial decree no 286/2008 which states "Operations of high temperature must be isolated in separate areas where only a minimum number of workers will be affected." In addition to that, constant supervision on employee's medical condition multiple times throughout their shift should be done to ensure they are in stable medical conditions and that they are able to continue working without being vulnerable to possible heat related illnesses. In addition to that, every employee should be informed of heat stress symptoms and that they should decrease their work rate whenever they are experiencing any of them. Furthermore, as maintained by article (17) of the Omani Ministerial decree no 286/2008, "Rest rooms should be availed close to workplaces" and that "They must be equipped with adequate furniture and ventilation" , as such, following that, designated rest rooms or cooling areas that contain air conditioning or fans should be seen throughout the facility which would allow for the employees to cool down and drink water to prevent dehydration whenever it is needed, employees should also be given longer and more frequent breaks in days that have hotter weather conditions. Moreover, before employees start working on the job, they should all be tested for how vulnerable and acclimated they are to very hot conditions and to also identify who might be the most at risk for them to get monitored more consistently for potential symptoms of heat related illnesses. Finally, workers should be encouraged to wear light clothing in order to stay cool and not get warm easily.*

PPE: *Due to the fact that turbomachinery is not necessarily utilized in heat treatment facilities, Personal Protective Equipment regulations are far less strict in comparison the ones seen in machining or die casting processes. Therefore, as stated by (Smith, 2002), OSHA recommends clothing that revolves around keeping the workers cool in order to decrease the potential of heat stressing should be the one prioritized, with the main aspects that should be taken into account are that the color should be light – optimally white – and that the wear should be loose and light. Other PPE that might be needed are face shields for whenever the workers must look directly into the furnace while it is running to check on the condition of the product and to ensure the operation is running well, in addition workers must also wear heat resistant gloves if they're going to be physically interacting with the material or tools that are specifically utilized for the furnace.*

Light H&S outfit

Human factor

Human factor brief

Human factor refers to the employment and organizational abilities at the head of the company such as the workload and staffing. In addition to that it also entails to the ethical, physical, or mental aspects of each individual at the company, with all of which that was stated contributing and causing a major impact on the overall quality of the product as well as the workflow and safety of the procedure. Human factor is one of the most prominent components to be taken into consideration when hiring employees as the stated aspects have a major contribution to the success of a worker within the workplace, in addition to that, human factor also entails how efficient the worker is going to be and how much they are going to contribute to the company. Moreover, human factor must also be kept in mind when enforcing rules upon the employee as said rules would have to follow the specifications of workers to maintain a healthy relationship between the employer and the workers and to also ensure the satisfaction of the workers and their mental and physical well-being.

Failures

Brief: *Failure within the workplace is comprised of multiple aspects, some of which could be a failure regarding a stage within the manufacturing process which would undermine the overall quality of the product, by not following health and safety regulations, or by going against company policies which could involve anything from safety measures to legal requirements. Failure can be seen in two different ways, with them being either Human Errors and Violations, both of which having to be approach in separate methods and ways to ensure that the failure does not reoccur.*

Human error: *Human errors are unintentional failures occur due to issues that generally are outside of the employee's control at the time of the failure. Errors can occur in two different manners, the first of which being in the form of skill-based errors, which is when an employ forgets to do a particular task due to the lapse of memory or they do not do their tasks with the intended method due to a slip of action. Said errors usually occur due to a lack in the person's ability in terms of memorization and concentration. Another way in which human error could occur is in the form of mistakes, which can be split into knowledge-based and rule-based mistakes, both of which generally stemming from the employee not being informed about said rules or information, however it could also stem from doing multiple complicated tasks simultaneously or by doing too many tasks at once, which – again – causes a lack of concentration that could affect the employee's working capabilities. Human error is generally by external factors such as stress, time pressure that could be put on the required task., social or organizational issues, and so on.*

When it comes to reprimanding human error, it ought to be done in a formal manner in which the employee that caused the error is warned and not penalized in the case that it does not reoccur often and consequences of the error were not significant. That is the case since as human, error is something to be expected and is generally outside of a person's control.

Violations: *Violations – unlike human errors – are intentional breaches of rules and regulations done by an employee within a workplace. Although violation of rules could occur due to a multitude of reasons, with them being categorized into three different sections, with them being exceptional, situational, and serious or malicious violations. Exceptional violations are when employees violate rules due to exceptional circumstances such that if they had not, other – potentially more serious – complications could have occurred, an example of this might be violation of material handling rules in order to assist a person that might have been or is being harmed due to a hazard. Situational violations are when employees feel forced to violate rules due to either organizational aspects of the job such as the lack of proper equipment and tools or time pressure put onto the assigned tasks making workers violate health and safety regulations. In addition to that, improper environmental conditions such as unsuitable weather conditions or inappropriate levels of lighting could cause employees to violate organizational or health and safety rules in order to work in a more suitable environment. Finally, serious violation are ones where an employee intentionally violates regulations with malicious intentions such as intentionally harming another employee due to external issues between the two, in addition to that, serious violations could also come in the form of stealing items from the company for personal gains or by utilizing social engineering methods.*

When it comes exceptional violations, examination of said violation should be done in order to reach to an appropriate decision, which is the case since exceptional violations could have occurred due to many different circumstances and intentions. In terms of situational ones, proper analysis of the situation should be done in order to improve on organizational and environmental effects that led the employee or employees to breaching regulations. However, when it comes serious violations of company policy or health and safety regulations, immediate suspension or

discharge of the employee must be carried out, and if deemed necessary, contact with the appropriate authorities such as the police department should be done.

Ethical behavior

Brief: *Ethical behavior is sometimes a very neglected aspect of human factor, with it generally being seen as having little to no significance to the production quality and flow. However, although a person's ethical behavior might not immediately affect the quality of the product in comparison to their mental and physical capabilities, having a person with poor ethics within the workforce would cause a significant impact on the team's attitude and therefore also effect the production quality. And due to that, this aspect of human factor should be taken seriously and should be a major determining factor when it comes to the employment of the worker.*

Integrity: *Integrity stems from a person's honesty and having a strong moral compass. Having a person with poor integrity within the workforce could cause varying issues, with the one of the main ones being that it opens the chance for potential misdemeanors to occur within the workplace due to intentional violations of the workplace guidelines. This could be from tasks as simple as petty lies to a superior about an undone tasks to issues as big as stealing potentially confidential documents for personal gain or other forms of social engineering, in addition to that this could also cause the safety within the workplace to be vulnerable due to a lack of care that the person might have to their coworker's safety and well-being. On the other hand, if a person with great integrity were to be a part of the workforce, they would cause a significant positive impact by keeping the workplace's mentality healthy for everyone that joins the team.*

Respect: *Respects generally refers to the professionalism between a person and their coworkers as well between their superiors. One of the most common violations of respect within the workplace that could be seen within the workforce is a superior having an overall negative attitude towards their team, if this were to occur, it would undermine the team's capabilities and overall willingness to work which would consequently affect the workflow within any of the production process stages, and hence also affect the quality of the product, this issue is peculiarly impactful if it were towards a new engineer or worker especially from a moral standpoint as having a disrespectful superior would undermine their career admissions. In addition to the damaging of the team's morale, the absence of respect could also lead to legal issues of varying severities, as respect is a barrier that prevents physical or verbal harassment issues that could easily lead to lawsuits that can potentially cause significant financial loses to both the company and the persecutor. Additionally, said lawsuit could also cause the jeopardy of the company's reputation and overall image to the public.*

Responsibility: *Responsibility is a very important aspect to be look for in employees and to ensure that said human factor is available as this factor means that the worker has the willingness to work on time and carry out assigned task with a sense of duty. Having an irresponsible team member risks both productivity instability and the violation of Health and safety guidelines. That is the case since said person would most likely have minimal care safety guidelines, which would cause endangerment to both themselves as well as the rest of the workers at the facility. In addition to that responsibility is one of the key factors to ensuring work is done thoroughly and on time, and therefore lack in such regard would lead to potentially delaying the process due to certain tasks being incomplete as a result of said irresponsibility and care, which would be a major risk especially in client-based projects that involve strict due dates. A lack of responsibility in the specific manufacturing process that is going to be utilized for motor housings would be issues such as not heating raw material to prevent surface moisture for accumulate in the casting process, which would endanger the entire facility due to the possibility of high amounts of moisture contact with molten material and could also affect the overall quality of the product as evaporation of the steam within the molten material could lead to deformations of the material. In terms of machining the issue could be not setting the CNC tools accurately such as the tap. Finally in terms of heat treatment the issue could arise from taking out the material too early or too late from the furnace in order to speed up the process due to a lack of care.*

Workload management: *One of the most important ethical matters within companies is workload management. That is the case since improper management of such matter would lead to the delay of tasks required to complete the manufacturing procedure and – as stated earlier – this is especially disrupting when providing a client-based service that entails strict due dates. Said strict due dates consequently lead to employees having to work overtime – more recently known as 'crunch time' – to achieve particular tasks. This matter and inefficient workload management would impact the employees mentally and decrease their motivation to work by causing both physical and mental burnout and would also lead to high levels of stress due to the time pressure. As of recent times, this issue has been prominently seen within the video game development and the animation industry, and due to said incidents, the related companies received major backlash from multiple areas from both related industries and from the public, which consequently hurt the company's image severely and also decreased the public's trust in them,*

which in turn affected the overall value of the company. And hence, workload management is an important factor that should be taken with the great seriousness in terms of both practicality as well as moral value.

Taken measure to ensure ethical behavior: *Unfortunately, finding a reliable and foolproof solution for the stated issues is not something that could be possibly done as there are many other parameters that would have to be considered when it comes to hiring. In addition to that, a person would try to appear as best as possible when being interviewed and therefore integrity, respect, or responsibility issues would not be evident. However, there are certain procedures that could be taken in order to reduce the possibility of allowing people with major ethical flaws to join the workforce. Said procedure would be conducting a background report on people that will potentially be hired, which would be done to analyze previous work experiences and detect possible ethical issues that the interviewee's superior or coworkers might have complained about which might disallow the person from being hired.*

The stated solution will work for most of the stated ethical behavior apart from Workload management as the solution is not particularly relevant in that regard. However, an appropriate measure to be taken for this particular issue is to give the due date as a range rather than a specific date, with the contract stating that said range could be moved forward depending on the conditions of the operation, this would help in alleviating a significant amount of stress from the workers and prevent the possibility of having to work overtime. This would be of great assistance especially if a set amount of motor housings were to be required.

Mental capabilities

Brief: *The mental capabilities of an employee stem from their motivation to work and ability to learn and improve. Having a person with great mental capabilities within the workforce generally leads to a more efficient workflow, that is the case since a smart worker would be able to understand newer implementation to the company easier and would also be able to keep up to date with potential improvements and technologies within the industry that could be utilized for improving the manufacturing process. In addition to that, a smart employee would generally be capable and would inspire to improve and better both themselves and the team, this also means that they will be able to be consistent In their work.*

Memory:

Factor: *A major factor that greatly effects both new and senior employees alike is memory, which is the case as the capability of comprehending memories and facts that might be used in a particular tasks within the job, this is especially prominent if a said task is not practiced. The human brain is also limited since it is unable to retain a large of amount of information. Moreover, any person is prone to forgetting certain aspects that might be essential for their task.*

When it comes to the manufacturing process of the motor housings, this issue could be seen at any stage during the procedure. In terms of die casting, this could occur with a worker forgetting to lubricant the mold cavities, which would then cause major issues when removing the product, another area where this could be seen is also if a person forgets the required pressure utilized for the casting piston. This issue could stem from forgetting certain G-code syntax or commands that might be utilized for operating the CNC machine in the tapping process if an error occurred. Finally, in terms of heat treatment, one of the main factors that could occur is forgetting the required temperature and soaking time for the material, and if not handled properly could entirely affect the heat treatment process and the crystalline structure of the material, which would undoubtedly produce a subpar product. Although there are many issues that might arise from memory issues that an employee might go through, the ones stated are some of the most prominent ones that have the highest chance of occurring.

Assurance: *It cannot be guaranteed that a person or a worker would never forget certain sets of information as that is simply a part of human habit. However, certain measures could be taken in assisting a person that might have forgotten something related to the job. The main measure that could be taken is to encourage asking within the workforce, this would be of great assistance as anyone that have forgotten a particular fact would not be reluctant to asking a senior or someone that might know it, since if employees were to feel discouraged about asking, they would simply attempt to work with potentially false information that they might have thought was true, which would consequently affect the quality of the product and in certain cases even endanger other people. In addition to the stated solution, posters about basic facts such as utilized parameters should be seen throughout the workplace, which would act as a guide if an employee ever forgets something.*

Motivation:

Factor: *A particular aspect of human factor that needs to be taken into account is the motivation for an individual as well as the team as a whole. That is the case since a very prominent issue that can be seen within many industries – with the manufacturing industry being included – is burnout, which is defined as the lack of motivation and pleasure that stems from working. Said issue could be very impactful to the overall quality of production and workflow, as an unmotivated team is likely to be mentally fatigued, which consequently results in an overall slower pace of work and less concentration, care, and dedication in producing a product while still meeting the required quality in any of the stages that could be seen throughout the manufacturing process when producing the motor housings.*

Assurance: *Motivation is a rather complicated matter to address due to it being an issue that could occur anywhere during the production cycle, as people generally start as being very motivated and then afterwards, they gradually lose said motivation the longer they remain within a particular environment or job. Nevertheless, motivation is something that could be rejuvenated within an individual or a team, this could be done with the use of a variety of method, however, as stated by (Sodexo Engage, 2022), one the main method that could be used to keep an employee motivated is by having regular team meeting in which employees could voice any issues they may have about the manufacturing process or about the company which would increase engagement and participation within the workforce and consequently the motivation. In addition to that emphasis on teamwork and healthy coworker relationships would assist in keeping employees motivated to work.*

Knowledge:

Factor: *Knowledge is regarded as one of the most prominent aspects that is required from an employee. Knowledge is represented by an employee's academic background such as university and total GPA as well as their prior work experience that involved theoretical-heavy jobs in which the employee was able to achieve the required result. In addition to that, knowledge also stems for ease of adaptability to different work environment and tasks. In terms of the manufacturing process related to the production of motor housings, an employee within the workforce that has relatively little knowledge about the process and the technology could cause a variety of problems. When it comes to casting this could stem from the lack of knowledge in terms of utilizing different tools and casting methodologies as well as the ability to change the parameters accordingly depending on the requirements of the material and other conditions that could affect the die casting process. In terms of CNC machining, - as stated earlier – the ability to utilize and work with G-code in order to have utmost control over the machine is extremely important knowledge that a CNC operator should have as it would prove to be extremely important in the circumstance that a change in parameters were to be necessitated which requires slight adjustments to the G-code. In addition to that, potential logical errors occur with the machining process which in turn requires adjusting to the code the CNC machine runs on. When it comes to heat treatment processes the lack of knowledge could cause issues if the worker is unable to adequately change heating parameters depending on external conditions and therefore would damage the quality of the product.*

Assurance: *One of the main methods that is utilized when determining an employee's knowledge is by mostly by looking at their academic background and prior work experiences and projects that the person has worked within relative fields. However, although this method can work and is usually effective, it also closes the door for potentially talented individuals that might have important theoretical knowledge that would greatly assist in the production process but might not have studied or worked at popular universities and companies. As such, a more efficient methodology to be utilized when selecting employees in terms of knowledge is to utilize a system similar to the one seen in the software development industry, which is by creating a set of challenges that the employee must pass, after which they would be asked theoretical question and their reasoning behind their provided solution for said challenges.*

In addition to what was stated, providing courses and conferences on a regular basis about new technologies seen in the industry and potential enhancements that could be added to the manufacturing process would be extremely beneficial in keeping employees updates on said technologies, which would therefore assist in enriching their knowledge about the field.

Leadership:

Factor: *Leadership is one of – if not the most – important factor that is required within the workforce which is the case as bad leadership could very easily jeopardize the entire manufacturing process. Bad leadership could result in many complications and disputes. One of the leading factors of great leadership is communication, and if said aspect is not present it would lead to low morale and an unwillingness from the employees to work and perform well which would consequently decrease the production quality and workflow. On the other hand, a great leader would share their ideas and communicate with their try to find possible solution to issues that could be affecting the manufacturing process. Bad leadership also generally results in poor management which could easily lead to high employee turnover and even potentially a strike action from the employees, which would cause significant damages to the company's reputation and would also damage it financially.*

Assurance: *Varying methods could be used in order to decrease the likelihood of having poor leadership. Some of the main methods could be increasing the criteria and requirements when choosing leaders and not allowing one to attain the position before proper analysis of prior work experiences. In addition, if poor leadership behavior were to be seen, immediate action should be taken from subordinates working for the person currently allocated as the leader. Leaders should also have regular and more dedicated courses that go through aspects such as Human*

resources and proper communication, which would assist in being able to share potential vision for the production process with their team and also to be able to express aspects in a more respectful and appropriate manner.

Physical capabilities

Brief: *The physical capabilities of an employee determine the consistency of the product in terms of its overall quality. That is the case since although a person might be theoretically knowledgeable in their own respective field, their physical capabilities and their ability to work practically has an immediate affect towards the quality of the product itself as inexperience in practical work would lead to the employee being uncomfortable in their work environment, which would consequently lead to mistakes during the production process, and therefore effect the quality. Additionally, good physical health is just as important as bad physique would cause the worker to easily get injured or tired, which would also affect their inability to work and accordingly affect the quality too.*

Practical skill:

Factor: *The practical skill of a worker determines their prior work experiences and how skillful they are in utilizing and using tools and machinery relative to their role in the manufacturing process. A person with minimal practical skills would generally require going through courses to learn some skills that might be essential for the job, which would increase the overall expenditures of the company that would be going to staff training. In addition, lacking practical skills also means that the employee is very vulnerable to making mistakes, even they know the theory behind the procedures they might be working in. Lack of practical skill in the different section of the manufacturing process could lead to complications when working with the die casting machine, which could ruin a batch of the product and cause major financial losses. When it comes to the machining process, the lack of practical skill would cause a variety of issues from both the G-code standpoint as well as general procedures and handling of the machine in terms of accurately setting the tools required for the machine that – if not done properly – would severely affect the dimensional accuracy and overall quality of the product. When it comes to normalizing lack of practical skill would mean that the person working might not be acclimated to the hot working environments which – as a consequence – would cause the worker to be more at risk of being vulnerable to heat related illnesses.*

Assurance: *Although practical skills are a major deciding factor on whether or not a person is chosen for a particular job, it should not be the major deciding factor, which is the case since practical skills would have to be developed, which can be done by providing course before starting the job about the basics of the machinery or the tasks that the job might entail, after which any remaining skills that usually take long would have simply be done alongside the job. An example of this would be learning CNC machine operation alongside working with the machine as a full-time job, this is generally done since CNC machine courses are generally ones that take four to five years, and when it comes something that would take that long, it would not be reasonable to expect for such a long course to have been fully completed prior to applying for the job. Additionally, regular courses should be done on tasks that are not done on a regular to basis to ensure that the workers retain the skillset if they are ever required to use them.*

However, the stated solution should not be utilized for senior positions or positions of great importance to the manufacturing process as said positions would be integral to the quality of the product, and therefore practical experience is to be expected. Furthermore, people applying for senior positions should be tested for their skills in relevant tasks, with said tests including both theoretical knowledge as well as testing for practical capabilities.

Fatigue:

Factor: *Fatigue resistance from a human factor standpoint stems from the ability of a person to endure physical activity without succumbing to tiredness or weakness of the body. Having a person that gets easily fatigued would usually slow down the workflow, this would be extremely inefficient under time pressure and if the person forces themselves to continue on, it could cause the person work at suboptimal conditions and cause potential errors and mistakes during any tasks that they have been assigned to, additionally, forcing themselves to work while being fatigued would also make them extremely vulnerable to any potential hazard. Relating to the manufacturing process of the motor housings, this could mean that the worker is going to be unable to properly monitor the die casting process. In terms of machining, they would most likely be unable to concentrate during the process which would cause them to make mistakes while operating the CNC machine and therefore hurt the overall quality of the tapping if any manual operation had to be done. Finally, they might simply be unable to work when it comes to heat treatment processes without carrying a lot of risk or be under constant supervision and health monitoring to ensure their safety.*

Assurance: *Unfortunately, poor physical physique and fatigue resistance is a major liability and risk to both the employee themselves and the workforce in general. Therefore, people that have an extreme case of the issue should not be assigned to tasks that require heavy physical labor.*

As such, simple tests should be done before starting the job to ensure and analyze a person's physical strength and overall fatigue resistance to ensure that they are assigned to appropriate sections. Additionally, people that have started developing poor fatigue resistance due to external factors such as old age should be kept under regular supervision and health monitoring to make sure that they are not putting themselves under any major risk.

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"Safety is not an intellectual exercise to keep us in work. It is a matter of life and death. It is the sum of our contributions to safety management that determines whether the people we work with live or die."

-Sir Brian Appleton