Computational Case Study to Examine the Deficiencies of NNPB Plunger Production Processes in the Glass Industry

Master degree in Product Design Engineering

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Project Report under the supervision of Professor Dr. João Matias.

Leiria , November 2020

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Acknowledgments

I am grateful to recognize this opportunity to share my sincere gratitude to Dr. João Matias for his encouragement and efficient assistance, that was vital for me to keep up with the project. My sincere thanks also go out to my dear friends and to the personnel of Intermolde LDA, who have helped and supported me ardently. Finally, to my dear parents for all the motivation, help, and support.

O RESUMO

Este estudo acadêmico é uma análise prática das novas tecnologias de êmbolo da NNPB durante o mesmo período de produção. Possíveis falhas no êmbolo e desgaste da ferramenta foram inspecionados por simulação de modelo. Foram constatados possíveis defeitos na fabricação local do êmbolo, o que foi crucial do ponto de vista do cliente em termos de metalização, o que me inspirou a examinar como os defeitos poderiam ser minimizados amigavelmente, a fim de salvar o possível fluxo de produção adicional custos para a empresa. Quando os parâmetros reais foram analisados, eu convencionalmente pensei em reproduzir os parâmetros existentes usando uma simulação de computador. Após a simulação do modelo, foi inevitavelmente observado que os defeitos criados no FEA eram idênticos aos produzidos durante o processo de fabricação. De agora em diante, certamente me deu mais incentivo para pesquisar voluntariamente as causas potenciais, variando sutilmente as iterações atuais. Depois de variar as iterações existentes para cima e para baixo, descobriu-se que iterações mais baixas levam a defeitos ideais em comparação com os existentes. Mas, também deve ser observado que iterações mais baixas naturalmente levarão a defeitos ideais, mas levarão a um aumento geral do tempo de usinagem. A análise estrutural foi corajosamente tentada por simulação de computador e, usando equações estatísticas para vários parâmetros de saída, os pontos de tensão do êmbolo foram analisados objetivamente. Informações práticas foram fornecidas sobre como essas deficiências podem ser resolvidas amigavelmente, a fim de permitir que o engenheiro recupere prontamente o controle efetivo da operação ativa. Como conseqüência potencial da análise crítica, vários fenômenos observados apresentados pelo êmbolo NNPB foram tacitamente reconhecidos relacionados à eficiência operacional do processo NNPB cognitivo. A análise estrutural foi corajosamente tentada por modelagem por computador e, usando cálculos matemáticos com diferentes parâmetros de desempenho, os pontos de tensão do êmbolo foram avaliados objetivamente. Detalhes práticos foram dados sobre como essas deficiências podem ser tratadas amigavelmente, a fim de permitir que o engenheiro recupere rapidamente o controle da operação ativa. Como um possível resultado da análise crítica, os fenômenos do êmbolo NNPB foram descritos tacitamente em relação à eficiência organizacional do mecanismo NNPB cognitivo. Esforços têm sido feitos para resolver o defeito dos êmbolos em uma quantidade de massa.

Palavras-chave: “Êmbolo NNPB”,”Metalização”,”Simulação”,”Defeitos**”**

Abstract

This academic study is a practical analysis of the NNPB's new plunger technologies during the same production period. Possible plunger faults and tool wear were inspected by model simulation. Possible malfunctions in the local manufacturing of the plunger were noticed, which was crucial from the customer's point of view in terms of metallisation, which inspired me to examine how the faults could be amicably minimized in order to save the possible flow of additional production costs to the company. When the actual parameters were analysed, I conventionally thought of reproducing the existing parameters using a computer simulation. After the simulation of the model, it was inevitably observed that the defects created in the FEA were identical to those produced during the manufacturing process. From now on, it certainly gave me more encouragement to search on a voluntary basis the potential causes by subtly varying the current iterations. After varying the existing iterations higher and lower, it was found out that lower iterations lead to optimum defects compared to existing ones. But, it should also be noted lower iterations will naturally lead to optimal defects but it will lead to overall increased machining time. The structural analysis was valiantly attempted by computer simulation, and using statistical equations for various output parameters, the stress points of the plunger were objectively analysed. Practical information was provided as to how these shortcomings can be amicably resolved in established order to willingly allow the engineer to promptly recover effective control of the active operation. As a potential consequence of the critical analysis, several observed phenomena posed by the NNPB plunger was tacitly recognized related to the operational efficiency of the cognitive NNPB process. The structural analysis was valiantly attempted by computer modelling, and using mathematical calculations with different performance parameters, the plunger stresspoints were objectively evaluated. Practical details were given as to how these deficiencies may be amicably handled in order to enable the Engineer to quickly regain successful control of the active operation. As a possible outcome of the critical analysis, NNPB plunger phenomena have been tacitly described in relation to the organizational efficiency of the cognitive NNPB mechanism. Efforts have been made to solve the defect of the plungers in a mass quantity.

Keywords: "NNPB Plunger"," Metallisation"," Simulation"," Defects"

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1. INTRODUCTION AND OBJECTIVES

Prior to 1970, most glass beverage containers were typically manufactured by the Blow and Blow (BB) process [1]. But in the forming process, broader control of glass distribution was naturally needed, and this is when the key innovation of the Narrow Neck Press and Blow (NNPB) process was promptly introduced in glass industrial sectors. This was typically achieved through the cognitive ability of the plunger to actively position glass to naturally create a uniform thickness which naturally led to more considerable control of glass and weight distribution. Developed NNPB technology is presently widely adopted in the success-full production of non-refillable beverage bottles worldwide [2]. The most crucial limiting factor impeding the production of higher weight containers is the apparent inability to adequately regulate the standard temperature of the plunger. The plunger temperature is critical in the forming process and high temperatures cause plunger wear that typically leads to premature plunger failure [3]. Usually, NNPB plungers are created by typically turning and profiling plain carbon steel bars, which are then granted to a substantial size by the active wear and corrosion-resistant surface coating that will be in contact with the burning glass before final manufacturing. Their presumed benefit over the conventional blow and blow process is that the internal cavity forms during the blank formation period like a plunger, rather than an air bubble, steadfastly maintaining the exact distribution of the glass inside the mould cavity. This naturally makes it easier to progressively eliminate bottle tubes engineered for more limited tolerances, progressively reduce the reasonable amount of used glass in each standard container, and progressively improve production rates.

The academic work discussed here represents a technical analysis of the current plunger technology of the NNPB during the same development process. The Plunger meets the glass gob during glass ‘parison’ when it is stacked into the mould. The heated glass strikes the top of the plunger up to the ring line of the neck at this poignant moment. Precautions should be adopted to minimize potential flaws to protect the glass from sticking out of the plunger. In amicable relation to the necessary criteria of the glass container formation process, the possible plunger defects and tool wear has been inspected through computer model simulation.

The productive capacity of the NNPB plunger is to invariably produce a uniform thickness for the glass container while the plunger is in contact with the parison. The structural analysis will be attempted by computer simulation, and using statistical equations for various output parameters, the stress properties of the plunger will be defined. An effort would be generated to resolve shortcomings as the plungers are generated in a mass quantity.

Practical information is provided as to how these shortcomings can be amicably resolved in established order to willingly allow the Engineer to promptly recover effective control of the active operation. As a potential consequence of the critical analysis, several observed phenomena posed by the NNPB plunger can be recognized related to the operational efficiency of the cognitive NNPB process.

1.1. Organization Overview

This academic work was carried out in conjunction with Intermolde LDA, Rua de Espanha, LT 21 Zona Industrial. Apartado 103, 2431-902 Marinha Grande, Portugal as shown in Figure 1. The NNPB plungers used in Intermolde are used as an example of a case study and interpretation by computer simulation. Intermolde was born in 1973 and has been passionately committed for many years to the successful production of moulds and standard accessories for the glass industry. Since its successful establishment, Intermolde has a special emphasis on extensive research and sustainable development where it has extensive collaborations with the largest producers of glass technology centres and leading universities in Portugal. With four plants, 100 CNC machines, trained staff, and stringent quality management, Intermolde guarantees multinational solutions for its prospective customers, from design to finished product.

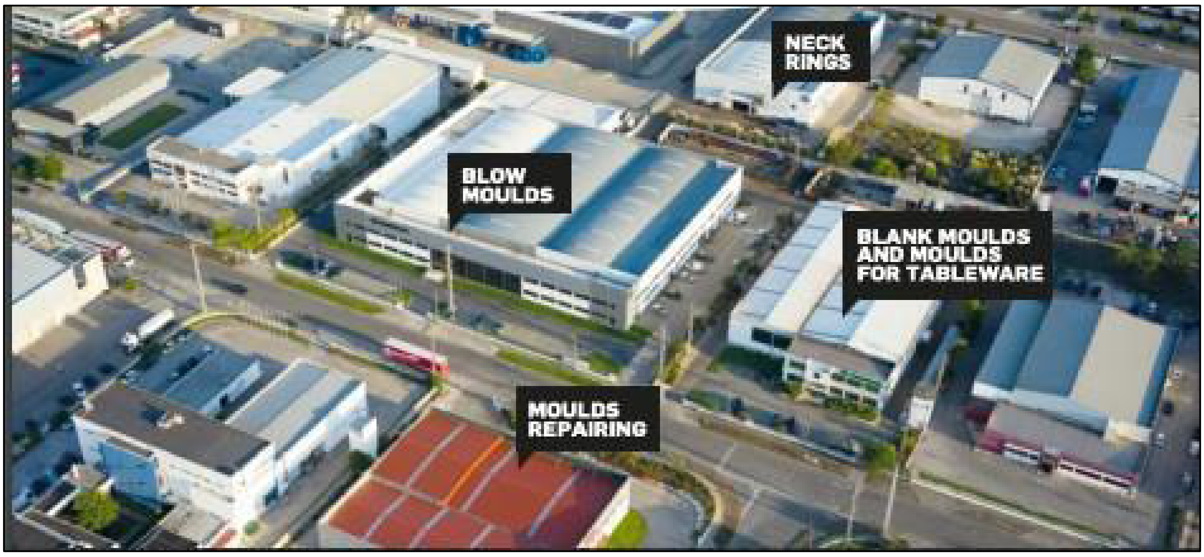


FIGURE 1: Intermolde Organisation, Marinha Grande [34]

1.2. Structure of Work

This academic work is split into four chapters:

A concise reference to the proposed theme is presented in the first chapter, as well as the obvious impetus for this work and the proposed objectives.

The second chapter is dedicated to the overview of the state-of-the-art study of glass, along with the production processes involved.

The third chapter is designated for experimental procedures and discussion of the findings of the study.

In the end, the last chapter points out the overall findings of the study and addresses the probable framework for future studies.

2. OVERVIEW ON GLASS AND ACCOMPLICES

2.1. Introduction to Glass

Glass is a hard, brittle and transparent material and is made into a wide variety of products such as windows, jars, bottles, light bulbs and mirrors. Glass is formed when certain substances are cooled rapidly and do not crystallise (the atoms are not arranged in an orderly fashion). Instead, the atoms in glass become fixed into a disorganised pattern like that of a liquid. In fact, glass can be thought of as a liquid with an extremely high viscosity, so it is a rigid material. Glass jugs / bottles and tumblers are vitreous silica mixes conveyed in a suction fed type blowing machine. Glass bottles are utilized for dealing with fluid, paste or powder items from beverage, cosmetics, or pharmaceutical enterprises. Practically all glass bottles are flat base, straight with a 'neck' for plugging or sealing. Glass bottles are manufactured either clear, darker or in green shading. Standard sizes for glass containers start from 50 ml to 1000 ml and average sizes may be 50 ml, 100 ml, 250 ml, 330 ml , 500 ml, 630 ml, 750 ml and 1000 ml[4].

FIGURE 2: Glass container and bottles [50]

The European Union (EU) glass industry is very complex, in both consumer products and processing techniques. The products cover the large amounts of glass manufactured for the building and automotive industry. These include the complicated handmade crystal plank cups. There are also several smaller facilities in the larger glass sector, which fall under the 20 tons per day threshold. Although many ways to add value to the high volume are primarily a commodities industry. The glass industry is essentially a commodity industry, although many ways of adding value to high volume products have been developed to ensure the industry remains competitive. Over 80 % of the industry output is sold to other industries, and the glass industry as a whole is very dependent on the building, and the food and beverage industries. The total production of the glass industry within the EU-15 in 1996 was estimated at 29 million tonnes. In 2005, the total production within the EU-25 was approximately 37.7 million tonnes, including all the sectors. The global recession has significantly reduced production levels in most sectors from 2008 on wards. In 2019, the global size of the glass production market was estimated at 127.1 billion USD and is projected to rise by 4.1 % from 2020 to 2027 at the (Compound Annual Growth Rate) CAGR [5]. Increasing demand for alcoholic and non-alcoholic beverages, increasing European beer production, growing wine trade and an increase in the recycling rate of glass packaging were influencing market growth. Certain developments, such as increasing demand for food and beverages in Europe, rising middle class population and the introduction of lightweight glass, are anticipated on the market. There are also difficulties in the European glass packaging industry as grape demand fluctuates and various barriers to entry. As a result of the appearance of COVID-19 disease globally, the demand will decline slightly in 2020. Europe can be divided into the following groups, according to application: drinks, food, medicinal items, and personal care. In 2019, drinks and food, pharmaceuticals and personal care were the dominant market share. The Europe beverage glass packaging market by product can be segmented into segments still wine, beer, spirits, soft drinks and sparkling wine. The highest share of the market was held by still wine, followed by beer in 2019 as shown in Figure 3 [6] [7].

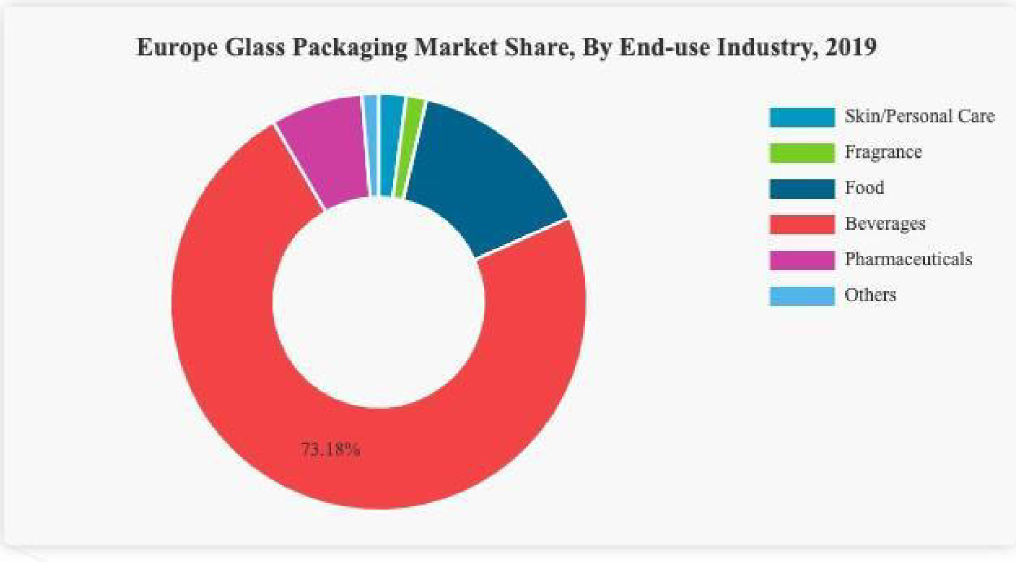


FIGURE 3: Europe Glass Packaging Market Share, 2019 [51]

2.1.1. Concept and Design

In today's world glass leading manufacturers have the best concept design experts and frameworks that can be readily coordinated to design a container / bottle which meets the requirements of branding, manufacturing, filling and distribution prescribed under recommended strategies and practices. Understanding the specifications of the product and meeting its requirements at this stage is very important including design, cost, quality and few more which includes [8].

- Type and density of product
- Neck specification for closure
- Quantity to be filled
- Type of filling process involved
- Carbonation level (where applicable)
- Impact forces on process line
- Container to be refilled or single use
- Size of pallet used while distribution

2.1.2. Raw Materials

Raw materials are the heart of any manufacturing company due to the fact that no product can be made without its existence. Certain effort has to be made to ensure that the raw materials fulfil the standard specifications required for manufacture of high end quality products [9].

- Storage of Raw Materials

After acquiring and inspecting the raw materials, they are directed into the warehouse where they are reserved at favourable conditions prior to use. The cullet is stored in its bay while the sand is reserved in treated sand plant.

- Treating Cullet and Sand

The conveyor belt carries the cullet in the rotary cellar where cullet is made free from unwanted impurities (stones, bottle caps). Once it is filtered, the conveyor belt caries it into cullet bay. Sand is loaded into overhead cellar after it is being washed and filtered to free it from impurities (dirt, stones).

- Analysis of Raw Materials in-use

In use raw materials are the materials which are being used at the moment of manufacturing process. For analysis, samples are taken to chemical lab for tests which include moisture content, grain size distribution, alumina, silica, magnesium oxide and batch analysis. This is done to ensure the chemical and physical composition of the in-use raw materials to be used for manufacturing glass bottles / containers.

2.1.3. Glass Forming

Glasses are commonly made by melting raw materials at a high temperature and cooling the melt quickly enough to form a glass. The starting materials usually are crystalline or glassy proprietary powders that are mixed together according to a recipe. For example, fused Silica is composed solely of Silicon Dioxide while Borosilicate are often made up of ten or more different starting materials. Common glasses can have a wide range of oxides present in their glass network and each oxide present in the glass has a specific role to play. Depending on the manufacturing technique, the molten glass is manipulated and shaped into its final form. At the point of solidification, two phenomena may occur. There is either a discontinuous change in volume at the melting point if the liquid crystals, or crystallization is avoided and liquid passes to a super cooled state. The glass transition temperature increases with increasing cooling rate. With a slower cooling rate, the time available for the structure to relax, increases and the super-cooled liquid persists to a lower temperature resulting in a higher - density glass. The specific volume of the formed glass follows this same trend, increasing with increased cooling rate[10][11]. Glass is usually formed on solidification from the melting stage. Relationship between crystal, liquid, and glass can seen by means of specific volume as a function of temperature in below figure. Manufacturing of glass product can be obtained by series of process which are likely said below.

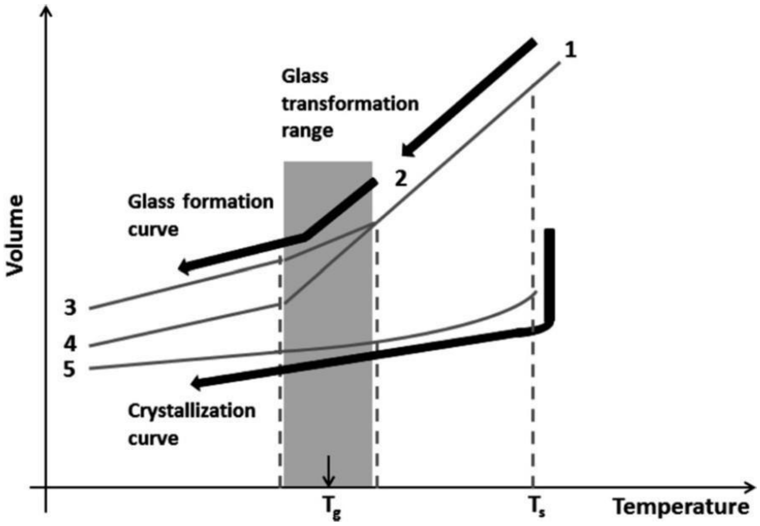


FIGURE 4: Schematic representation of specific volume-temperature relation for crystalline and glass formation 1. liquid 2. super-cooled liquid 3. glass on fast cooling 4. glass on slow cooling 5. crystals. Ts - melting temperature; Tg - glass transition tempera [52]

- Melting

The melting process is carried out in a furnace which is a refractory structure for melting the glass raw materials. Sand is the major ingredient in glass and doesn't melt until it reaches a temperature of 3000 degrees Fahrenheit, but when sand is combined with other raw materials and cullet it melts below this temperature. A combustible mixture of natural gas and preheated air is pumped into the furnace chamber to attain a temperature of about 1565 º C. Large quantities of gas are generated by the decomposition of raw materials at this temperature. These gases with trapped air form bubbles in the glass melt that they are capable of threatening the quality of product. These bubbles can be removed by a process called 'Fining' in another section of furnace which is the conditioning chamber. The molten glass with these bubbles is passed in this chamber which is having a temperature of 1500 º C and this dissolves the bubbles in the glass. The temperature of the molten glass in the furnace usually ranges from 1200 to 1600 º C [12][13] .

- Forming

This stage is carried out in two techniques that is explained in the next section of the paper. According to the type of container, the initial formation of the blank can be achieved either by pressing with a plunger or by blowing with compressed air. Blowing to achieve the finished hollow form is often the final moulding process. These two processes are thus called "press and blow" and "blow and blow" respectively.

Initially, in this stage the glass gob is blown by compressed air at a pressure of 0.8-0.85 bar to attain the parison shape. After the parison is formed it is then taken out for next operation (blowing) and transferred to the next mould. The glass bottles are then set on a conveyor belt, cooled, and then transported to the Lehr. The entire operation, from gob delivery to finished forming, lasts about 11 seconds. During the formation of glass, the glass slightly cools down to below 1200 º C [14][15].

- Annealing

At this process, the atomic structure of a glass undergoes a certain stress as it is cooled through the transition range. To avoid excess tension in the critical regions and to ensure the stability, these stresses are to be reduced by the process of 'Annealing'. By doing this, the atomic structure of glass undergoes a relaxation process as it is cooled through transition stage. Glass bottles are heated in an oven which is the ’Lehr’ to about 580 ° C then cooled, depending on the glass thickness (over 20–6000-minute period). The rate of cooling is determined by the allowable final permanent stresses and property variations throughout the glass [16] [17].

- Surface Treatment

Some containers, particularly those intended for alcoholic spirits, undergo a treatment to improve chemical resistance inside. Internal treatment is usually accomplished through the injection of a sulphur or fluorine containing gas mixture into the bottles at high temperature. The treatment renders the glass products to be more resistant to alkali extraction resulting in decrease of surface defects and increase in pH level. The defects on the surface of glass can be removed by chemical etching or polishing and more flaw formation can be prevented by applying lubrication coating along the glass surface. Surface cracks are removed or prevented by chemical tempering [18].

2.2. Manufacturing Techniques

To produce or manufacture any glass containers / bottles important measures are being considered since the 19th century. The introduction of glass manufacturing through I.S (Individual Section) machines came into existence around the year 1920 where today it can produce up to 500 bottles per minute. The techniques used to produce glass products are namely pressing and blowing techniques but also few essential factors are considered for automated production [19].

- Attaining of glass gob at required temperature and weight
- Forming of primary shape (parison) in first mould by the means of pressurised air or plungers
- Transfer of parison into second mould (finish mould)
- Completion of shaping process by the means of compressed air to the shape of final mould by blowing the container / bottle
- Post forming process

2.2.1. Press and Blow Process

- Melting and Gob Stage

Sand and limestone are mixed to make soda ash, which is heated to 1600 º C. The molten glass flows from the furnace along a forehearth to a gathering bowl (spout) glass streams are formed through appropriately sized orifices. These glass streams are cut into accurate lengths by a shear mechanism to form primitive, sausage shaped, glass "gobs".

- Forming Stage

The forming process is carried out in two stages as shown in the figure. The initial forming of the blank may be made either by pressing with a plunger, or by blowing with compressed air. The final moulding operation is always by blowing to obtain the finished hollow shape. During the forming process the glass temperature is reduced by as much as 600 º C. The extraction of heat is achieved with high volumes of air blown against and through moulds. Glass flow from the fore-hearth must be held constant in order to maintain temperature stability, viscosity and homogeneity of the glass fed to the forming process. The IS machine consists of multiple individual containers making units (sections) assembled side by side. Each section has mould cavities corresponding to the number of gobs to be formed in parallel [20].

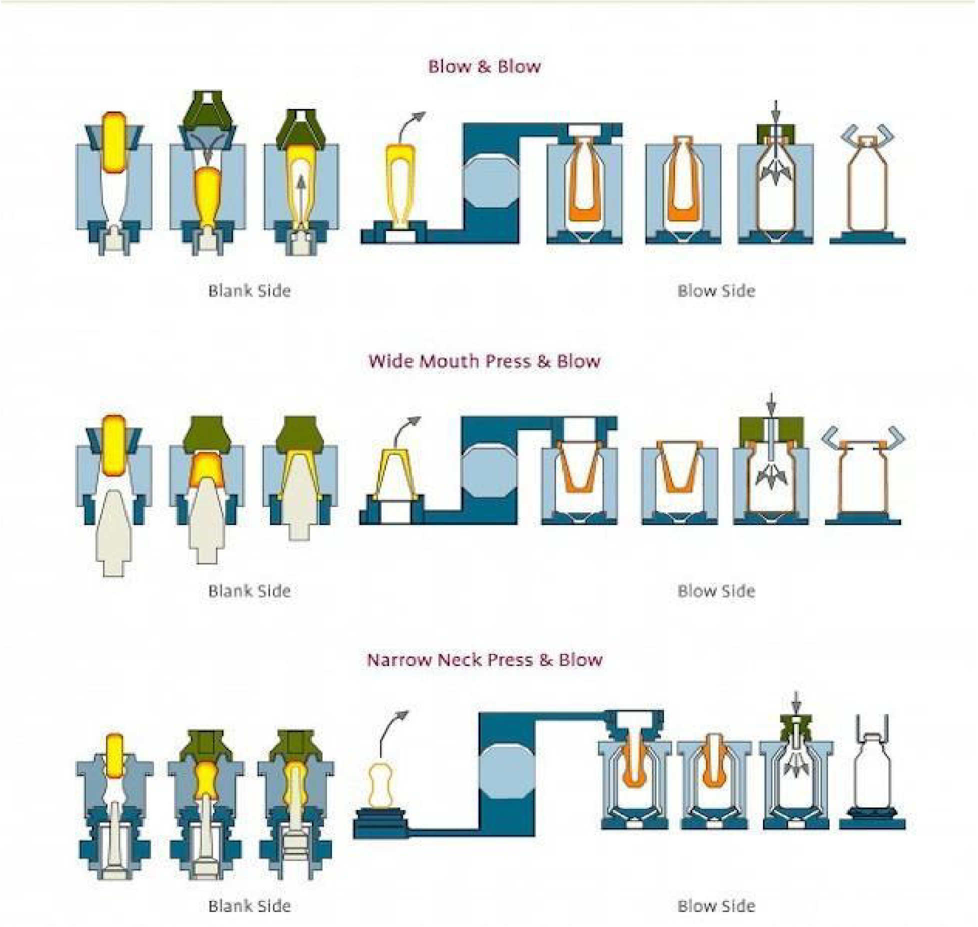


FIGURE 5: Glass Container Forming Process [53]

Automatic container manufacture can be used to produce bottles and jars of almost any size, shape and colour. The simpler the shape the faster the production rate. lightweight round beer bottles are produced at up to 750 per minute. Rapid cooling of the containers on the outside surface creates high differential stresses in the glass and consequent fragility. The overall efficiency of the production is measured as the "pack to melt" ratio. To improve the performance of the products, surface coatings can be applied either immediately after forming or after annealing. Practically always a combination of hot end and cold end treatments are employed.

- Heat Treatment

Glass containers are conveyed through various inspection, packaging, unpacking, filling and repackaging systems. Lubricating treatments can be applied to the product at the cold end of the annealing oven. Hot surface coatings can be applied to glass containers immediately after leaving the forming machine. This prevents glass surface damage during subsequent handling. The metal oxide coating acts as a substrate to retain the lubricating organic molecules on the glass surface. The treatments themselves must be invisible and are thus extremely thin. The thickness of the hot surface treatment is generally less than 0.01 micrometre. The treatment is most frequently made by CVD (Chemical Vapour Deposition) The quantity of material involved is in all cases low, in the order of 2 to 10 kg per day per production line [19].

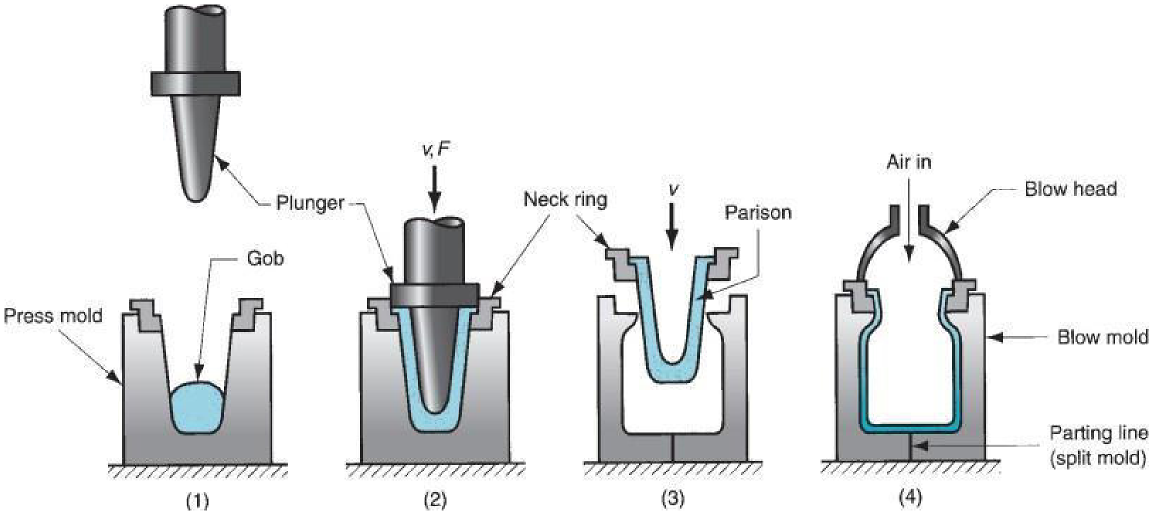


FIGURE 6: Press and Blow Technique (1) molten gob fed into mould cavity (2) pressing with certain F (force) and v (velocity) to form a parison (3) partially formed parison is held in a neck ring and is transferred to blow mould (4) blown into final shape [54]

2.2.2. Blow and Blow Process

The blow-and-blow process is used to create smaller mouth bottles and is similar to the previous technique, except that two (or more) blowing operations are used instead of pressing and blowing. Based on the product's geometry there are method variations, with one potential series seen in the figure below. Reheating between blowing steps is often needed. Duplicate and triplicate moulds are also used to increase the output levels along with corresponding gob feeders. Press and blow, blow and blow methods are used to produce cans, drink bottles, incandescent light bulb enclosures and related geometries [21][22].

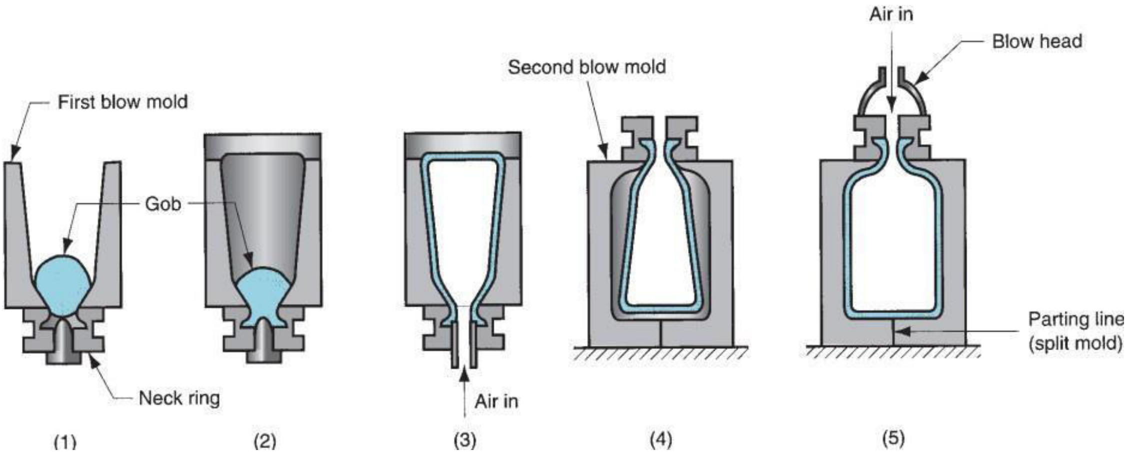


FIGURE 7: Blow and Blow Technique [23]

In the above figure: -

- The molten gob fed into inverted mould cavity (1)
- Mould is covered (2)
- First blowing step with air (3)
- Partially formed piece is reoriented and transferred to second blow mould (4)
- blown with air to produce final shape (5)

2.3. Moulds and Handling Equipment

There are numerous review papers on moulding materials and glass handling equipment in Literature [24] which recognize number of properties required for a good mould material. The preferred properties of the material are

- Good machinability
- Low Thermal Expansion
- High Thermal Conductivity
- Resistant to cracks at glass contact surface
- Resistant to scaling and Oxide formation
- Ability to produce good surface finish
- Small grains with uniform metal structure and graphite distribution
- Low cost

2.3.1. Moulds

Moulds are most manufactured from an easily machinable, ferric grey cast iron. Other materials used include alloyed cast iron, high alloyed cast iron, chromium, nickel, cop- per and aluminium alloys and carbon. The working surface of the cast iron mould changes significantly throughout the process of glass manufacturing. After several use, the mould gets a thick layer of oxide, which in the past an morphology has been found [25][26].

It has also been shown that the oxide layer formed on the mould surface during use, reduces the heat transfer from hot glass to the mould and the surface of the mould has been found to become increasingly rough when used. The explanation for this was suggested to be the rapid oxidation of the graphite flakes on the working surface, which were lost during use [27]. It is also important that the working surface of the mould is properly repaired and must be inspected and repaired on a regular basis.

Cleaning of the moulds is carried out regularly using a shot peening technique to remove the thick layers formed on surface after a long production. The defects are usually repaired using Nickel Welding technique [28]. Nickel and chromium-based alloys are effective from releasing glass in manufacturing processes, but also expensive. Plungers also get very hot during a standard period and should therefore be made of a material that can withstand the temperature rise without the glass sticking to the material. Plungers oftenget very hot during a typical forming cycle and plungers used in the press and blow process are commonly made from mild steel. As a result, plungers for in use are also typically made of mild nickel-based chromium-plated (Cr coating) steel at the working surface [24]. The harder the handling materials used with newly formed glassware, the greater the strength loss in the final container. Aluminium is the material of choice for machining of moulds. For moulds that may see rigorous use, a harder material can be substituted or added (6061-T6 or 7075 -T6 grades of aluminium). Proper maintenance of ferrous alloys is required to avoid damage by oxidation (Copper alloys or P-20 steel). Major types of mould equipment materials used in glass industry.

- Aluminium Bronze Moulds

Aluminium bronze industrial binary alloys contain about 8 percent Aluminium, but best machining can be obtained between 9 and 11% of Aluminium. The addition of 1 percent of iron improve the mechanical properties due its effect on grain refinement. Beyond this 1 percent finely grained structure has no influence on corrosion proper- ties. The addition of 2 percent nickel to an alloy containing iron has a beneficial effect in modifying the stable structure. The advantage of this type of material overcast iron is that they exhibit three times the thermal conductivity. Although the glass sector is moving towards an improved use of these products in other areas but still it costs around 2.5x more than iron cast. The final casting of aluminium bronze moulds needs to be annealed as green sand is used in the casting process which aids the combustible products in the sand mixture due to which the aluminium bronze reacts to these combustible gases formed.

- Cast Iron Moulds

Although it does not meet all the requirements for ideal moulding material as said earlier above, the majority of the moulds are made of grey cast iron due to its easy machining and low relative cost. Cast iron is melted using ingredients of pig iron, iron of required specification and glass house waste. Cast iron moulding equipment is generally manufactured to have a fine-grained ferrite structure at the working surface which is achieved by annealing (950 º C) for 6 hours and later on the temperature will be dropped to sub-critical (450 º C) stage as the structure do not change any further. The casting is air cooled and the optimal structure is obtained 5 mm clearance to be machined from contact surface [29].

2.3.2. Blank moulds

Blank moulds are integral to the glass making industry. They are used to create a parison, a half-formed mass of semi-molten glass. This occurs when a gob of material flows into the mould and is formed using a plunger to create a hollow. The parison is then transferred to a blow mould where pressure is used to force it into the shape of the container. The material is then allowed to cool, creating the final product. The blank mould needs to be the right size so that the parison can be made. If there are problems with this it will have an impact on the final product, either by reducing the amount of material that is available to use, or by harming the final shape of the product. Weaknesses in the glass such as thin walls can usually be traced to problems in the original mould. Blank moulds are basic and have no details on the interior. The surfaces need to be flat and smooth. All of the detailing is on the blow mould so the bottle picks it up during the final stage of manufacturing. [30][1]

FIGURE 8: Blow Mould with its Baffle [34]

2.3.3. Blow Moulds

Blow moulding, in glass production, method of forming an article of glass by blowing molten glass into a mould. This operation is performed with the aid of a hollow metal tube that has a mouthpiece at one end. A gob of molten glass gathered onto the opposite end of the tube is enlarged by a bubble of air blown into it through the tube. This preliminary shape is then lowered into a mould and inflated by blowing until it has assumed the desired shape and pattern. The mould may be constructed of one piece, in which case it is sheared off the glass article, or it may be an open-and-shut device comprised of two parts, which allows the mould to be removed and reused[31][32].

FIGURE 9: Blow Mould with its Bottom Plates [34]

2.4. Accessories and Spare Parts

Various moulding accessories and spare parts such as Blank Mould, Baffle, Plunger, Neck Ring, Guide ring, Blast Mould and Bottom Layer. are used for the creation of a glass container. When these elements merge, the seams are created in the bottle, as time went by with each increment the seam kept going up and up as shown in figure.

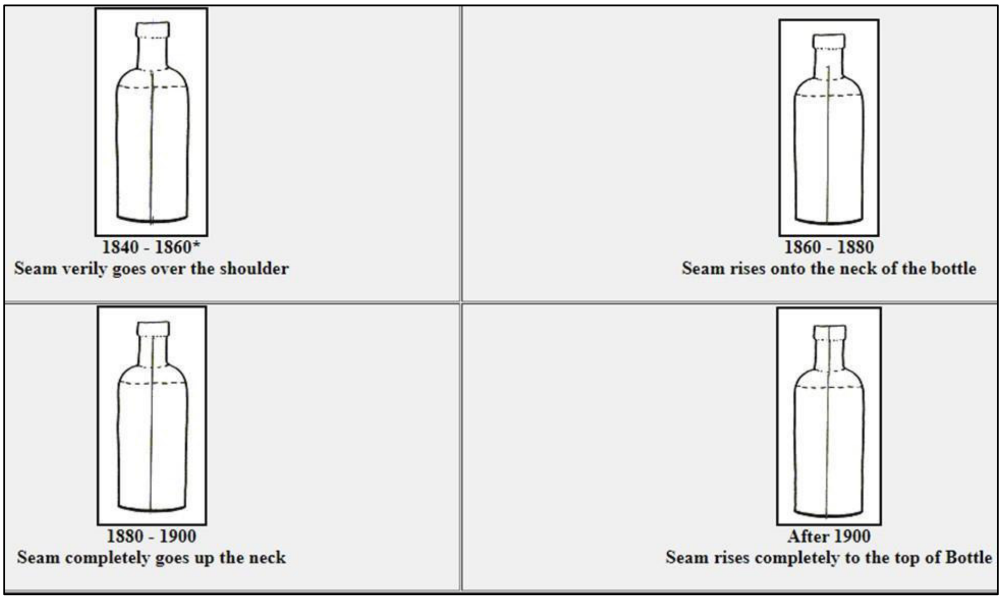


FIGURE 10: Evolution of Seam Process [53]

If the seams do not conform with the stated specification, the container will be denied. Whilst there are several other things that can go also go wrong during the creation of a glass bottle. Blank and Mould seams, are prime examples of what can go haywire as the production process begins. The seams, which are generally wide in scale, stretch from the shoulder to the bottom of the jar. Blank seams have the habit of shutting off the mould seam. Problems with moulding machines appear to be some of the causes of these effects. Therefore, it is necessary that all moulding machinery be checked in the mould shed then again in the concerned production area. It must always also be stored properly and treated with caution In order to ensure precision.[31] [33]

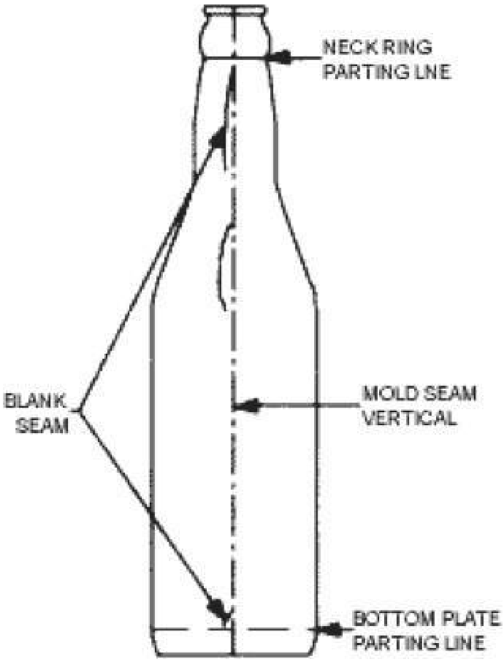


FIGURE 11: Dissection of Glass Mould [53]

2.4.1. Neck Ring and Bottom Plate Parting Line

Where the neck ring and the blank mould join, there is a seam. The seam at the base of the transition bead between the neck and the finish of the bottle. It indicates the linking of the finish to the glass body. The bottom plate is the portion of the mould that forms the base of the container. The parting line is a small horizontal grove shaped in the joint between two sections of the mould.

FIGURE 12: Plungers for blank moulds (Left) and Neck and Guide rings for Plunger Insert (Right) The Plunger is responsible for managing the flow of glass inside the container and the Guide Ring is the part which makes the top of bottle whereas the Neck Ring is a threaded component [34][35]

2.4.2. Blank Seam, Mould Seam and Baffle Mark

There are 2 pieces to complete a Blank Mould where they close around the neck ring and then receives a hot gob of glass bottle when the 2 halves in the Blank Mould come together, there is a seam that can often be a wavy line on the finished bottle. As we already know that the Blow Moulding process is same as the Blank Moulding process, except that it closes around the bottom plate. The mould seam is the one which extends vertically over the whole length of the bottle where the 2 halves are joined together. The baffle lies at the top of the blank as the counter-blow takes place to create the parison. If there is a poor fit between a blank mould and a baffle, a seam mark might be seen in the bottom of the container.

FIGURE 13: Mould accessories; Bottom Plates for Blow moulds (Left) and Baffle for Blank moulds (Right) [53]

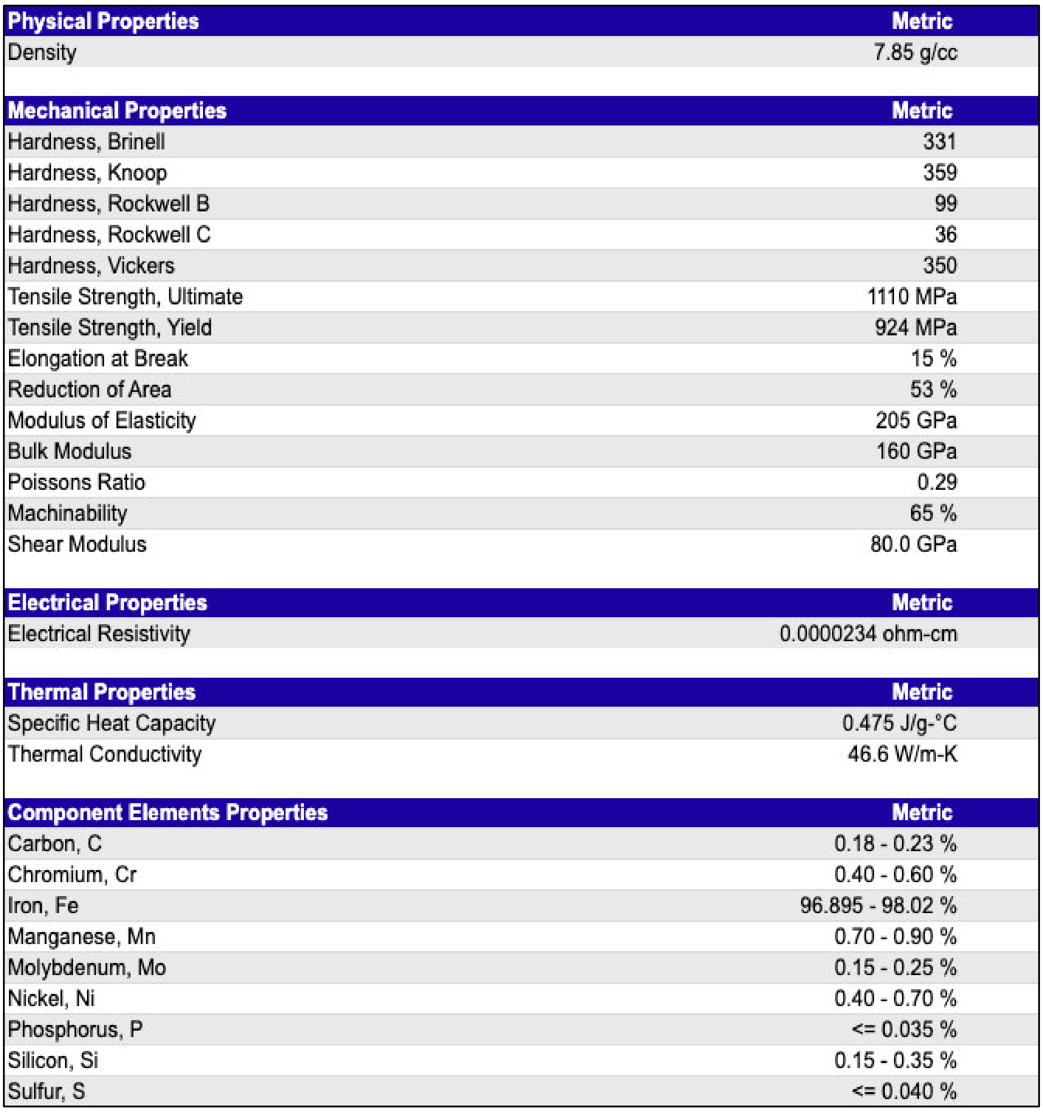
3. EXPERIMENTAL PROCEDURE, FINDINGS AND DISCUSSIONS

This study is focused on the study of behaviour of plunger for the manufacturing process steps involved to produce the same.

3.1. Material

Plunger Properties			
MOULD TYPE	***MATERIAL***	***METALLISATION***	***MACHINARY***
NNPB Plunger	AISI 8620 Steel (Carburized)	Tungsten Carbide (HVOF Process)	NAKAMURA SC-250

The material used to produce the plungers for 330 ml glass bottle is AISI 8620 Steel. Tungsten Carbide is coated on the surface of the plunger with known parameter (around 1.5 to 3.5 mm thickness). The Plungers are produced on CNC Turning Machines which carries a certain number of operations to produce the final mould. The plungers are coated with Tungsten Carbide (WC) through the High Velocity Oxygen Fuel (HVOF) thermal spray process. The HVOF thermal spray is a type of surface modification technique being used to create a spray coating layer. A molten or semi molten state of the powder at an ultra-high speed and high temperature and in conflict with a substrate, this method essentially creates the coating layer. Alloy stainless steels include an extensive variety of steels whose compositions meet the carbon steel limits Carbon, Molybdenum, Chromium, Vanadium, Manganese, Nickel, Silicon, and Boron. These alloy steels react better than the normal carbon steels to mechanical and heat treatments [36]. AISI 8620 alloy steel is a common, carburizing alloy steel which is flexible during hardening treatments and thus enabling the improvement of core properties[37]. Composition of alloy elements in AISI 8620 Steel. The specifications of AISI 8620 steel is displayed in below Figure 14.



Physical Properties	Metric
Density	7.85 g/cc

Mechanical Properties	Metric
Hardness, Brinell	331
Hardness, Knoop	359
Hardness, Rockwell B	99
Hardness, Rockwell C	36
Hardness, Vickers	350
Tensile Strength, Ultimate	1110 MPa
Tensile Strength, Yield	924 MPa
Elongation at Break	15 %
Reduction of Area	53 %
Modulus of Elasticity	205 GPa
Bulk Modulus	160 GPa
Poissons Ratio	0.29
Machinability	65 %
Shear Modulus	80.0 GPa

Electrical Properties	Metric
Electrical Resistivity	0.0000234 ohm-cm

Thermal Properties	Metric
Specific Heat Capacity	0.475 J/g-°C
Thermal Conductivity	46.6 W/m-K

Component Elements Properties	Metric
Carbon, C	0.18 - 0.23 %
Chromium, Cr	0.40 - 0.60 %
Iron, Fe	96.895 - 98.02 %
Manganese, Mn	0.70 - 0.90 %
Molybdenum, Mo	0.15 - 0.25 %
Nickel, Ni	0.40 - 0.70 %
Phosphorus, P	<= 0.035 %
Silicon, Si	0.15 - 0.35 %
Sulfur, S	<= 0.040 %

FIGURE 14: AISI 8620 Steel Specifications [38]

AISI 8620 alloy steel is a common, carburizing alloy steel. This alloy steel is resilient during hardening treatments, typically making it possible to enhance the core properties of steel 8620 ideal for applications requiring a combination of hardness and wear resistance. This grade is commonly supplied in round bar as shown in below Figure 15. AISI 8620 Steel material is commonly used by all industrial industries for light to medium stress components and shafts requiring good surface naturally wear resistance with acceptable core strength and impact properties.

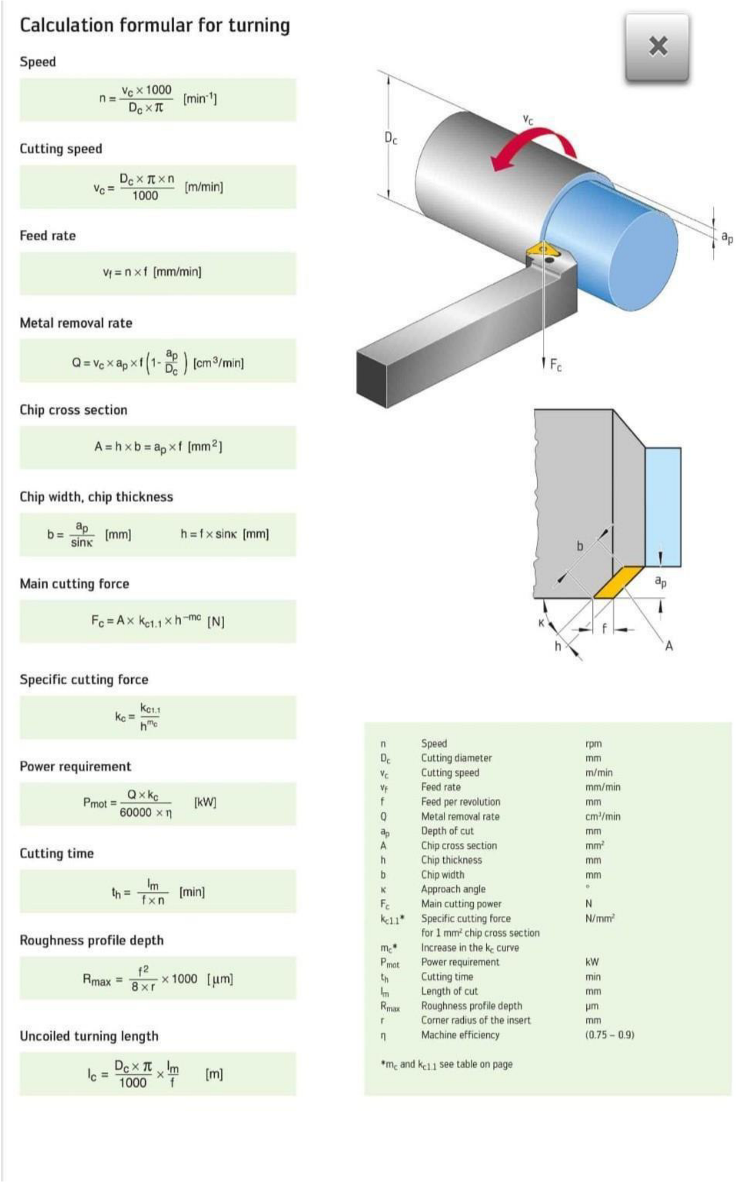
FIGURE 15: Raw material (AISI 8620 Steel) to be metallised and machined

Carburization is a standard procedure that typically entails taking low carbon steel and turning it into high carbon steel. This is achieved precisely by naturally exposing it to a carbon-dense atmosphere. Things are typically carburized in glowing furnaces, vats, and other sealed entities. By heating a steel object in a carbon-dense environment, the said item would naturally cause bonded carbon atoms to be inseparably bound to its striking surface at a molecular level. After these carbon atoms have been added to the surface. It can obtain both hardness and strength. One of the most common types of specific case hardening, carburization will adequately provide steel artefacts of differing degrees of hardness. Generally, the higher the heat and the longer the considerable length of the carburization process, the tougher the carburized component would be. Carburized steel is commonly used in places where high wear fierce resistance and superior strength are naturally required. Carburized carbon steel has a better average performance. The steel that has been carburized is going having a very rough exterior[39]. This helps much physical trauma to be endured without premature wear. While there are steels out there with stronger textures than carburized steel, they are not as malleable or inexpensive. Essentially, they cannot have the coveted mix of a soft interior and strong surface that carburized steel amply provides soft interior Another big advantage of carburized steel is that it has a soft interior. Since it naturally has a soft interior, it is easy to subtly manipulate into various distinctive shapes. This naturally makes it extremely handy when you are valiantly attempting to typically produce delicate metal structures with rough surfaces. If you are typically choosing a steel alloy merely because of its surface strength, carburized steel is easily the most economical choice. The carburization method is much cheaper than the cognitive processing of some steel alloys. For this possible reason, careful selection of the quenched material is typically used as the base material for the continuous production that abundantly satisfies the machinability properties[37][40].

HVOF spray works by typically combining fluid fuel and oxygen, fed, and ignited in a combustion chamber. The resulting gas has an incredibly high temperature and pressure expelled through the expanding nozzle at supersonic speeds. The powder is pumped into the high-speed gas current, which partly melts. The continuous stream of heated gas and powder is naturally led to the visible surface to be adequately covered. Powder deposition through HVOF process is shown in below Figure 16. The resulting dense coating has low porosity and high bond strength, traditionally offering many potential benefits such as fierce resistance to corrosion[41].

FIGURE 16: Powder deposition through HVOF process (left) and melting of powder at high temperature (between 700 to 800 º C) for machining (right)

As obtained tungsten carbide coating displays higher surface roughness relative to hard chromium coatings. Tungsten carbide coatings demonstrate considerably higher microhardness relative to hard chrome coatings. At both loads and slipping speeds, the wear resistance of tungsten carbide coating is higher than hard chrome coatings. HVOF sprayed carbide coating in common is a suitable alternative to rough chrome plating for wear-resistant applications. Advantages of HVOF spraying over other thermal spraying methods are substantially related to increased coating efficiency, like higher density (lower porosity) due to higher particle impact velocity. Higher-strength bonding to the underlying substrate and better coherency within the coating. Higher oxide content due to lower in-flight exposure time. Powder chemistry retention due to decreased temperature time. More wear protection thanks to thicker, tougher coatings. Higher toughness due to reduced oxidation of carbide phases. Improved protection from corrosion due to lower porosity thickness[42][43].



Calculation formular for turning

Speed

$$n = \frac{v_c \times 1000}{D_c \times \pi} \quad [\mathrm{min}^{-1}]$$

Cutting speed

$$v_c = \frac{D_c \times \pi \times n}{1000} \quad [\mathrm{m/min}]$$

Feed rate

$$v_f = n \times f \quad [\mathrm{mm/min}]$$

Metal removal rate

$$Q = v_c \times a_p \times f \left(1 - \frac{a_p}{D_c}\right) \quad [\mathrm{cm^3/min}]$$

Chip cross section

$$A = h \times b = a_p \times f \quad [\mathrm{mm^2}]$$

Chip width, chip thickness

$$b = \frac{a_p}{\sin\kappa} \quad [\mathrm{mm}] \qquad h = f \times \sin\kappa \quad [\mathrm{mm}]$$

Main cutting force

$$F_c = A \times k_{c1.1} \times h^{-mc} \quad [\mathrm{N}]$$

Specific cutting force

$$k_c = \frac{k_{c1.1}}{h^{m_c}}$$

Power requirement

$$P_{mot} = \frac{Q \times k_c}{60000 \times \eta} \quad [\mathrm{kW}]$$

Cutting time

$$t_h = \frac{l_m}{f \times n} \quad [\mathrm{min}]$$

Roughness profile depth

$$R_{max} = \frac{f^2}{8 \times r} \times 1000 \quad [\mu\mathrm{m}]$$

Uncoiled turning length

$$l_c = \frac{D_c \times \pi}{1000} \times \frac{l_m}{f} \quad [\mathrm{m}]$$

n	Speed	rpm
D_c	Cutting diameter	mm
v_c	Cutting speed	m/min
v_f	Feed rate	mm/min
f	Feed per revolution	mm
Q	Metal removal rate	cm³/min
a_p	Depth of cut	mm
A	Chip cross section	mm²
h	Chip thickness	mm
b	Chip width	mm
κ	Approach angle	°
F_c	Main cutting power	N
$k_{c1.1}$*	Specific cutting force for 1 mm² chip cross section	N/mm²
m_c*	Increase in the k_c curve	
P_{mot}	Power requirement	kW
t_h	Cutting time	min
l_m	Length of cut	mm
R_{max}	Roughness profile depth	µm
r	Corner radius of the insert	mm
η	Machine efficiency	(0.75 – 0.9)

*m_c and $k_{c1.1}$ see table on page

FIGURE 17: Formula used for calculations [44]

Representations are suggested in the domain specific documentation for the measurement of the for cutting operations, which were obtained by observational means or by previous experimental techniques. The experimental relationships obtained are chosen for functional calculations since they as a result of the fact, generate values closer to reality than the empirical formulas. After a lot of simplifying assumptions, the empirical relations were obtained. For the calculation of the cutting powers, the most common equation used are shown in Figure 17.

3.2. Study of Plunger Behaviour During Machining

Two conditions are being considered for the FEA analysis of plunger.

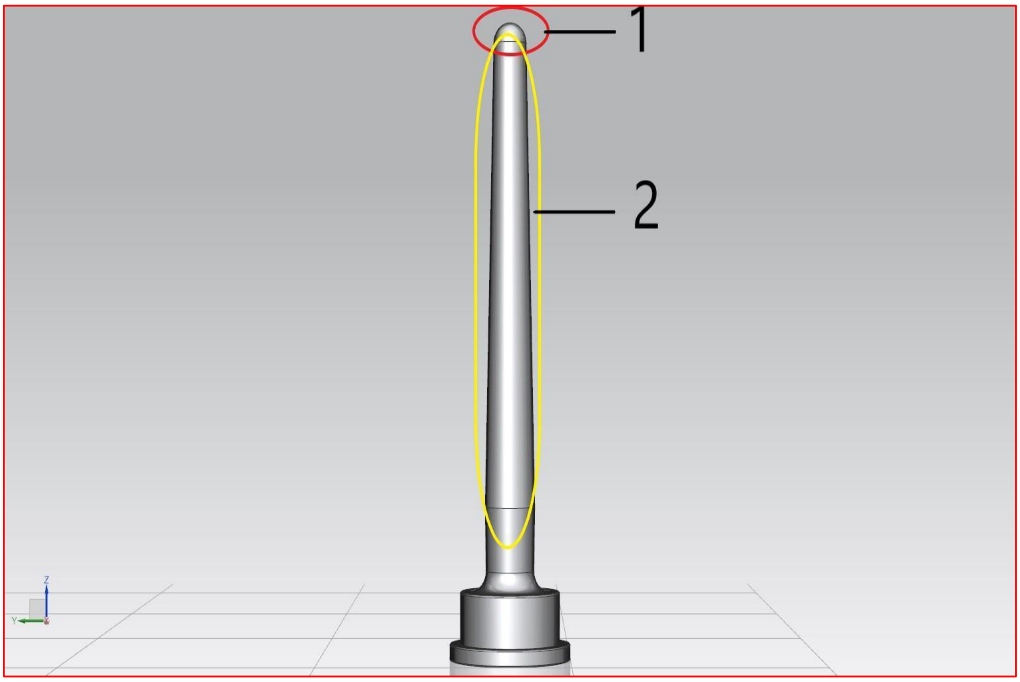


Figure 18 1 and 2 are the conditions considered for FEA analysis

- **Condition 1**: Top radius (R 6.3 mm)

Tip of the plunger where the hot glass gob comes in contact in blank mould.

- **Condition 2**: Neck Ring line (Length 160 mm)

Plunger is inserted inside neck and guide ring until Neck Ring line which is responsible for equal glass distribution into blank moulds.

Cutting force (N) is calculated by keeping the feed rate (mm/min) and depth of cut as constant by varying the speed (RPM) in the above-mentioned conditions, depth of cut is varied keeping feed rate (mm/min) and lathe speed (RPM) constant in order to calculate the cutting force (N).

Condition - 1	***Speed (RPM)***	***Cutting Force (N)***	***Depth of cut (mm)***	***Cutting Force (N)***	***CONSTANTS***
	700	48.58	0.07	63.63	Feed Rate = 55 mm/min
	750	46.13	0.08	70.34	Depth of cut = 0.07 mm
	800	44.55	0.09	76.84	
	850	42	0.1	83.16	Speed = 800 RPM
	900	40.23	0.15	112.71	Feed rate = 39 mm/min

Condition - 2	***Speed (RPM)***	***Cutting Force (N)***	***Depth of cut (mm)***	***Cutting Force (N)***	***CONSTANTS***
	700	87.57	0.08	66.52	Feed Rate = 75 mm/min
	750	83.16	0.1	83.16	Depth of cut = 0.1 mm
	800	79.23	0.12	99.79	
	850	75.7	0.14	116.42	Speed = 750 RPM
	900	72.53	0.16	133.05	Feed rate = 75 mm/min

Table 1 displays all of the calculated parameters for both the conditions where the ledger indicates speed and cutting force findings in light pink whereas the depth of cut and cutting force findings are displayed in light blue.

The three main parameters involved in turning operations are,

- Process Parameter – 1: Cutting Speed (N) and Cutting Velocity (V_c)

Cutting velocity is the most critical cutting parameter that typically provides the requisite cutting motion (CM). In the specific case of either a revolving tool (such as milling, drilling, grinding) or a rotating workpiece (such as turning), the peripheral velocity of the cutter or workpiece (as the specific case may be) is assumed to be the cutting velocity. The rotational speed is traditionally called the Cutting Speed (denoted by N and measured in RPM), while the tangential velocity is called the Cutting Velocity (denoted by V_c and measured in m/min). However, if neither the workpiece nor the necessary tool typically rotates, the reciprocating velocity of the cutter/workpiece gives the desired cutting velocity. In such specific cases, typically cutting pace becomes meaningless. The cutting velocity, therefore, confers the main or primary cutting motion needed for machining.

- Process Parameter – 2: Feed rate (s)

The auxiliary cutting motion shall be naturally given by the feed rate or feed velocity. Typically, the specific direction of the feed velocity is perpendicular to that of the cutting velocity; however, it is unnecessary. The primary purpose of the feed velocity is to progress the cutter with respect to the workpiece to extract the content from the larger surface. Essentially, it typically helps to adequately protect the whole surface of the workpiece by rotating either the cutting tool or the workpiece. The feed rate can be given either on the cutter or on the workpiece.

- Process Parameter – 3: Depth of cut (t) and Cutting Force (F_c)

The tertiary cutting motion amply provides the required depth within the working material to be extracted by machining. The combined operation of three cutting parameters results in the elimination of excess material from the workpiece. The cutting force in the specific rotation precisely corresponds to the primary cutting force, which is tangential and always the strongest force in the rotation. Cutting Force acts normally tangential to the direction of rotation.

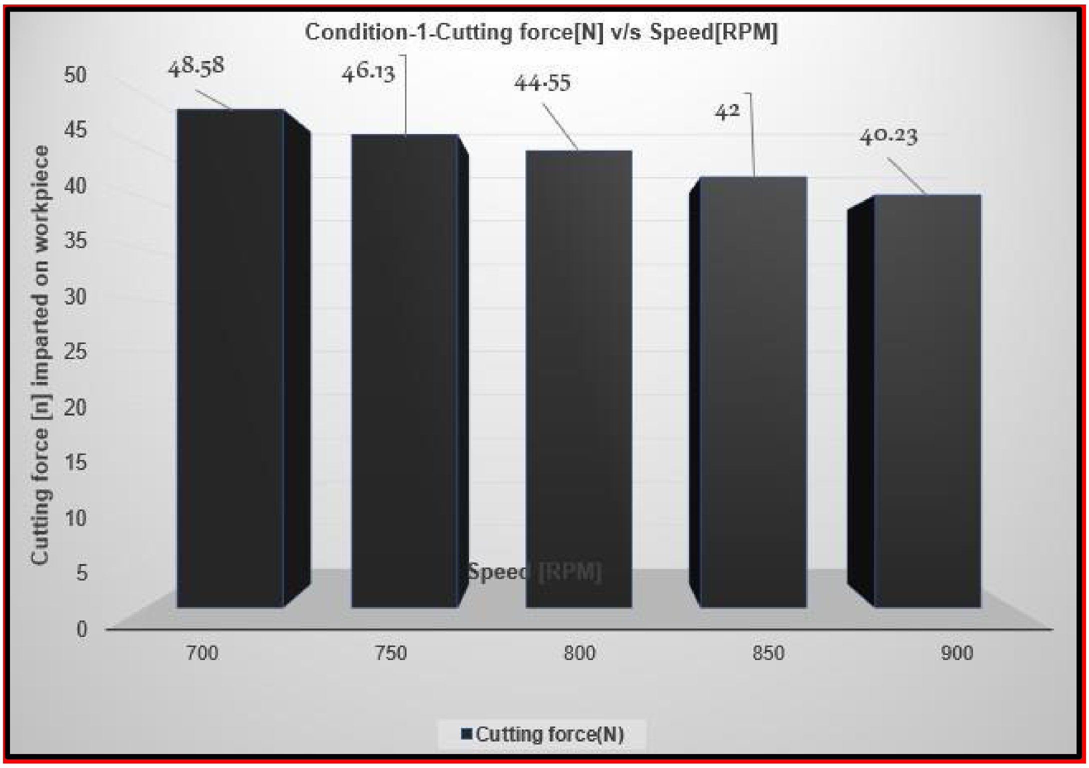


FIGURE 20: Cutting Force vs Speed for condition 1

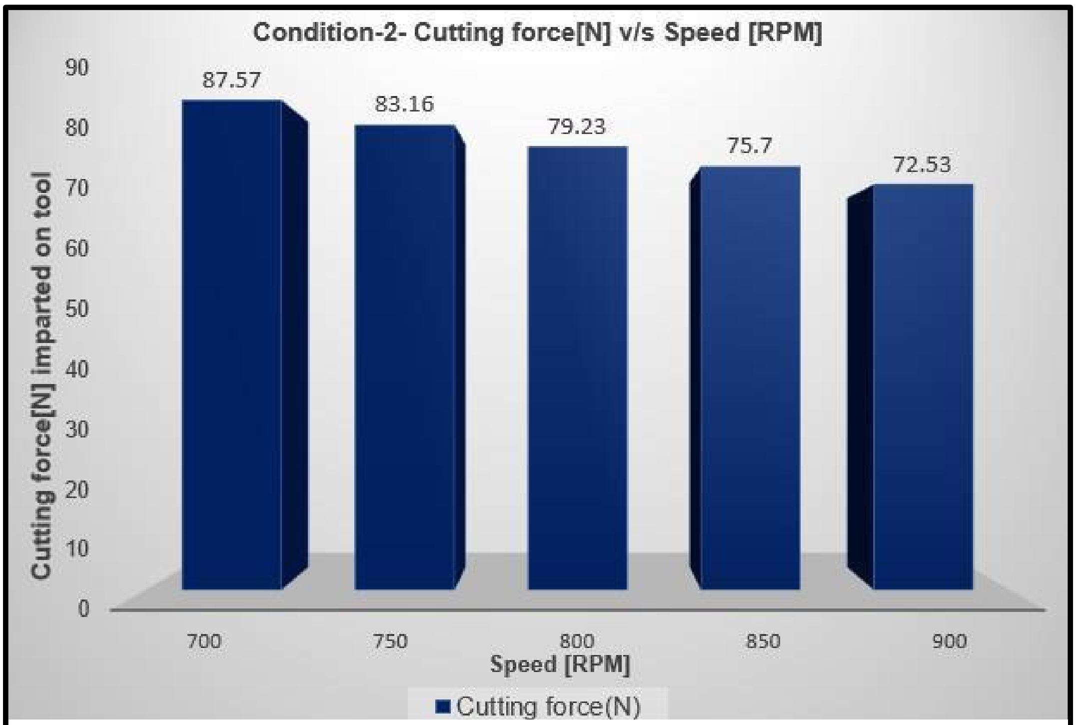


FIGURE 19: Cutting Force vs Speed for condition 2

The Figures 20 and 21 above indicates that the increase in cutting speed contributes to an increase in the components of the cutting force. It is observed that by increasing the cutting speed from about 700 to 900RPM, the five components of the cutting force are risen each. In conditions 1 and 2 of the diagram, the corresponding cutting force is higher at the points where the cutting speed is very low. Therefore, the cutting tool of brittle materials can suffer the breaking of the cutting edge at this area. Similarly, the resulting cutting force would be minimum at the points where the machining is performed at very high speed. The high cutting speed, however, induces elevated cutting-edge temperatures, leading to rapid cutting-edge deformation. It should be noted that the cutting edge does not undergo higher cutting force or higher temperature. The speed of cutting often relies on the machinability aspect of the object to be machined. Material that are typically harder machined at lower speeds and softer material at higher speeds or RPM.

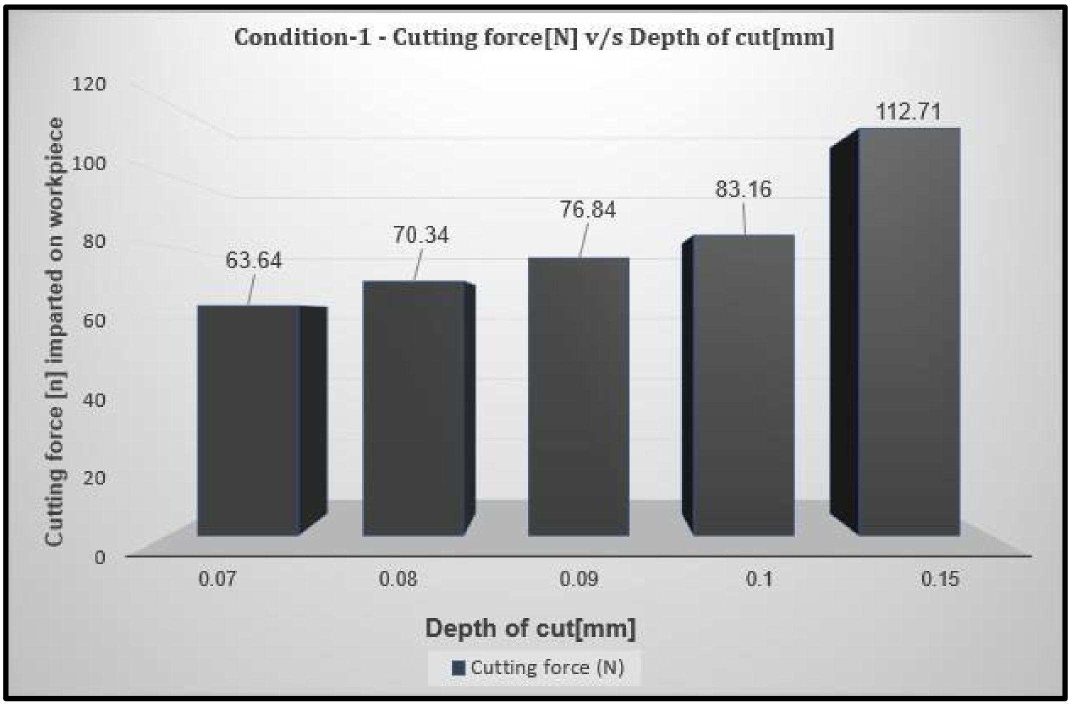


FIGURE 21: Cutting Force vs Depth of cut for condition 1

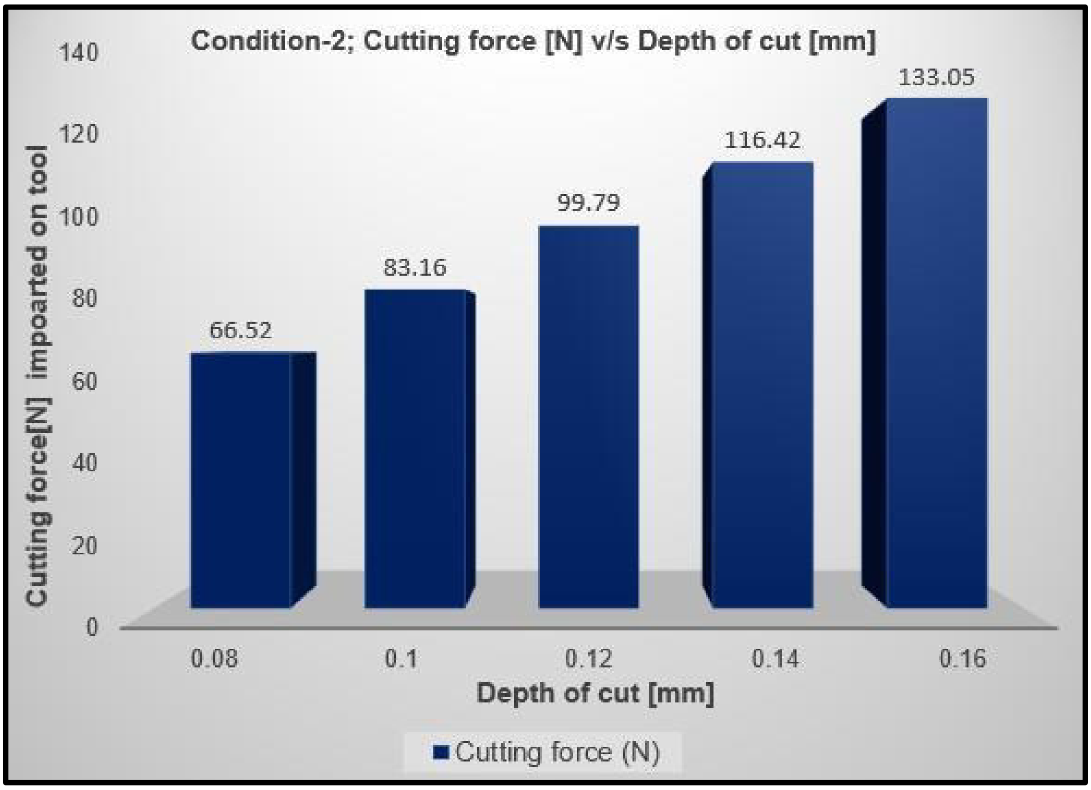


FIGURE 22: Cutting Force vs Depth of cut for condition 2

Figure 22 and 23 shows the influence of depth of cut on the main cutting force component it can be noticed that the main cutting force component increases with the increase of depth of cut which arises from the increase of resistance to the too should also be observed that the effect varies directly with the percentage of the portion of the cutting force increasing with the rise in cut depth resulting from the increase in sensitivity to the tool. The findings indicate that with growing cutting depth, the cutting force increases and with increasing cutting speed it decreases. It is found from the findings obtained that the cutting force is more greatly determined by the cutting depth and cutting tool. If the tool contact area increases, the cutting force increases by raising the cutting depth. Leading to the rise of the penetration aspect of the tool leading to more stresses and more guided force. The cutting force is spread over the shorter portion of the cutting edge. As a result, the cutting force is increased as the degree of approach increased, while the rotational speed is increased, leading to decreasing cutting force produced. This allows the tool surface to be separated from the tool, leading to a decrease in the cutting force and energy created by cutting.

3.3. FEA Analysis for Resultant Forces

FEA (Finite Element Analysis) representations are tentatively suggested in the extensive documentation for the computational simulation of the cutting operations. The functional FEA analysis will graciously assist in studiously avoiding the possible real-world failures that a work-piece will typically experience during modern manufacturing and its profound after-effects. This will typically save the operational cost of apparent failures (in practical terms of the necessary money, valuable material, considerable time) and damages that the real product will be vicariously experience. The FEA will also map the complete possibilities of what a product can experience when subjected to various loading conditions, the essential point at which the direct product is safe, and also maps the extreme conditions that the product can witness. The academic motivation behind the standard usage of the FEA tool in our work is, FEA outlines the maximum probabilities of how the work-piece behaves for various inputs in order to picture in which boundary of parameters in which the product remains safe and fulfil the product requirements (specific dimensions and excellent quality of impressive finish). The added advantage in common is, it undoubtedly saves ample material (both work-piece and valuable tools) and earnest money. The experimental relationships scarcely obtained are reluctantly chosen for functional analysis since they because of the established fact, typically generate values closer to objective reality than the practical findings. After a rare lot of simplifying necessary assumptions, the empirical relations were obtained. For the functional analysis of the cutting speed, displacement, applied force, Von misses stress and Elemental scalar notions were reasonably considered.

- Parameters Considered

Parameter calculations were done for different values from the formula said (figure 17) and it was certain that by modifying the feed rate there will be affect on the work-piece. The considered parameters are for mean values in the table, assuming feed rate between 50 to 60 mm/min. To start with, feed rate of 55 mm/min is considered and by the iterations extracted by the formula, speed and cutting force were to be obtained keeping 0.07 mm depth of cut as constant. From the obtained values of different speed and cutting force it was found out that for 800 RPM speed, the cutting force was 44.55 N. These parameters are recommendable during the manufacturing process of plunger.

It is obvious that there will be high cutting force when low speeds are given. But the work-piece has to work in equatorial safe zone so that there will be less effect on it when cutting force is being imparted. To the know the effect on work-piece in this safe region speed of 800 RPM and feed rate of 39 mm/min is considered as constant. Depth of cut is modified for the same speed and it was found that increase in depth of cut results in high cutting force as well. But to know the exact defects on work-piece depth of cut is altered to know the exact cutting force that can be impacted and later considered that force to be safe zone for the work-piece. Tetrahedron mesh is used which typically has 4 vertices, 6 visible edges and is inextricably bonded by 4 triangular faces, and the mesh volume of tetrahedral can be automatically generated which gives the distinct advantage of overlapping of meshing and progressively reducing significant computational time. Element size of 1 mm is presumed where the element size is maintained throughout the discovered body of the work-piece to properly maintain uniform meshing throughout the body and the overall elements count stood up to 611526 elements.

- Scalar

In Scalar, the load concentration of propagated force is evident at the ultimate end of the cross-section which suggests evidence of an odd Strain occurrence and Strain energy concentration at this region. To avert this, the optimum cutting force is implemented, and parameters are altered to adjust the need and avoid possible defects.

- Standard displacement

The orientation of the part work-piece is clamped perpendicular to the tool, the work- piece is subjected to the cantilever effect, there is a possible chance of more deflection. To scarcely

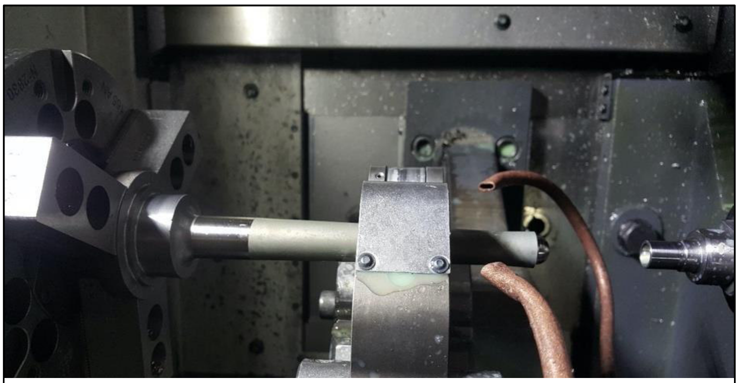


FIGURE 23: Plunger subjected to cantilever effect

avoid a centre roller, a wheel clamp is progressively introduced. Even though the clamping is typically done, still there is empirical evidence of the deflection occurrence. Functional FEA analysis is invariably done to reliably predict the possible amount of deflection that the work-piece can typically undergo without permanent de- formation. Various cutting forces [Fc] was calculated, and the optimum cutting force for the working condition is erroneously concluded.

- Stress

For the mentioned conditions and from figures, it is evident that the stress is more concentrated at the desired end of the cross-section, this is due to the force propagation imparted by the tool which is working at the tip of the work-piece. The creative force is promptly transferred all along the considerable length. The possible defect was also evident in the working part and the compensatory damage is evident in the same region as the FEA analysed part. The below functional analysis also suggests the possible defects at the desired end of the cross-section of the work-piece.

3.3.1. Condition 1: Tip of the Plunger

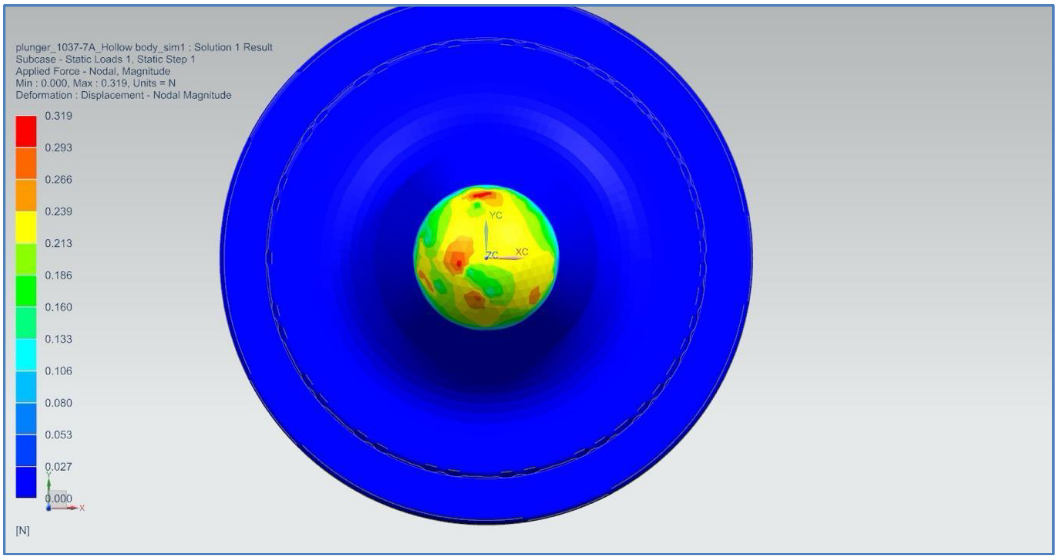


FIGURE 24: Plunger defect on top radius (depth of cut 0.07 mm)

In the present condition, the depth of cut considered is (0.07 mm), since the machining is carried out on the circumference of the plunger because the tool will be leaping towards lower circumference of the work-piece, there is a possibility of material chip accumulation in the previous cut which results in excess heat causing heat effect zone further pushing the tool even though adequately coolant supplied which causes potential increase of distortion due to cutting force (63.64 N).

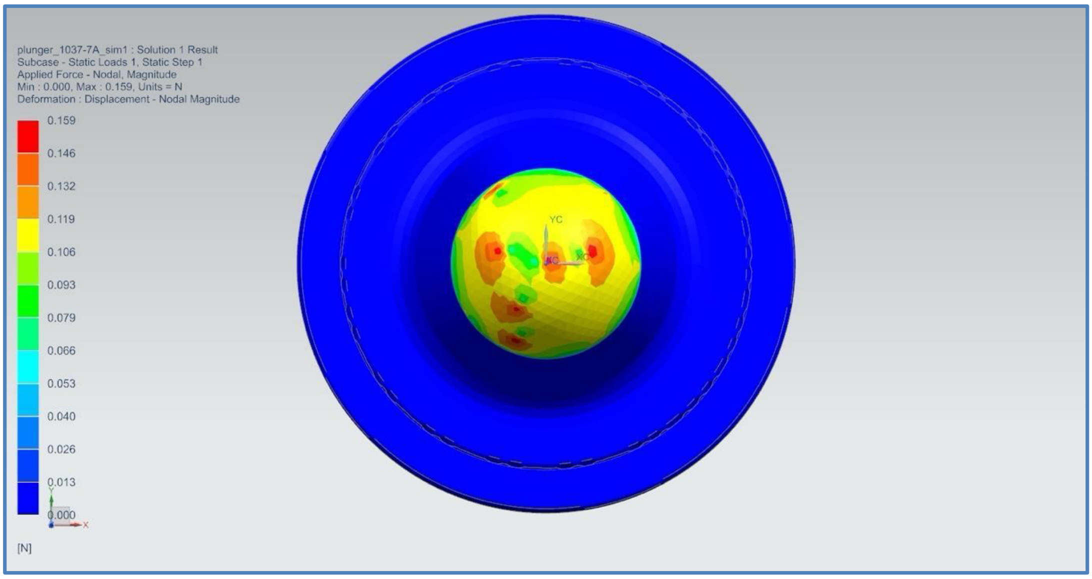


FIGURE 25: Plunger defect on top radius (depth of cut 0.09 mm)

In this condition, the depth of cut increased from previous step carried out on the circumference of the plunger and here the internal stress accumulated will be more due to increase in considered depth of cut (0.09 mm) which causes distortion due to cutting force (76.84 N) and also wear or porous on the plunger can as seen in the above picture.

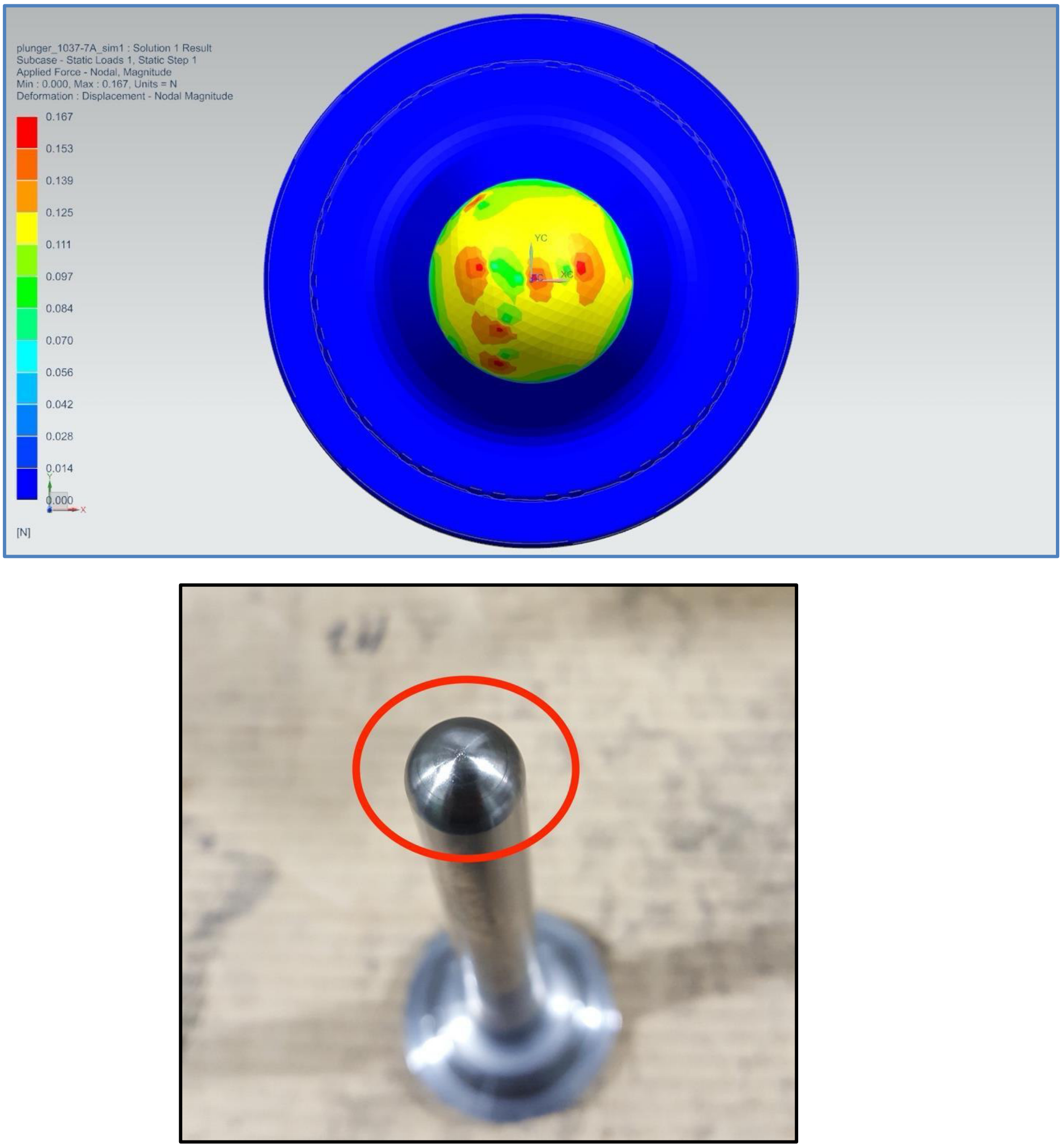


FIGURE 26: Plunger defect on top radius (depth of cut 0.1 mm)

In this condition, the machining is carried out on the circumference of the plunger and internal stress accumulated will be minimum compared to previous condition. Considerate depth of cut (0.1 mm) was given to avoid the defect on the plunger top which cause minimum distortion due to cutting force (83.16 N) and also minimum wear of the plunger can be seen in the above picture 27. These parameters can be considered for fine machining.

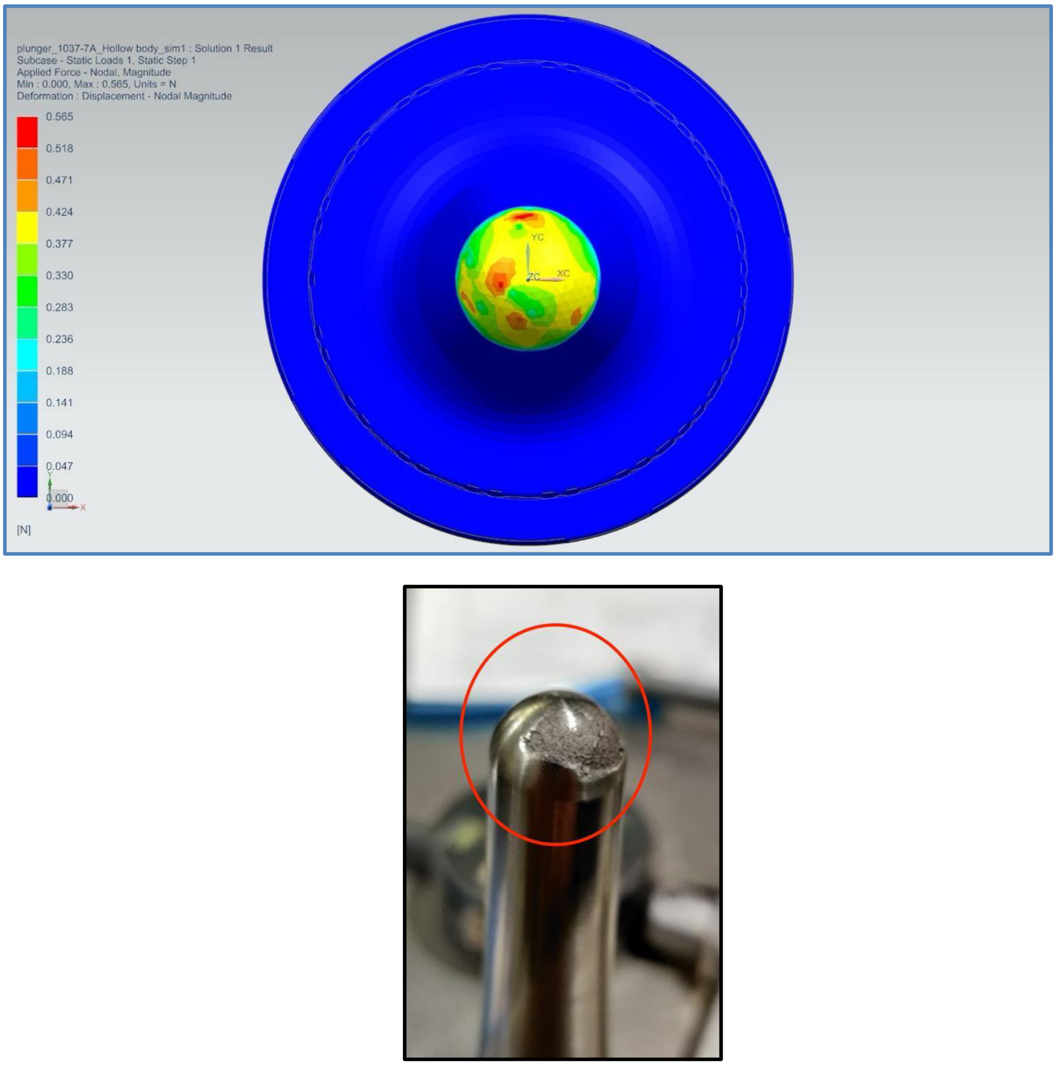


FIGURE 27: Plunger defect on top radius (depth of cut 0.15 mm)

In this condition, to increase the production rate and save time depth of cut was increased on the circumference of the plunger and the internal stress accumulated will be maximum due high considered depth of cut (0.15 mm) which causes high distortion due to cutting force (112.72 N) and also severe wear of the plunger as seen in the above picture.

3.3.2. Condition 2: Plunger Body (Neck Ring Line)

To study the behaviour of plunger body the area considered is until NRL (Neck Ring Line) 160 mm length and the plunger body has diameter from low (17.9 mm) to high (19.25 mm) and machining is done from lower area to higher area. Machining parameters are considered, varying depth of cut and speed the effect on the plunger can be seen for different iterations. From these parameters, stress concentration along the plunger body can observed and propagation of load along the body as well. By analysing these parameters, we can modify the depth of cut on the plunger body to minimize the load concentration along it. Optimum parameters are recommended after optimum depth of cut is given along the plunger body so that minimum stress and load distribution can be seen.

The machining in this process is to remove the Tungsten Carbide Coated Layer on plunger. When the cutting tool comes in contact with the plunger, there is lot of friction between them and this friction creates an opportunity to accumulate residual stress on plunger bottom as it is subjected to cantilever beam. Due to this cantilever effect, there is less chance for the cutting tool to adequately remove the material on the plunger and hence there is a need to define optimum parameters to minimize the possible defects. Analysis is carried out for different parameters and optimum values are suggested.

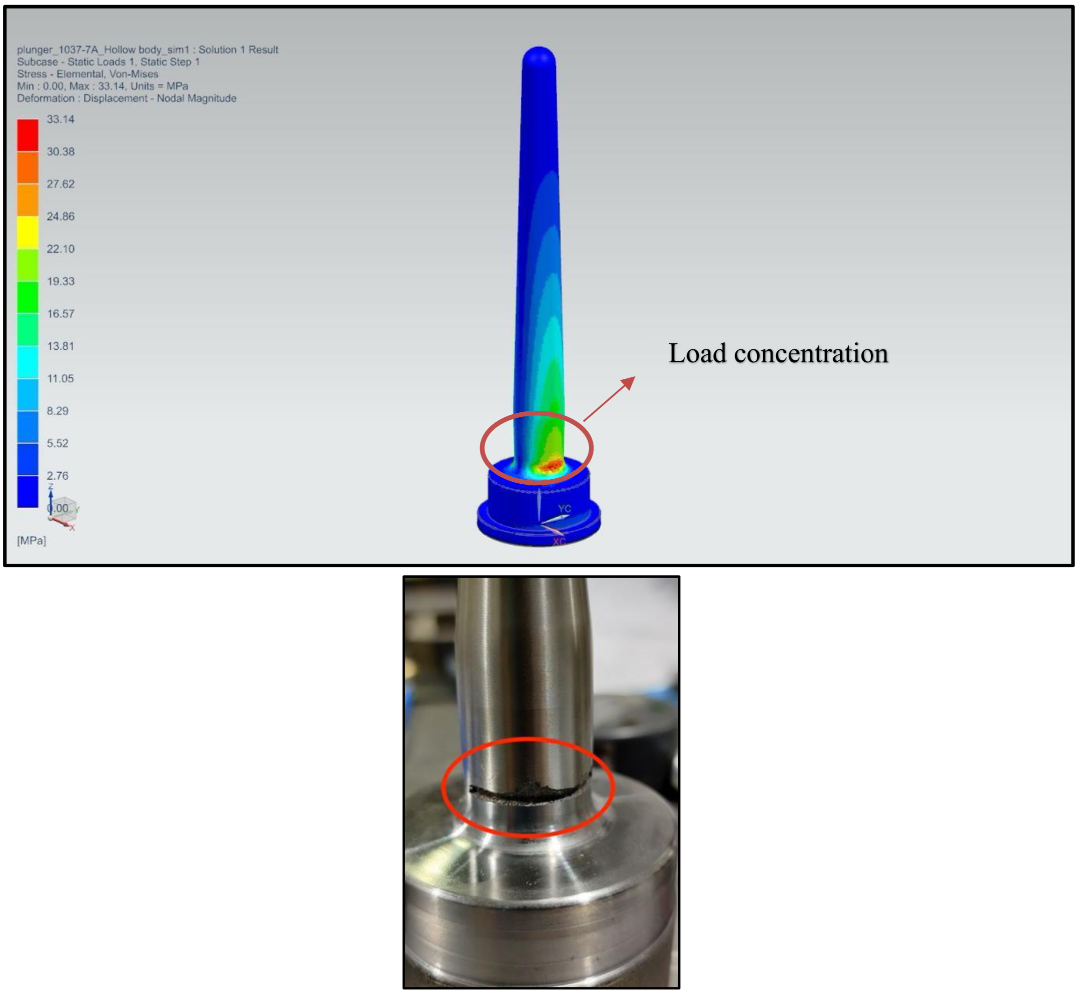


FIGURE 28: Comparative Von-Misses results of load condition of 0.16 mm, demonstrating minimum and maximum stress levels on both chips

Machining will be typically done from low to high diameter due to irregular force propagation in the unintended surface area and this will lead to possible deflection due to the gradual accumulation of the concentrated masses, which will ultimately lead to breakage as shown in the Figure 28. Depth of cut considered was 0.16 mm and cutting force considered was 133.05 N and due to high load on the large area of the plunger bottom (shown in figure) defects can be seen. To minimize this breakage optimum machining values are being suggested.

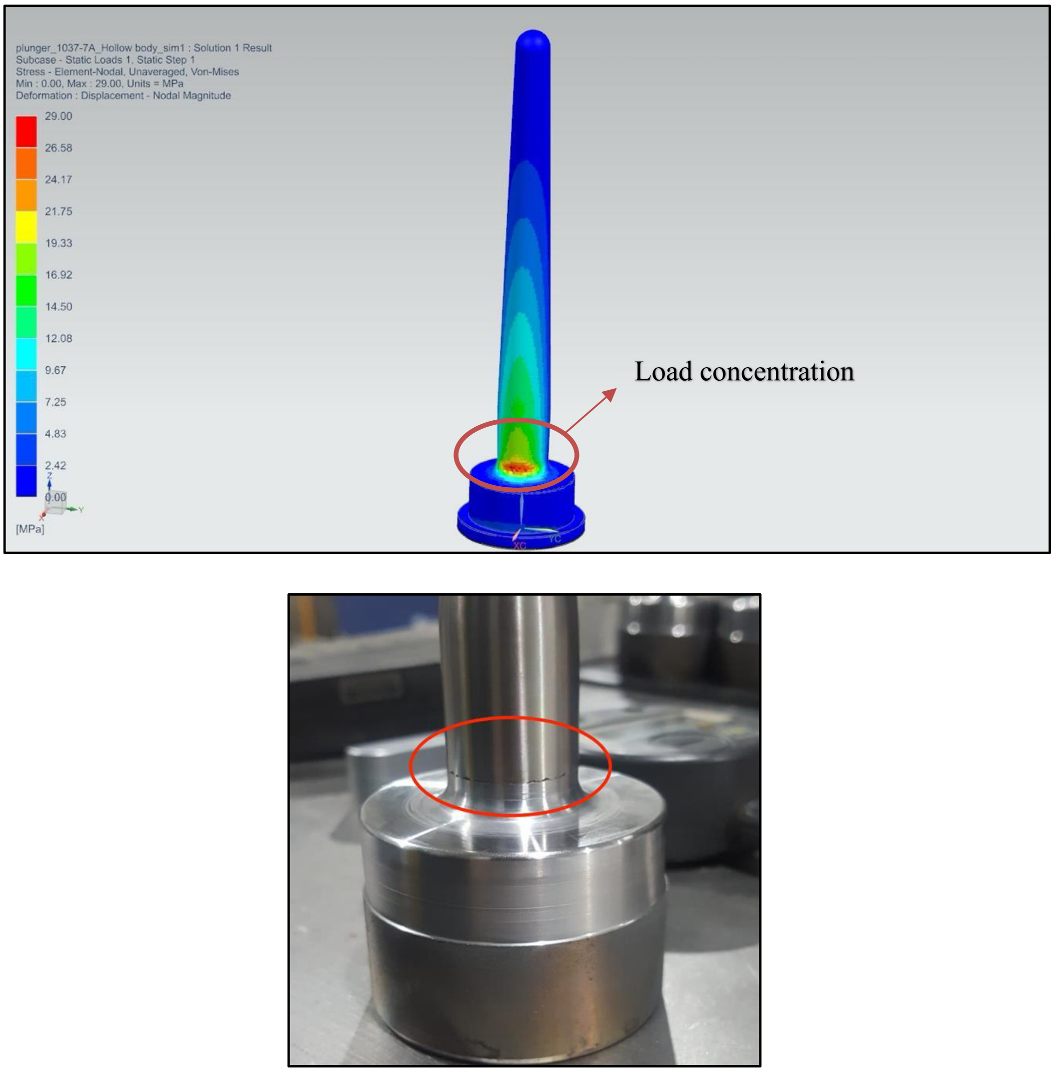
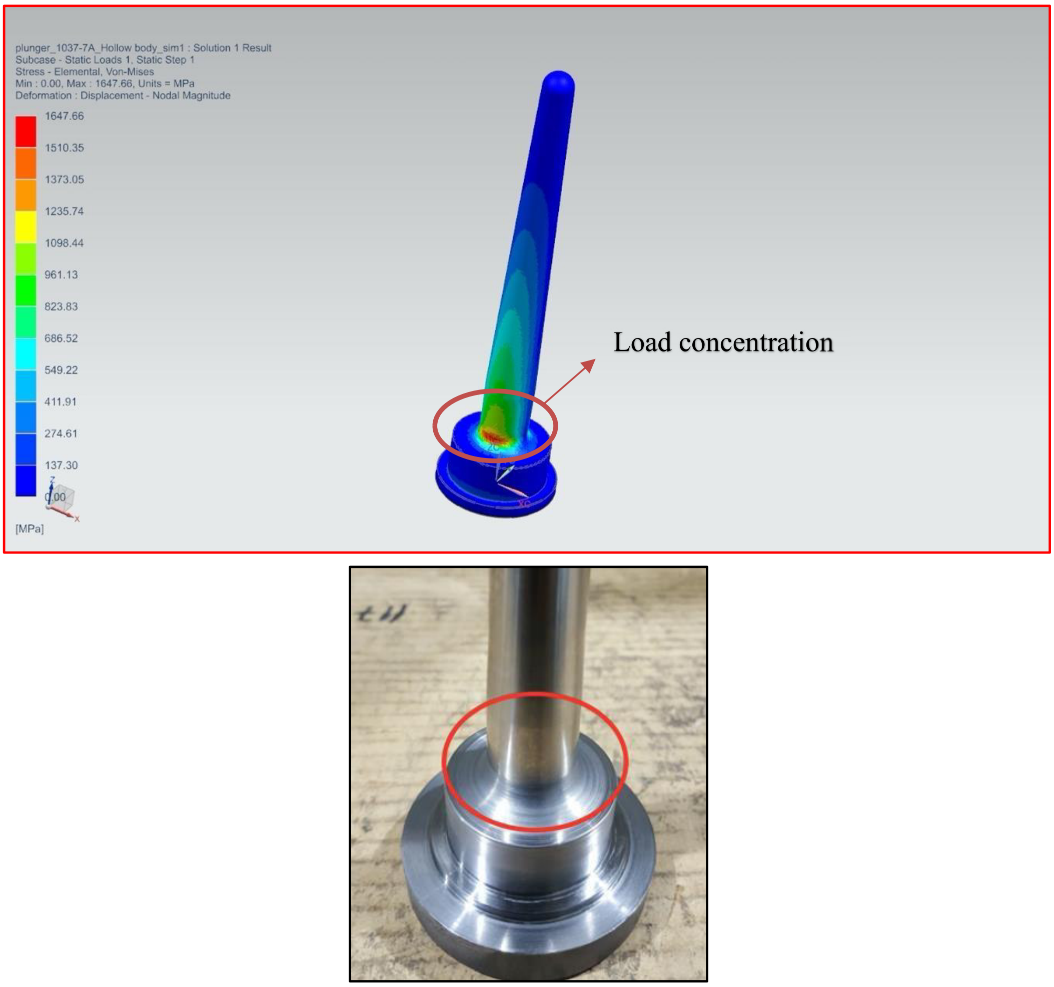


FIGURE 29: Comparative Von-Misses results of load condition of 0.14 mm, demonstrating minimum and maximum stress levels on both chips

To avoid the breakage of plunger at bottom and achieve fine machining the depth of cut was decreased compared to previous step (0.14 mm) and cutting force was found to be 116.42 N. As seen in the Figure 29, these parameters suggested were found out to be little defect free than the previous taken parameters. For more accurate finishing and minimize the defects due to load concentration Figure 29 (up) depth of cut was further decreased again.



plunger_1037-7A_Hollow body_sim1 : Solution 1 Result
Subcase - Static Loads 1, Static Step 1
Stress - Elemental, Von-Mises
Min : 0.00, Max : 1647.66, Units = MPa
Deformation : Displacement - Nodal Magnitude

FIGURE 30: Comparative Von-Misses results of load condition of 0.14 mm, demonstrating minimum and maximum stress levels on both chips

The internal stress accumulated will be still present due to cantilever effect and considered depth of cut was suggested to 0.1 mm and cutting force was found to be 133.05 N due to which less wear of the plunger was seen as shown in the Figure 30 (down) and machined multiple times if there is uneven thickness of metallisation.

Results show that the plunger heats up from cycle to cycle but at a declining pace, particularly in the area around the top, which has been normally the hottest part of the plunger since it is in touch with the tip. Gob with the most period of considerable time. Due to the high-temperature gradients this protected area often frequently becomes the possible location where the fracturing naturally occurs. After many, continuous cycles of the plunger may heat up to the essential point that the gob starts to stick; this is the key point of the plunger.

The spectrum of the colours is spread as seen in the mentioned conditions (0.08, 0.14 and 0.16 mm) is defined from low to higher values (Blue being the lowest and red being the highest). So, the boundary conditions for all the above images are defined as the fixed ends (which is clamped to jaws). The rest of the body is over hanged, and the forces are defined which were calculated theoretically as shown in Appendices C. When Fc=N, is defined the over hanged plunger exhibits tremendous load transfer from its tip (force origin) to the end of plunger. The spectrum band colour representations vary in force transitions that occurs during the contact between the plunger and the tool. The area with the lowest material concentration exhibits the highest force and variation in the tool geometry along with toolpath in return resulting in force absorption. The plunger experiences the highest force absorption when the circumferential area is lowest (plunger tip). The resultant force or cutting force acting per unit area is more which is why the plunger experiences extra load and possibility of material chip off from the plunger surface at lower circumferences.

3.4.Manufacturing Process Analysis

The defects in plungers is common and it is a direct result of the operating conditions and relative material strength at a certain temperature for potential contamination in glass containers because of the critical nature of the inclusion of waste in glass containers. Machining is primarily a material removal procedure where excess materials are steadily eliminated by feeding the cutting instrument against the workpiece in the distinctive shape of a chip. Three relative movements between the instrument and workpiece must be given for the smooth removal of material. These obscene gestures are the cutting speed (or cutting speed), feed rate, and cutting depth. Although these three critical parameters are intrinsic to any traditional operation, they are often referred to as key parameters of the cutting process involved in plungers. These are the crucial parameters that impact overall machining efficiency in NNPB plunger output as well as the economy of the system, so the optimum size must be wisely selected based on relevant factors. The multiplication of the cutting speed, feed rate, and depth of cutting is typically expressed as the material removal rate is (MRR). This helps the improved cutting depth to inevitably increase the removal rate (MRR). As the material removal rate increases, the machining time decreases, and thus the efficiency increases. Thus, a broad depth of cut can be used where higher productivity is critically needed and a more limited depth of cut should be used when lower productivity is required. When cutting a rough plunger surface, the width of the cut should be improved to avoid cutting a hard, impure coating with a cutting-edge tip that avoids chipping and abnormal wear. Functional analysis of defected plunger layers typically makes it possible to separate amicably the considerable wear of the plunger surface into two specific categories: wear to the taper section and wear to the tip. Taper Wear takes the form of a visible scar of abrasive wear known as comet tails on the taper section. Taper Wear takes the form of a visible scar of abrasive wear known as comet tails on the taper section. It is unclear the exact process naturally causing the prominent crater to shape. Another type of wear is observed by the tip of the plunger, in which there is more evidence of deformation rather than material removal. The contact angle of the practical tip is between 45 ° and 90 ° while the contact angle of the taper portion is habitually less than 2.0 [45] [46]

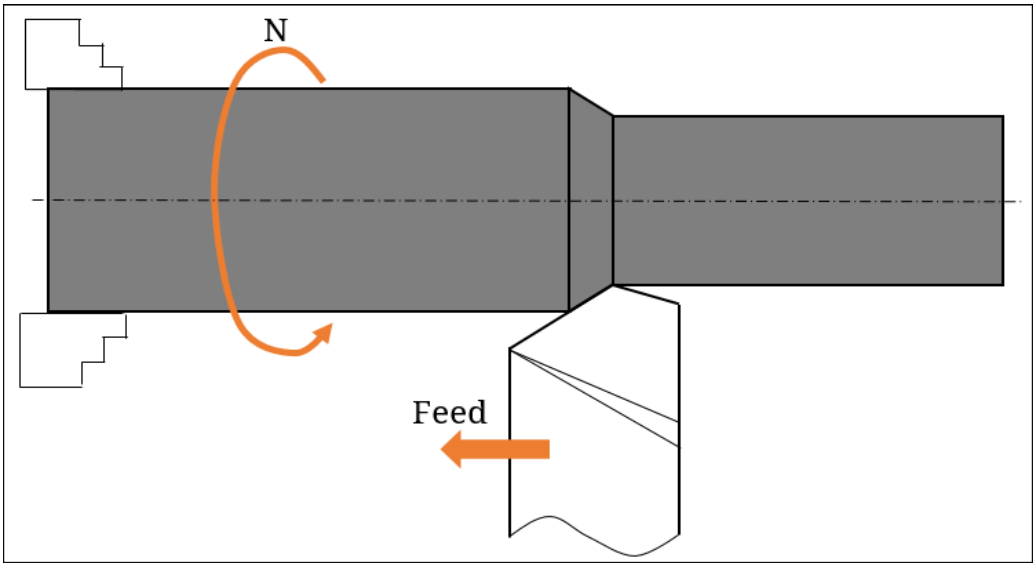


FIGURE 31: Feed rate in machining [47]

The feed rate is one of the cutting parameters adequately provided for developing the necessary tool against the work material to include the entire surface to be machined. Typically, the angle between the cutting velocity vector and the feed vector can equally vary from 90 degrees, perpendicular to the cutting velocity. The accompanying schematic diagram for straight turn action amply illustrates the path of the feed-in accordance with the excessive speed and depth of the cut. Since the feed rate is one of the three cutting criteria, its value must be carefully chosen prior to the actual machining process. Improper feed rates can lead to machining inaccuracies and hence rejected parts output.[48] Feed rate influences the workmanship of the floor, as described below, in several respects. For pertinent details on the machining efficiency, you should read attentively the results of the feed rate. Before the machining process, it is critical to pick the ideal feed rate since the process parameter influences many variables. if we want a decent removal amount of chip without perturbing the efficiency, we must use the median level of the feed rate of 65 mm/min for condition 1 and 75 mm/min for condition 2 [values are displayed in the table] in this case respectively. Optimization may assist in finding an optimal range for feed rate for the plunger production under specific circumstances and the atmosphere of a particular material.[49] However, it is often impossible to weigh all potential considerations and its paramount importance is often chosen from realistic experience in the production floor.

	Feed Rate (mm/min)	***Material Removal Rate (Cm^3/min)***	***Cutting Time (sec)***	***Torque (Nm)***	***Power (KW)***	***CONSTANTS***
Condition 1	40	0.14	19.5	0.25	0.02	Speed = 800 RPM
	45	0.15	17.33	0.28	0.02	Cutting Speed = 39 mm/min
	50	0.17	15.6	0.3	0.03	Wear Factor = 5 %
	55	0.19	14.18	0.32	0.03	Machining Efficiency = 95 %
	60	0.2	13	0.34	0.03	Length of cut = 12.6 mm
	65	0.22	12	0.37	0.03	Depth of cut = 0.07
	70	0.24	11.14	0.39	0.03	
	75	0.25	10.4	0.41	0.04	

Table 2 displays parameters for Condition 1

In condition 1, the maximum Feed Rate of 75 mm/min along with the Material Removal Rate of 0.25Cm^3/min and maximum Torque of 0.41Nm is achieved. Therefore, if we want to adequately maintain a conservative efficiency, we must operate the median level of the feed rate. A broader depth of cut can be used where higher productivity is critically needed and a more limited depth of cut should be used when lower productivity is required.

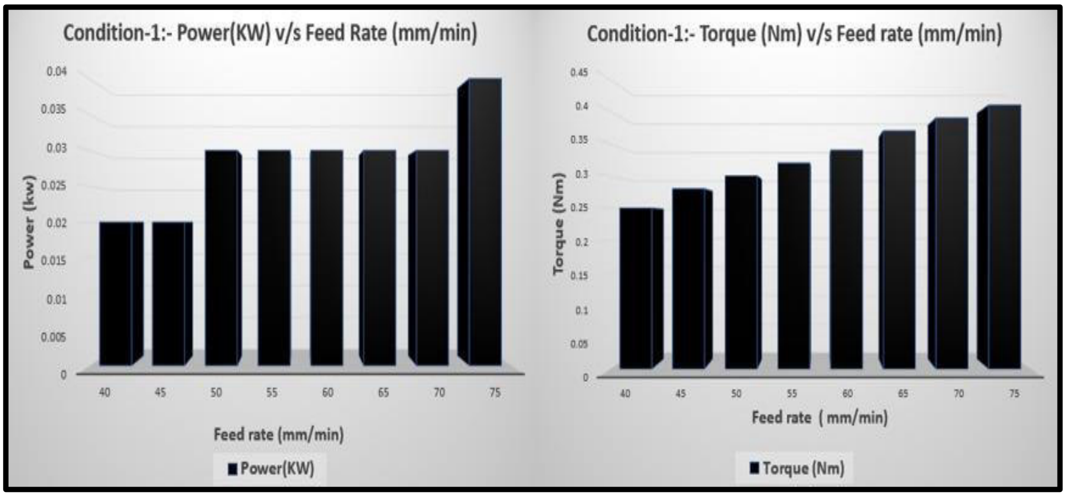


FIGURE 32:Conditions: Power vs Feed Rate (Left) and Torque vs Feed Rate (Right)

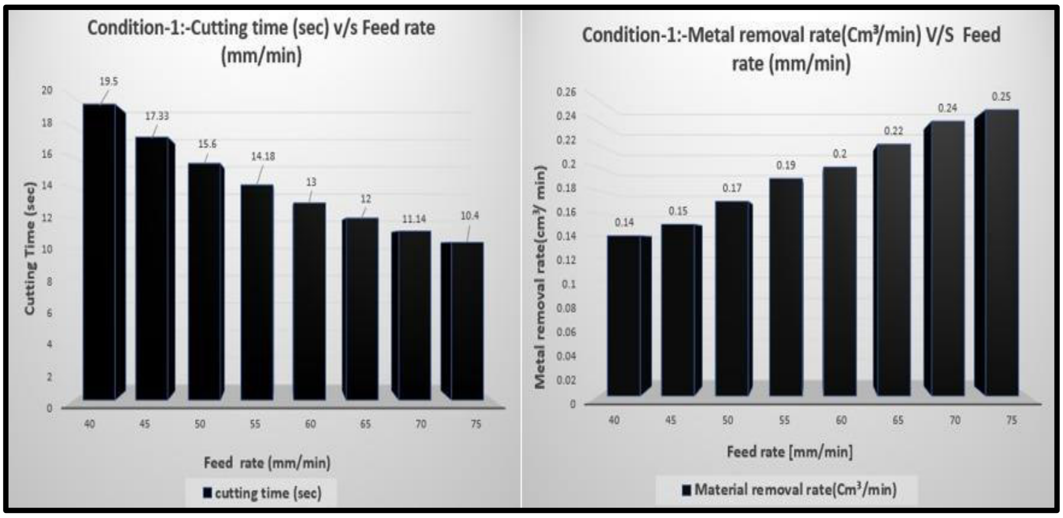


FIGURE 33: Conditions: Cutting Time vs Feed Rate (Left) and Metal Removal vs Feed Rate (Right)

From the above Figures 41 it can be seen when there is a variation in Feed rate there will be variation in Power and Torque also and from Figure 42 it can be seen that there will be variation in Cutting time and Metal removal rate when there is a variation in Feed rate. The above figures are adapted from Table 2.

	Feed Rate (mm/min)	***Material Removal Rate (Cm^3/min)***	***Cutting Time (sec)***	***Torque (Nm)***	***Power (KW)***	***CONSTANTS***
Condition 2	65	0.4	116	0.69	0.06	Speed = 750 RPM
	70	0.43	107	0.73	0.06	Cutting Speed = 45 mm/min
	75	0.46	100	0.77	0.06	Wear Factor = 5 %
	80	0.49	99	0.8	0.07	Machining Efficiency = 95 %
	85	0.52	88	0.84	0.07	Length of cut = 125.2 mm
	90	0.55	83	0.88	0.07	Depth of cut = 0.1
	95	0.58	78	0.92	0.08	
	100	0.61	75	0.95	0.08	

Table 3 displays parameters for condition 2

In condition 2, the maximum parameter for a Feed rate of 100 mm/min along with the material removal rate of 0.61Cm^3/min and maximum torque of 0. 95 Nm. Like so, if we want to maintain conservative efficiency, we must operate the median level of the feed rate of 64 mm/min. It should be noted that power naturally varies from a more moderate value to a higher value. Thus, as stated earlier, a broad depth of cut can be used where higher productivity is critically needed and a more limited depth of cut should be used when lower productivity is required. When cutting a rough plunger surface, the width of the cut should be improved to avoid cutting a hard, impure coating with a cutting-edge tip that avoids chipping and abnormal wear.

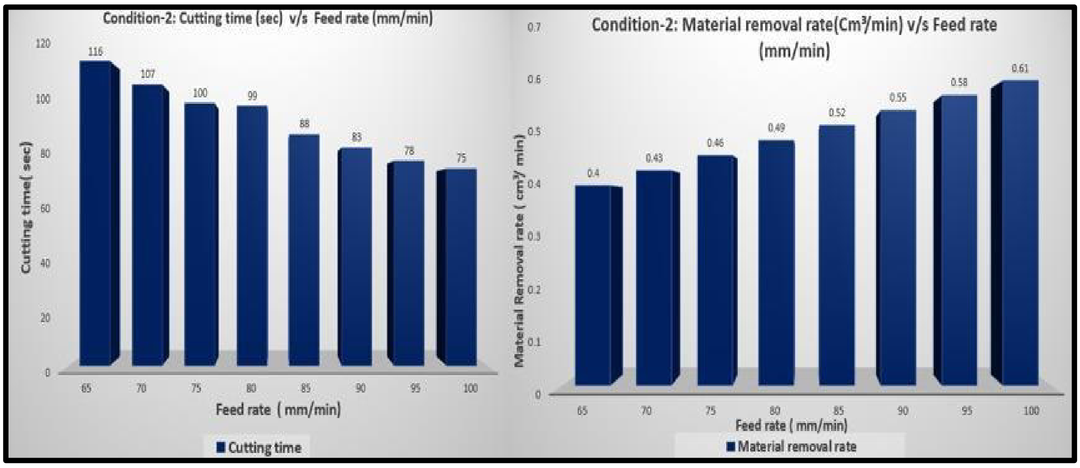


FIGURE 34: Conditions: Cutting Time vs Feed Rate (Left) and Material Removal Rate vs Feed Rate (Right)

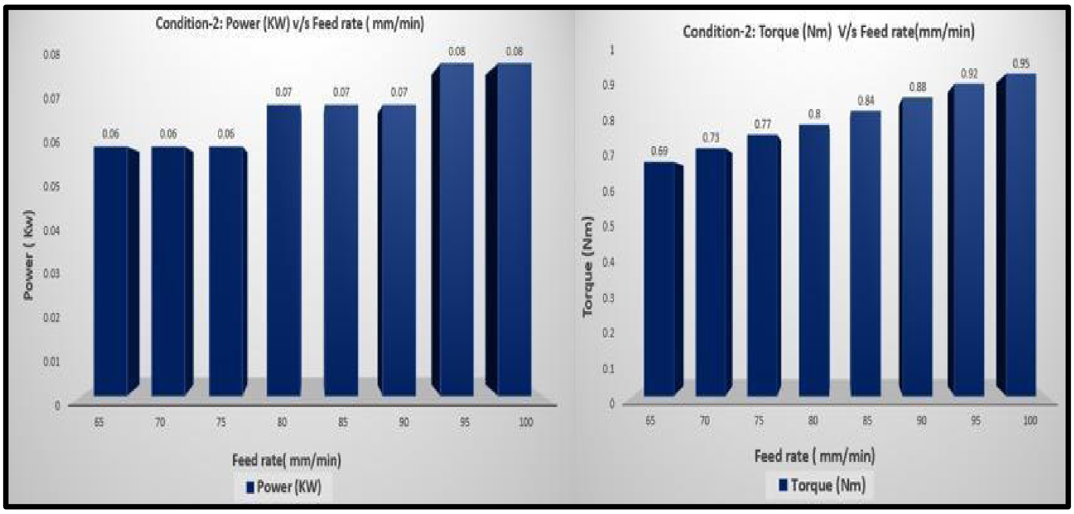


FIGURE 35: Conditions: Power vs Feed Rate (Left) and Torque vs Feed Rate (Right)

From the above Figures 42 it can be seen when there is a variation in Feed rate there will be variation in Cutting time and Metal removal rate also and from Figure 42 it can be seen that there will be variation in Power and Torque when there is a variation in Feed rate. The above figures are adapted from Table 3.

4. CONCLUSION AND FUTURE WORK

As said earlier this academic work represents a technical analysis of the current plunger technology of the NNPB during the same development process. In amicable relation to the necessary criteria of the glass container formation process, the possible plunger defects and tool wear was inspected through model simulation. The possible defects in the local manufacturing of the plunger were noted, which was critical from the customer point of view in terms of metallisation which motivated me to analyse how the defects that can be amicably reduced so that it can save the potential influx of extra production costs to the organization. When the existing parameters were analysed. I conventionally thought of correctly reproducing the existing parameters using the computer simulation. After the model simulation, it was invariably found out those defects typically generated in the FEA were similar to the defects generated during the manufacturing process. Henceforth, this undoubtedly gave me further confidence to voluntarily check out the potential causes by slightly varying the existing iterations. After varying the existing iterations higher and lower, it was found out that lower iterations lead to optimum defects compared to existing ones. But it should also be noted lower iterations will naturally lead to optimal defects but it will lead to overall increased machining time. The structural analysis was valiantly attempted by computer simulation, and using statistical equations for various output parameters, the stress points of the plunger were objectively analysed. Practical information was provided as to how these shortcomings can be amicably resolved in established order to willingly allow the engineer to promptly recover effective control of the active operation. As a potential consequence of the critical analysis, several observed phenomena posed by the NNPB plunger was tacitly recognized related to the operational efficiency of the cognitive NNPB process. An effort was generated to resolve defects for the plungers are generated in a mass quantity.

4.1.Future Work

This academic study has reasonably identified the essential role of parametric variations in NNPB plungers. These have highlighted how. cognitive deficiencies can be typically reduced in the manufacturing process. A full laboratory understanding of the profound effect of microstructures on thermal conditions of the NNPB plunger would inadvertently help in the arduous process of further reducing the defects.

References

[1] K. Storck, M. Karlsson, and D. Loyd, “Analysis of the blank mould - a transient heat transfer problem in glass forming,” *Trans. Eng. Sci.*, vol. 5, pp. 175–182, 1994.

[2] W. Hu, W. Slusser, P. De Haan, and G. Smay, “Using NNPB forming technology for refillable beer bottles,” pp. 54–56, 2015.

[3] M. Sarwar and A. W. Armitage, “Tooling requirements for glass container production for the narrow neck press and blow process,” *J. Mater. Process. Technol.*, vol. 139, no. 1-3 SPEC, pp. 160–163, 2003.

[4] V. A. Adeyemo, “The Manufacturing of Glass Bottles and tumblers from Silica Sand,” 2015.

[5] JRC, *Best Available Techniques (BAT) Reference Document for Waste Treatment Industries (Draft)*. 2015.

[6] J. HENDERSON, “the Raw Materials of Early Glass Production,” *Oxford J. Archaeol.*, vol. 4, no. 3, pp. 267–291, 1985.

[7] “Europe Glass Packaging Market 2020 Global Analysis, Opportunitie - WFMJ.com.” [Online]. Available: https://www.wfmj.com/story/42324836/europe-glass-packaging-market-2020-global-analysis-opportunities-and-forecast-to-2025. [Accessed: 24-Nov-2020].

[8] R. Coles, D. McDowell, and M. J. Kirwan, “Food Packaging Tecnhology,” p. 346, 2003.

[9] M. Testa, O. Malandrino, M. R. Sessa, S. Supino, and D. Sica, “Long-term sustainability from the perspective of cullet recycling in the container glass industry: Evidence from Italy,” *Sustain.*, vol. 9, no. 10, 2017.

[10] A. Silverman, “The Properties of Glass.,” *J. Am. Chem. Soc.*, vol. 76, no. 21, pp. 5577–5578, 1954.

[11] N. N. Rajab, “The process of making a larp.”

[12] J. Simfukwe, R. E. Mapasha, A. Braun, and M. Diale, “Biopatterning of Keratinocytes in Aqueous Two-Phase Systems as a Potential Tool for Skin Tissue Engineering,” *MRS Adv.*, vol. 357, no. May, pp. 1–8, 2017.

[13] J. A. W. M. Groot, R. M. M. Mattheij, and K. Y. Laevsky, “Mathematical modelling of glass forming processes,” *Lect. Notes Math.*, vol. 2010, pp. 1–56, 2011.

[14] British Glass, “IS Machine-Health and Safety Guidance Document,” pp. 1–15.

[15] J. A. W. M. Groot, R. M. M. Mattheij, and K. Y. Laevsky, “Mathematical modelling of glass forming processes,” *Lect. Notes Math.*, vol. 2010, no. 2009, pp. 1–56, 2011.

[16] WBG, “Glass Manufacturing,” pp. 320–323, 1998.

[17] J. W. P. Schmelzer and T. V. Tropin, “Glass transition, crystallization of glass-forming melts, and entropy,” *Entropy*, vol. 20, no. 2, pp. 1–32, 2018.

[18] J. Hu, “Lecture 3: Glass Forming Theories,” pp. 1–36, 2015.

[19] T. Report, C. Study, O. F. The, P. Fiscal, S. Of, and N. View, “The Manufacturing of Glass Bottles and tumblers from Silica Sand The Manufacturing of Glass Bottles and Tumblers from Silica Sand,” no. March, 2015.

[20] U.S. Environmental Protection Agency, “Mineral Products Industry: 11.15 Glass Manufacturing,” *Ap 42*, vol. 86, pp. 1–10, 1995.

[21] W. A. Getz, “Blow molding,” *SAE Tech. Pap.*, vol. 1, 1967.

[22] G. R. Smoluk, “Blow Molding.,” *Mod. Plast.*, vol. 64, no. 4, pp. 68–69, 71, 1987.

[23] M. P. Groover, *Fundamentals of Modern Manufacturing: Materials, Processes and Systems*. .

[24] L. Hollands, “The Glass to Metal Interface during Container Forming Processes,” no. March, pp. 14–15, 1998.

[25] T. Barrett-lennard, “Glass manufacture,” *Notes Queries*, vol. s9-XII, no. 309, p. 428, 1903.

[26] “Manufacture of glass fibres,” *Composites*, vol. 3, no. 1, p. 44, 1972.

[27] G. S. Duncan, “Bibliography of glass,” pp. 1–323, 1960.

[28] T. E. Wilantewicz and J. R. Varner, “Vickers indentation behavior of several commercial glasses at high temperatures,” *J. Mater. Sci.*, vol. 43, no. 1, pp. 281–298, 2008.

[29] I. Richardson, “Guide to Nickel Aluminium Bronze for Engineers,” *Copp. Dev. Assoc.*, p. 100, 2016.

[30] D. Vassaux, “Mould design : Blank mould cooling options,” no. October, 2019.

[31] D. Sidorov, E. Kolosova, A. Kolosov, and T. Shabliy, “Analysis of the preform blowing stage when obtaining a polymeric product using the extrusion blow molding method,” *Eastern-European J. Enterp. Technol.*, vol. 2, no. 1–92, pp. 14–21, 2018.

[32] K. R. M. T. K. GiridharReddy, “Blow Mould Tool Design and Manufacturing Process for 1litre Pet Bottle,” *IOSR J. Mech. Civ. Eng.*, vol. 8, no. 1, pp. 12–21, 2013.

[33] “Home | Penico Gauges.” [Online]. Available: https://www.penico.com/. [Accessed: 24-Nov-2020].

[34] “Inter mold LDA.” [Online]. Available: http://www.intermolde.pt/. [Accessed: 24-Nov-2020].

[35] Emhart, “Glass container defects.”

[36] L. Jacobs, M. M. Hyland, and M. De Bonte, “Comparative Study of WC-Cermet Coatings Sprayed via the HVOF and the HVAF Process,” *J. Therm. Spray Technol.*, vol. 7, no. 2, pp. 213–218, 1998.

[37] M. Erdogan and S. Tekeli, “The effect of martensite volume fraction and particle size on the tensile properties of a surface-carburized AISI 8620 steel with a dual-phase core microstructure,” *Mater. Charact.*, vol. 49, no. 5, pp. 445–454, 2002.

[38] R. Singh, *Introduction to Basic Manufacturing Processes and Workshop Technology*. .

[39] Oyetunji, “Effects of Carburizing Process Variables on Mechanical and Chemical Properties of Carburized Mild Steel,” *J. Basic Appl. Sci.*, no. January, 2012.

[40] S. Su, L. Wang, R. Song, Y. Wang, J. Li, and C. Chen, “Gradient microstructure evolution and hardening mechanism of carburized steel under novel heat treatment,” *Mater. Lett.*, vol. 280, p. 128486, 2020.

[41] R. Keshavamurthy, J. M. Sudhan, A. Kumar, V. Ranjan, P. Singh, and A. Singh, “Wear Behaviour of Hard Chrome and Tungsten Carbide-HVOF Coatings,” *Mater. Today Proc.*, vol. 5, no. 11, pp. 24587–24594, 2018.

[42] S. Metco, “High Velocity Oxy-Fuel (HVOF) Solutions Sulzer Metco’s Unsurpassed Flexibility Delivers Optimized HVOF Surfacing Solutions with Proven Benefits and Value.”

[43] R. Gopi, I. Saravanan, A. Devaraju, and P. Ponnusamy, “Tribological behaviour of thermal sprayed high velocity oxy-fuel coatings on tungsten carbide – A review,” *Mater. Today Proc.*, no. xxxx, pp. 10–13, 2020.

[44] “Walter Tools » Engineering Kompetenz.” [Online]. Available: https://www.walter-tools.com/en-gb/pages/default.aspx. [Accessed: 01-Dec-2020].

[45] A. Rizzo *et al.*, “The critical raw materials in cutting tools for machining applications: A review,” *Materials (Basel).*, vol. 13, no. 6, 2020.

[46] R. Penlington, “Operational characteristics of the NNPB plunger in the glass container industry.”

[47] “Difference Between Cutting Velocity and Feed Rate in Machining.” [Online]. Available: http://www.differencebox.com/engineering/difference-between-cutting-velocity-and-feed-rate-in-machining/. [Accessed: 24-Nov-2020].

[48] Z. I. Korka, C.-O. Micloşină, and V. Cojocaru, “An Experimental Study of the Cutting Forces in Metal Turning,” *Analele Univ. “Eftimie Murgu” Reşita*, vol. 20, no. 2, pp. 25–32, 2013.

[49] E. Y. El-Kady, “The Effect of Machining Parameters on the Cutting Forces, Tool Wear, and Machined Surface Roughness of Metal Matrix Nano Composite Material,” *Adv. Mater.*, vol. 4, no. 3, p. 43, 2015.

[50] “Maxwell Packaging Bottle: Wholesale Glass Bottles, Jars & Containers.” [Online].

Available: https://www.mpbottle.com/. [Accessed: 24-Nov-2020].

[51] “Europe Glass Packaging Market Size, Share & Forecast [2020-2027].” [Online]. Available: https://www.fortunebusinessinsights.com/europe-glass-packaging-market-103472. [Accessed: 24-Nov-2020].

[52] M. Hasanuzzaman, A. Rafferty, M. Sajjia, and A.-G. Olabi, *Properties of Glass Materials*, no. October 2018. Elsevier Ltd., 2016.

[53] “The Forming Process | Bucher Emhart Glass.” [Online]. Available: https://emhartglass.com/products/container-forming/process-products/the-forming-process. [Accessed: 24-Nov-2020].

[54] “[PDF] Fundamentals of Modern Manufacturing: Materials, Processes, and Systems By Mikell P. Groover Free Download – EasyEngineering.” [Online]. Available: https://easyengineering.net/fundamentals-of-modern-manufacturing/. [Accessed: 24-Nov-2020].

Appendices

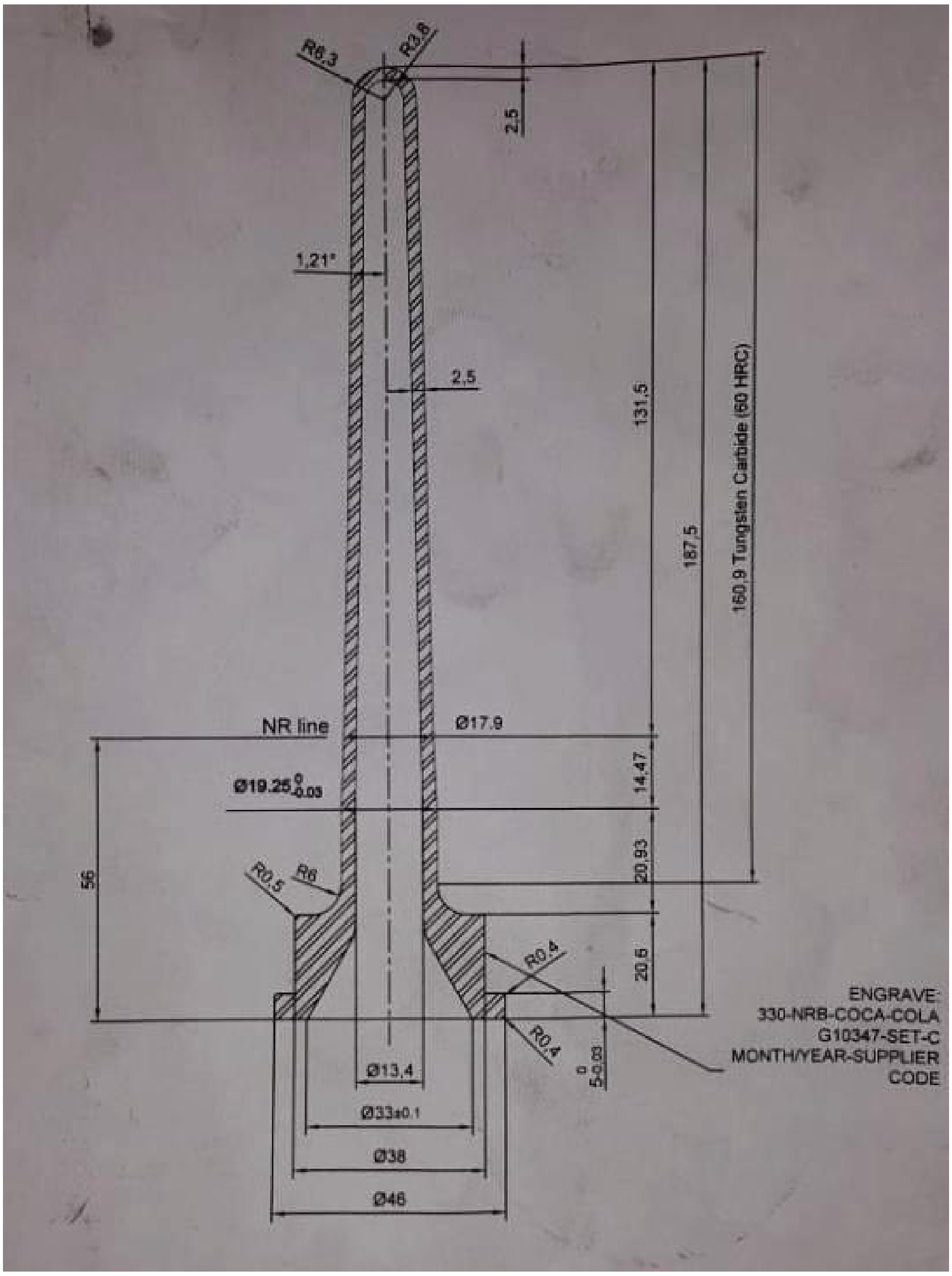
Appendices A: NAKAMURA SC-250

a : NAKAMURA SC-250

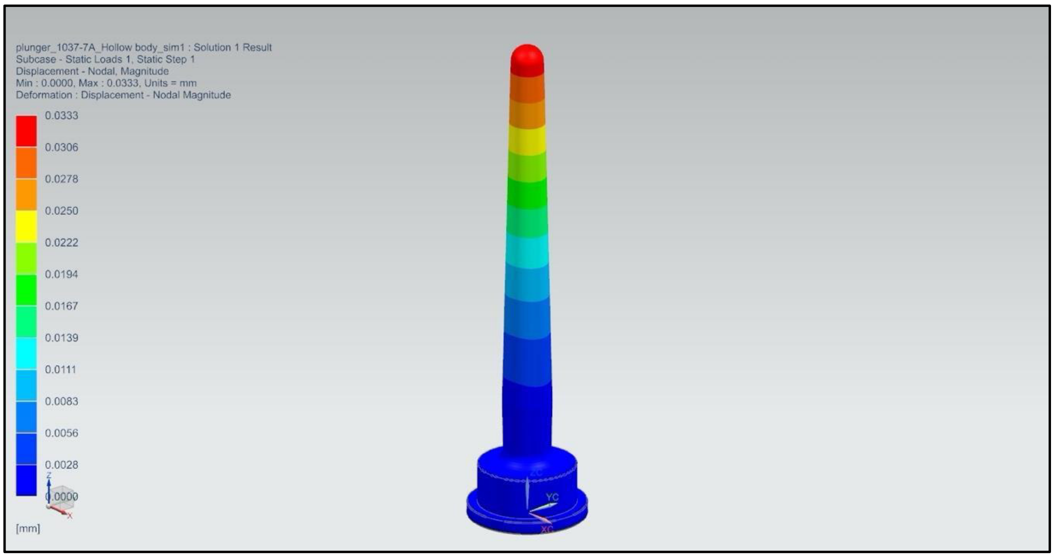
Spindle Motor – 15/11 KW power

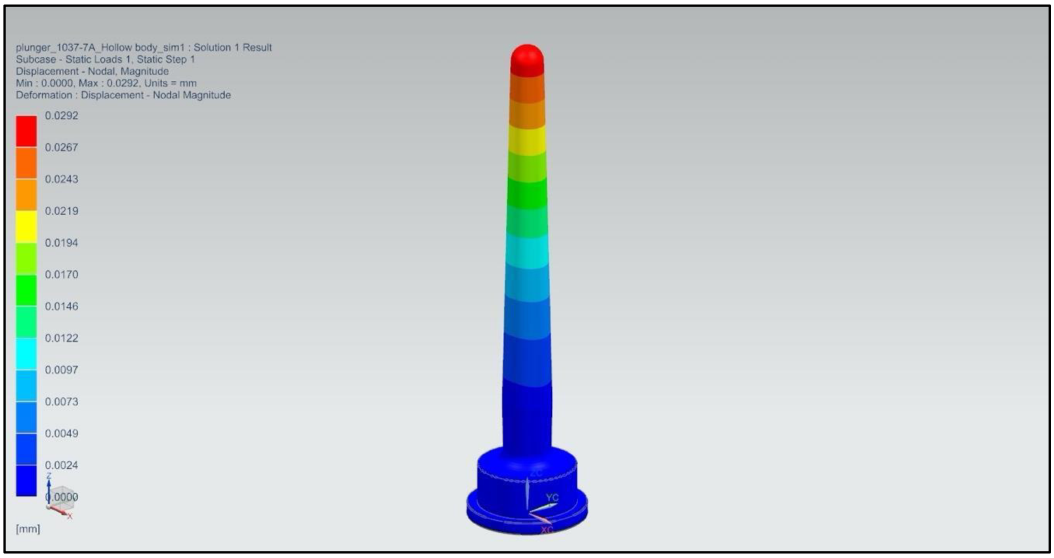
	φ51mm	φ65mm(op.)
Max. Turning Diameter(12st)	300mm	
Max. Turning Diameter(op.10st)	-	300mm
Max. Turning Length(12st)	500mm	
Max. Turning Length(op.10st)	-	480mm
Distance Between Spindles(op.)	780mm	
Distance Between Centers(op.)	689mm	
Bar Capacity	51mm	65mm(op.)
Chuck Size	8"	
L Spindle Speed	5,000min^{-1}	4,500min^{-1}
L Spindle Drive Motor	15/11kW, 18.5/15kW(op.)	
Milling Spindle Speed(op.)	3,600min^{-1}	
Milling Drive Motor(op.)	5.5/3.7kW	

Appendices B: Plunger Dimensions



Appendices C: Condition – 1 (Minimum and Maximum Displacements)


plunger_1037-7A_Hollow body_sim1 : Solution 1 Result
Subcase - Static Loads 1, Static Step 1
Displacement - Nodal, Magnitude
Min : 0.0000, Max : 0.0333, Units = mm
Deformation : Displacement - Nodal Magnitude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Subcase - Static Loads 1, Static Step 1
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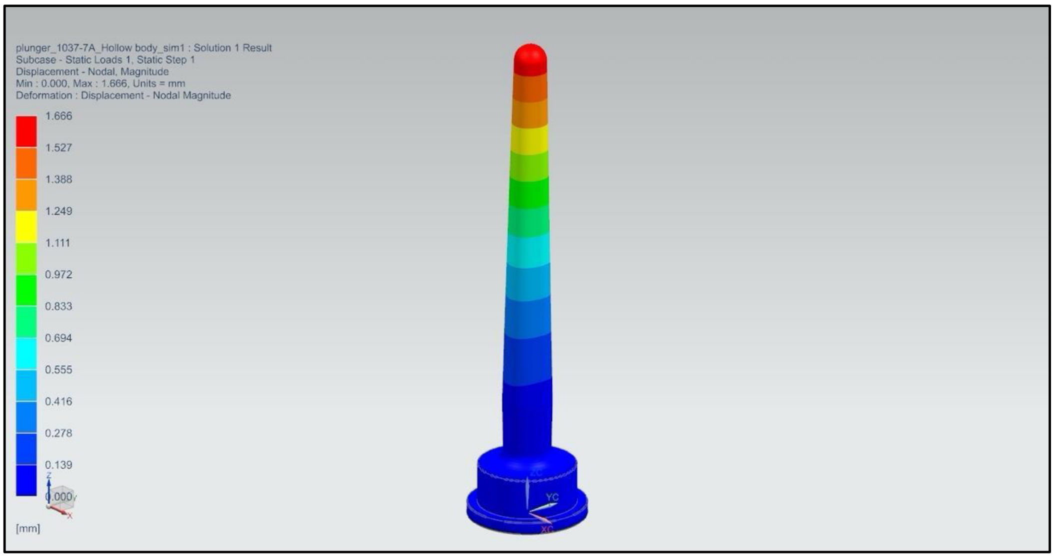
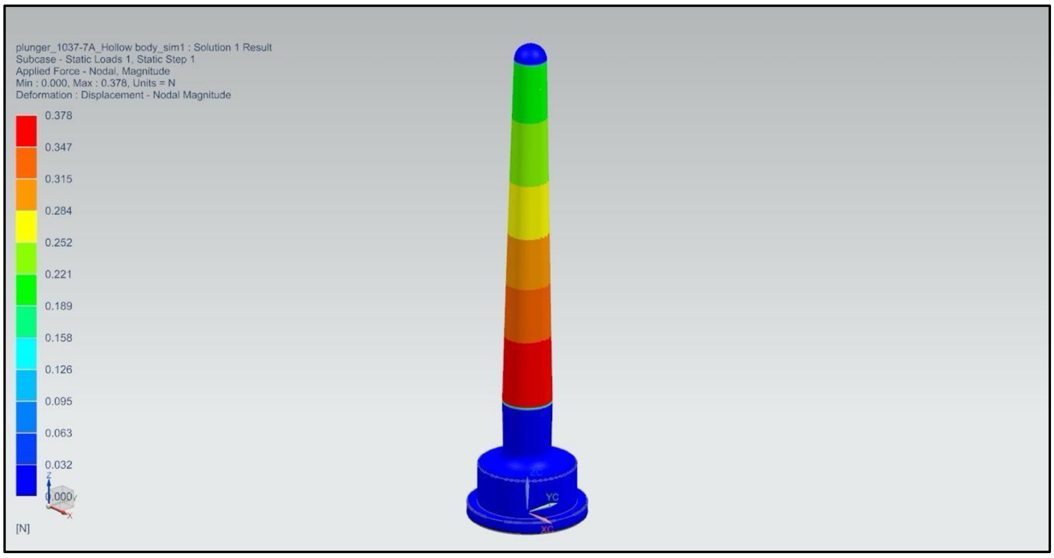
Deformation : Displacement - Nodal Magnitude

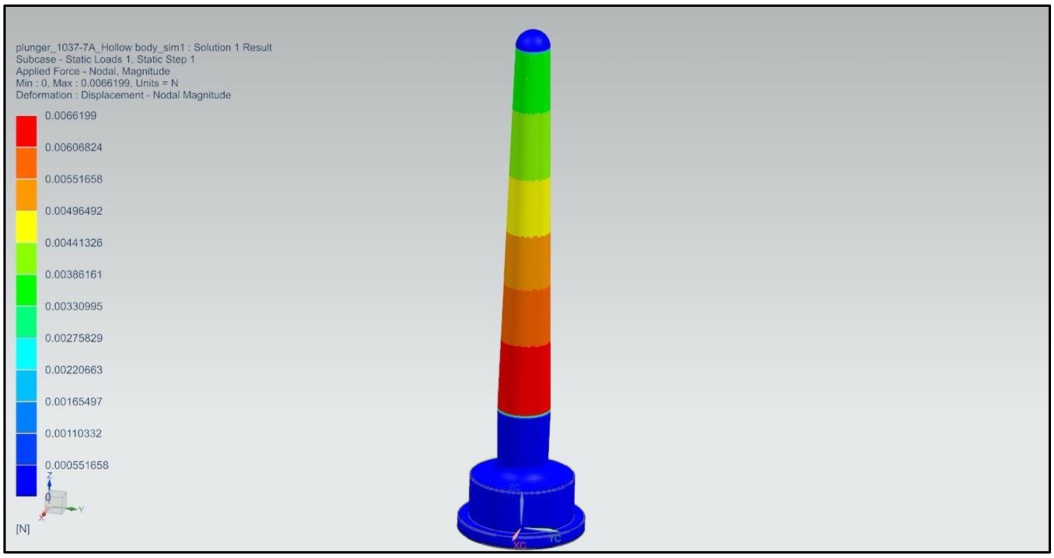


plunger_1037-7A_Hollow body_sim1 : Solution 1 Result
Subcase - Static Loads 1, Static Step 1
Displacement - Nodal, Magnitude
Min : 0.000, Max : 1.666, Units = mm
Deformation : Displacement - Nodal Magnitude

Appendices D: Condition – 2 (Minimum and Maximum Displacements)



plunger_1037-7A_Hollow body_sim1 : Solution 1 Result
Subcase - Static Loads 1, Static Step 1
Applied Force - Nodal, Magnitude
Min : 0.000, Max : 0.378, Units = N
Deformation : Displacement - Nodal Magnitude



plunger_1037-7A_Hollow body_sim1 : Solution 1 Result
Subcase - Static Loads 1, Static Step 1
Applied Force - Nodal, Magnitude
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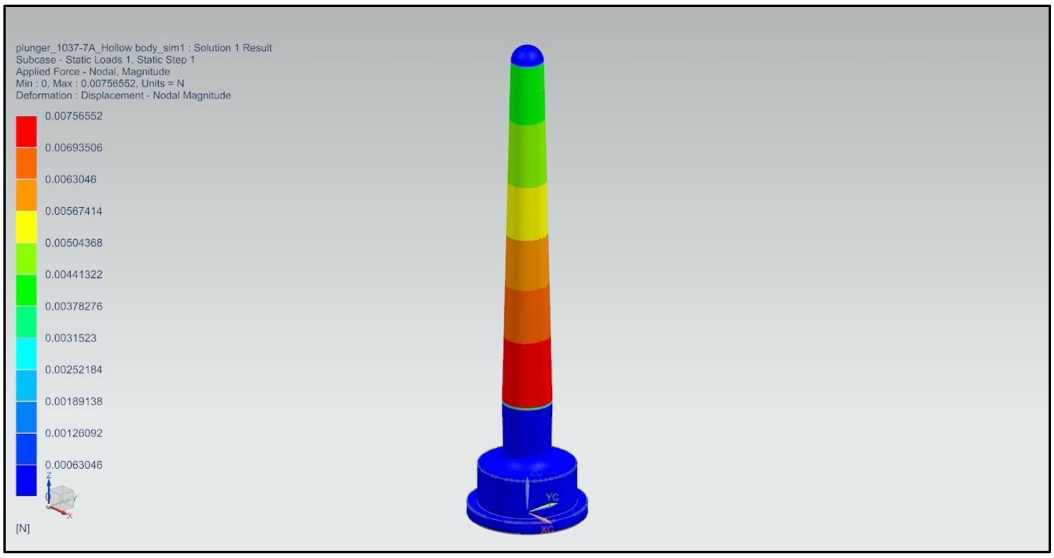
Deformation : Displacement - Nodal Magnitude



plunger_1037-7A_Hollow body_sim1 : Solution 1 Result
Subcase - Static Loads 1, Static Step 1
Applied Force - Nodal, Magnitude
Min : 0, Max : 0.00756552, Units = N
Deformation : Displacement - Nodal Magnitude