Manufacturing technique advances in tool and die production

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Research Article

Keywords: Advanced manufacturing techniques, computer numerically controlled machining, Steel Press Die, AutoCAD, Design

Posted Date: January 17th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1246895/v1

Abstract

Extant research on fabrication of machine parts have contributed to an understanding of manufacturing processes for a tank cover, using conventional methods. However, the gap lies in the need to tap on advanced manufacturing processes in the production of a leak-proof tank cover, to achieve not only precision, dependability, and mass production but also to promote the issue of context in the manufacturing industry. To respond to this gap, we present research that utilizes novel experimental techniques for tool and die production, to demonstrate superiority over existing research in terms of using modern trends in the production line. The contribution lies in buttressing the synergy between conventional ways of fabricating machine parts in the workshop by using current trends to achieve same results as conventional ways of fabricating machine parts by exploiting advantages of using computer numerically controlled machines in the production of the minting ink tank cover. A numerically controlled milling machine was used to achieve better results compared with conventional methods. Engineering design software was used to generate 2-D coordinates of the work piece diagram with which a computer program was written, duly simulated and certified fit to produce the work piece. Results showed an exact replication of the minting ink tank cover that is more importantly, capable of producing 25 pieces per hour and an annual volume of 48000 pieces. These results are significant to the manufacturing industry in achieving four things: time and energy management, mass production, super surface finish, and consistent quality.

1 Introduction

The production of moulds or dies is a tedious process that is and energy demanding. It involves a lot of processes that take time and waste human effort. Press steel die making is laborious and involves heavy metal for haulage. Manufacturing of engineering products with intricate shapes and requiring mass production necessitates production of moulds and dies. The use of moulds and dies in manufacturing cannot be overemphasized. Hence to facilitate quick moulds or die production, the need for automation through Computer Aided Design (CAD) and Computer Aided Manufacture (CAM), using Computer Numerical Controlled (CNC) machines and other semi-automatic machines cannot be neglected [1].

Development and modelling of a computer aided programme from a well detailed dimensional Auto CAD drawing allows the point-to-point co-ordinates of the pattern for the programming. This is presented in codes and instructions that are best understood by the machine. A programming language for the computer numerical controlled (CNC) machine is chosen by the manufacturer. Examples of these programming languages include Siemens Programming, GSK programming, and Aldehan and Sinumeric. Engineers should therefore be versatile with the pattern language and instructions that the type of CNC machine allows [2].

Advanced manufacturing through CNC programming and machining techniques facilitate human effort in this laborious die making activity, and save energy and man hours. It is also made possible through efficient integration of tool inspection for optimum tool performance. Hence, this yields good surface finishing [3].

To produce most geometry shapes, the process of formation and manufacturing of the die may be affected by limitations such as: material availability and cost, machine size, processing speed, dimensional accuracy, surface finishing and cost effectiveness. However, it is safer, convenient, energy and time saving to use automation such as CNC machines in mould or die production [1].

The advent of CNC and other semi-automatic machines makes mass production possible. This is also favored in rapid prototyping (RP) and rapid tooling (RT). Other machines are developed to ease moulds and die production which are also more technologically advanced than CNCs, such as Stereo lithography (SLA), Selective Laser Sintering (SLS), Fused Deposition Modelling (FDM), Three-Dimensional Printing, Direct Metal Laser Sintering (DMLS), Laser Engineered Net Shaping (LENS), Electron Beam Melting (EBM) as additive manufacturing processes. Conversely, the subtractive manufacturing processes are CNC milling, CNC wire EDM, drilling, grinding, and lathe-turning [3]. All these machines can be fully utilized with the use of CAD, which provides a means of obtaining the programme for any operation, through the co-ordinate points obtained from the detailed design work [4].

Drop dies like this are meant for cold forming of materials into their desired shapes as the shapes of the dies. These drop dies are hence capable of mass producing quite a number of the products within minutes [4].

The die and mould making industrial development has been strong in recent years. Machine tools and cutting tools get more and more sophisticated every day and can perform applications at a speed and accuracy not even thought of twenty years ago. CAD/CAM has become popular for machining with High Speed Machining (HSM), which is a necessity for the die and mould making industry [2].

A die is a specialized tool used in manufacturing industries to cut or shape material using a press. Like molds, dies are generally customized to the item they are used to create (see Fig. 1). Products made with dies range from simple paper clips to complex pieces used in advanced manufacturing technology [6].

Forming dies are typically made by tool and die makers and put into production after mounting into a press. The die is a metal block that is used for forming materials such as sheet metal and plastic. For the vacuum forming of plastic sheet, only a single form is used, typically to form transparent plastic containers (called blister packs) for merchandise. Vacuum forming is considered a simple molding thermoforming process but uses the same principles as die forming [7].

For the forming of sheet metal, such as automobile body parts, two parts may be used. The first part, known as the punch, performs the stretching, bending, and/or blanking operation. The second part, known as the die block, securely clamps the work piece and provides similar stretching, bending, and/or blanking operation. The work piece may pass through several stages using different tools or operations to obtain the final form. In the case of an automotive component, there will usually be a shearing operation after the main forming is done, followed by additional crimping or rolling operations to ensure that all sharp edges are hidden and to add rigidity to the panel [8].

Machinability of most types of cast-iron involved in metal cutting production is generally good. The rating is highly related to the structure where the harder pearlitic cast-irons are somewhat more demanding to machine. Graphite flake cast-iron and malleable cast-iron have excellent machining properties, while SG cast-iron is not quite as good. The main wear types encountered when machining cast-iron are abrasion, adhesion and diffusion wear. The abrasion is produced mainly by the carbides, sand inclusions and harder chill skins. Adhesion wear with built-up edge formation takes place at lower machining temperatures and cutting speeds. This is the ferrite part of cast-iron which is most easily welded onto the insert, but which can be counteracted by increasing speed and temperature. On the other hand, diffusion wear is temperature related and occurs at high cutting speeds, especially with the higher strength cast-iron grades. These grades have a greater deformation resistance, leading to higher temperature [9]. This type of wear is related to the reaction between cast-iron and tool and has led to some cast-iron machining being carried out at high speeds with ceramic tools, achieving good surface finish.

Typical tool properties needed, generally, to machine cast-iron are high hot-hardness and chemical stability but, depending upon the operation, work pieces and machining conditions, toughness, thermal shock resistance and strength are needed from the cutting edge. Ceramic grades are used to machine cast-iron along with cemented carbide. Obtaining satisfactory results in machining cast-iron is dependent on how the cutting-edge wear develops: rapid blunting will mean premature edge breakdown through thermal cracks and chipping and poor results by way of work piece frittering, poor surface finish, and excessive waviness. Well-developed flank wear, maintaining a balanced sharp edge, is generally to be strived for [10].

Modern CAD/CAM-systems can be used in much better ways if old thinking, traditional tooling and production habits are abandoned. If instead, new ways of thinking that also approach an application, there will be a lot of wins and savings in the end. If using a programming technique in which the main ingredients are to “slice-off” material with a constant Z-value, using contouring tool paths in combination with down milling, the result will be:

i. a considerably shorter machining time;

ii. better machine and tool utilization;

iii. improved geometrical quality of the machined die or mould; and

iv. less manual polishing and try out time.

In combination with modern holding and cutting tools it has been proven many times that this concept can cut the total production cost considerably. A human being cannot compete, no matter how skilled, with a computerized tool path when it comes to precision. Different persons use different pressures when doing stoning and polishing, resulting most often in too big dimensional deviations. It is also difficult to find and recruit skilled, experienced labour in this field. The machining process should be divided into at least three operation types; roughing, semi-finishing and finishing, sometimes even super-finishing in the context of mostly HSM applications [11].

HSM processes have underlined the necessity to develop both the CAM and CNC-technology radically. HSM is not simply a question of controlling and driving the axes and turning the spindles faster. HSM applications create a need of much faster data communication between different units in the process chain. There are also specific conditions for the cutting process in HSM applications that conventional CNCs cannot handle.

The typical structure for generating data and performing the cutting and measuring process is depicted in Fig. 2.

This type of process structure is characterized by specific configuration of data for each computer. The communication of data between each computer in this chain has to be adapted and translated. The communication is always of one way-type. There are often several types of interfaces without a common standard [12].

2 Methodology

This part is divided mainly into four main parts viz; (1) the CNC coding programming, (2) CAD drawing of the mould, (3) mould fabrication process, and (4) simulation of CNC coding programme for mould fabrication.

2.1 CNC Coding (Programming) of the Mould Fabricated

Programming language in CNC operations varies according to the manufacturer. However, there are slight similarities since the programming codes are the same, but the instruction may be different. Having written the program, it should be test run using CAM software in the computer. The visual simulation will reveal that it is perfect. Another task is perfect speed (rpm) selection and tool, together with coolant, to save the tool life. Decisions involving these selections are necessary for proper chips removal and tool life maintenance.

The programme for the modeling of the steel die is written as depicted in Fig.3.

2.2 Computer Aided Design Drawing of the mould

A well detailed drawing of the design of the work piece of the steel press die for the manufacturing of a bucket cover was done, using AutoCAD.

The CAD was done in order to get coordinates necessary for the writing of the programming language for the CNC machine. This work was mainly milling, hence after materials and tools preparations, the steel plate was secured on the bed of the CNC milling machine for operation [12]. However proper reference was taken to ensure accuracy, since computer movements for the milling operation are as per quality of the programming code, such that garbage in equals garbage out. Fig. 4 illustrates a whole assembly of the mould in AutoCAD.

2.3 The Mould Fabrication Process

The operation is high speed (HS) manufacturing; hence proper cooling is necessary to avoid tool burns and damage. The modeling and development of steel die was adopted through selection of material for the die making. Steel was selected; and then the operation flow chart was done. Justification for selecting steel lies in its desirable and superior material properties such as yield strength, elastic modulus, leak-proof and Poisson ratio, in comparison to alternative materials. For the die production, the following steps were followed during mould fabrication of the die:

(a) Material selection and preparation
(b) Work detailing with AutoCAD
(c) Selection/Tools preparation
(d) Programmed development and Running Job setting and clamping
(e) Referencing
(f) Operations

Tooling, which is an act of workshop practice which deals with the grinding and forming of tools, was involved in making of grooves and contouring. Side cutters, face cutters and side and face cutters for material removal were selected; milling cutters for milling slots and groove were selected and ball nose end mill cutters for contouring were selected.

2.4 CNC Coding

The CNC coding, on running a simulation test in the computer, executed as it was programmed and gave the expected result, thus, validating the accuracy of the programme written for the fabrication of the mould.

2.5 Mould Fabrication

The CNC code was transferred to the CNC machine and the result of the fabrication is as shown in Fig. 5.

3 Experimental Research Results (On Tool And Die Production) And Evaluation

Comparative analysis of experimental results with conventional manufacturing methods demonstrated better results from the use of advanced manufacturing techniques discussed in section 2. These results are also comparable with recent research [13]. The evacuation is discussed in terms of four important aspects namely: (1) time and energy management, (2) mass production, (3) super surface finish, and (4) consistent quality.

3.1 Time and energy management

Optimum tool (milling machine) movements from both CADCAM drawing and CNC coding reduced machining time and hence manufacturing time, all of which improves machine tool utilization. This result enables cost reduction (i.e., electricity, tool life, and labour). For example, the absence of manual polishing and trying out reduces associated labour costs.

3.2 Mass production

The tank cover specimen (1 piece) was produced in 2.4 minutes. This production rate translate to production capability of 24 pieces per hour and hence 48,000 pieces per year.

3.3 Super surface finish

Analysis of surface defects using scanning electron microscope (SEM) showed that the fabricated specimen had no surface defects and hence of superior quality to conventional manufacturing methods. Furthermore, the surface roughness of the manufactured tank cover specimen was 100 micrometer, which indicates super surface finish as per recommended range of between 100 to 200 micrometer [13]. This level of precision enhances dependability in terms of industrial applications, particularly in industries such as automotive, defense, medicine and mining, where performance (influenced by a well-developed flank wear, balanced edge and good surface finish), is key.

3.4 Consistent quality

The use of advanced manufacturing processes discussed in this paper enables consistent quality in the finished product, which is a key issue in industrial applications. The CNC milling machine is capable of producing the same quality, through coding instructions from the computer program associated with of the 2D engineering drawing.

4 Conclusion

This research work explored manufacturing technique advances in tool and die production. A leak-proof steel die was proposed and die production moulds fabricated to demonstrate advances in manufacturing techniques in the production of a leak-tight tank cover. A simulation test of the CNC programme ran perfectly. The same programme was then transferred to the VMC and the mould produced. The standard process of material selection for the production of the mould was followed and the results obtained were in close agreement with those of similar work done by earlier researchers.

This research work clearly elucidate the use of engineering software, such as AutoCAD and CAD/CAM, for the generation of engineering design drawings before the fabrication of the dies, and application of CAD/CAM package for demonstration of technical “knowhow”, in relation to the use of computer numerical controlled machines (CAM) in the execution of the research work.

The main contribution to the field of manufacturing is the development of a novel die mould using advanced manufacturing techniques as opposed to conventional techniques, to achieve superior results in terms of improved benefits. The produced leak-proof steel tank cover showed the following superior material properties and results: super surface finish and absence of material specimen defects (in the absence of manual polishing), It follows that the value lies in improvements in machining time, efficiency, cost, mass production whilst achieving consistent quality suitable for commercial applications.

Industrial applications of this work are in industries such as mining, automotive, medicine and defense, where performance is key. The likely users in terms of industrial applications of this work are large organizations within these industries that seek to gain sustainable competitive advantage in advanced manufacturing techniques, to enable improvements in time and energy management, surface finish and consistent quality, whilst achieving mass production at reduced manufacturing costs.

Declarations

Statements and Declarations

Authors declare no conflict of interest in any way whatsoever.

Funding

The authors declare that no funds, grants, or other support were received for this research.

Competing interests

The authors have no relevant financial or non-financial interests to disclose.

Author contributions

Methodology and analysis were completed by Emmanuel C. Ufomba and Samuel W. Gadzama. First full draft of the manuscript and formatting for journal submission were performed by Lone Seboni. All authors read and approved the final manuscript.

Acknowledgements The authors would like to acknowledge Scientific Equipment Development Institute (SEDI), Enugu for providing the laboratory (equipment and materials) where the experiment took place.

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Figures

Figure 1

Progressive die with scrap strip and stampings

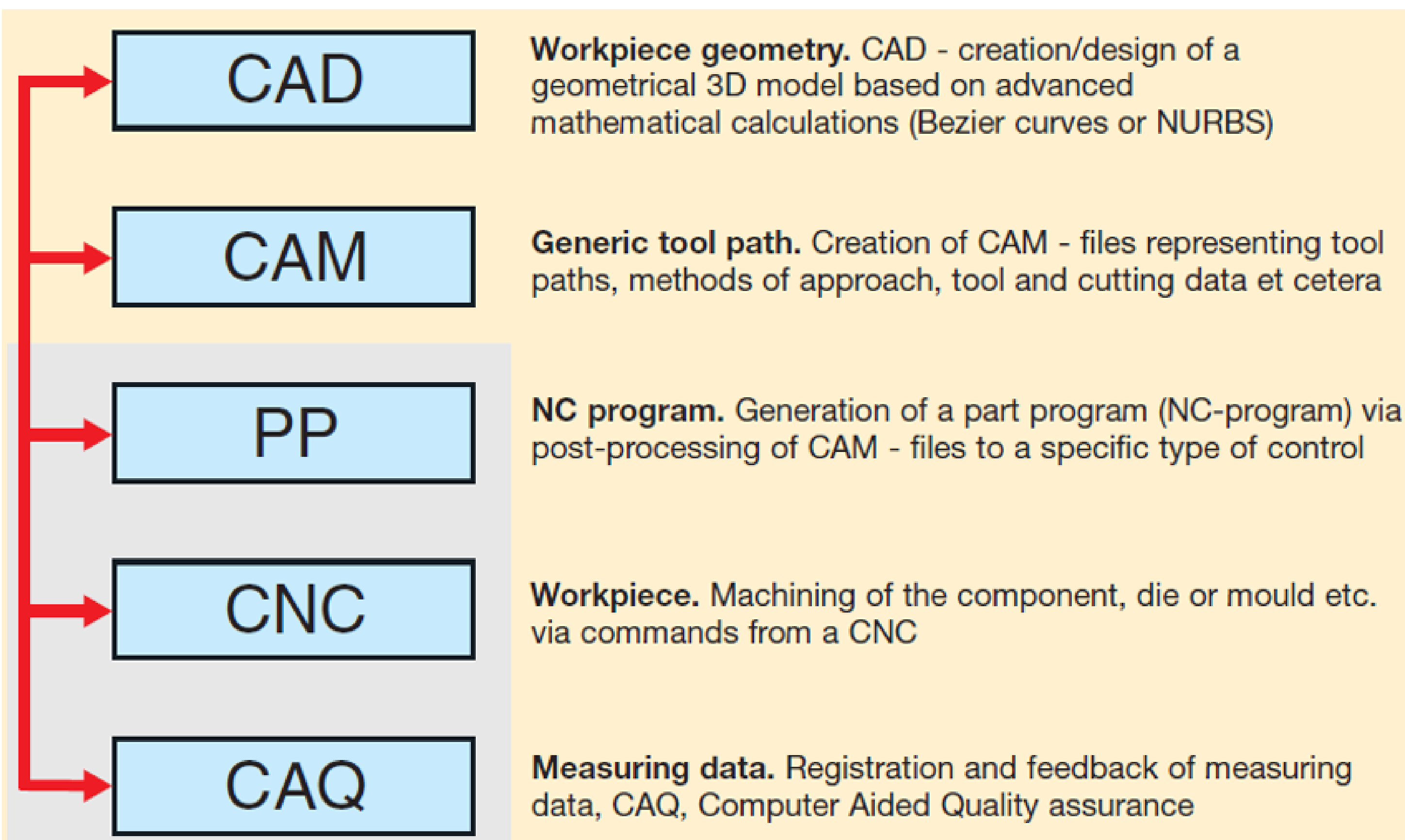

Figure 2

Data formation

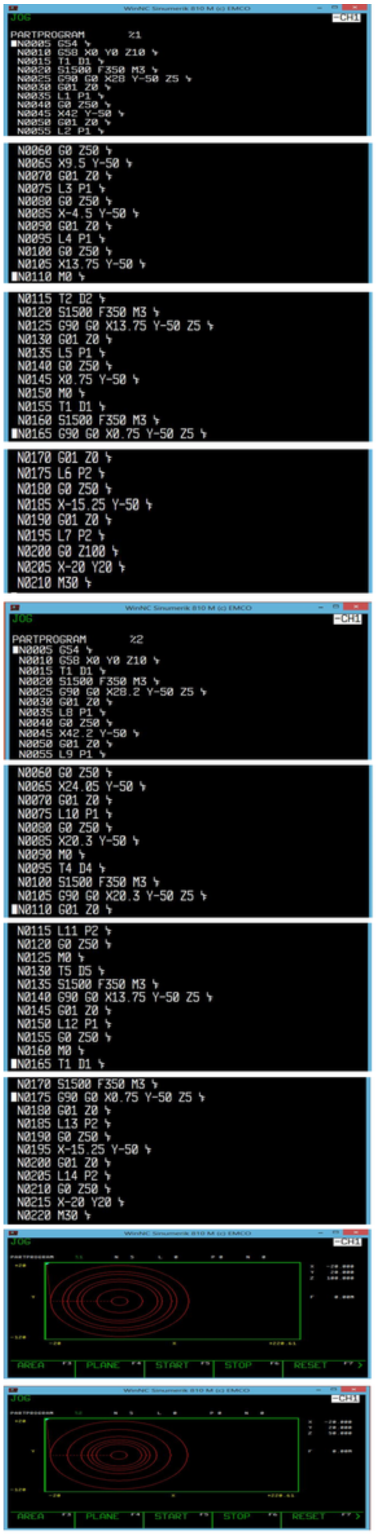

Figure 3

Flow pattern of coding sequence of the CNC operation

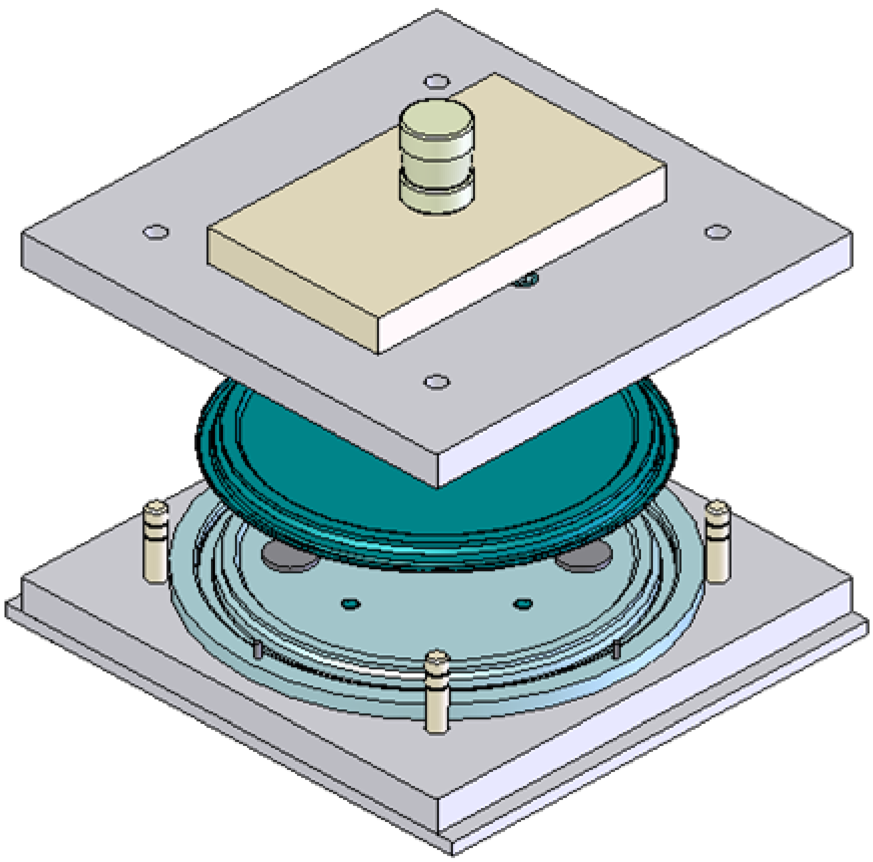

Figure 4

CAD assembled drawing of the mould

Figure 5

The fabricated mould