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An Investigation into Forming of Gears Using Rotary Forging Process

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Gears and toothed parts are significant components in power transmission systems. These parts usually manufactured by traditional methods such as machining by milling or forming by rotary forging. In this study, the forming of solid gears or toothed parts using a forging process that combines rotary forging and ballizing technique. The specimens were placed inside the die with excessive volume to fill the toothed part in the die. The forming tool applies pressure to the specimen while rotating it together with the die by the lathe machine chuck, while the tool advances continuously in the direction of the die. This reduces height of the specimen and increases its diameter, causing metal flow to fill die cavity teeth and form the gear or toothed part required for production. Two sets of experiments were performed. In the first set, optimization for the appropriate volume of four different sizes of dies and four forming tools was conducted. While in the second set, the effects of forming process variables on the forming load and tooth filling percentage was studied. The results showed that the best tooth filling ratio happened with specimen size of 1.2 to 1.4 times the volume size of the desired tooth for filling. The results also revealed that the forming speed, die size, and forming tool diameter affect the filling ratio and forming load.

Keywords: Forming of gears, Rotary forging, Externally splined, Ballizing technique, Filling ratio and process parameters

1 Introduction

Metal forming is a manufacturing process that involves the reshaping of metal into the desired shape. Gears and toothed parts are one of the most important and used elements in mechanical engineering, cars and power transmission equipment. Gears are traditionally produced by cutting processes. According to high engineering quality standards, cold forming represents a promising alternative for the production of high-load gears.

Wei Wang et al [1] presented a proposal for the forming process of serrated tooth gears by warm extrusion, using numerical simulation method. In order to reduce forming defects such as sample separation during forming, the main reason that causes insufficient gear face section is unbalanced speed distribution during the extrusion process; They succeeded in improving the product and machines and controlling defects. To overcome the manufacturing defects of gears produced by the rotary forging process and reduce the forming load of this process.

Wang Huajun et al [2] studied the rotary forging process for spiral bevel gears using the finite element method, and the load was analyzed with time at each stage. Thus obtaining the tooth filling stage during rotary forming of helical bevel gears. As a result, the reason for the difficulty of filling the mould was clarified through theoretical calculations and the lead sample was tested practically to verify the success of the rotary forging process to form a spiral bevel gear.

C. Kiener & M. Merklein [3] presented a numerical investigation of tool effects in cold forming of gears by extrusion process. Based on experimental results, FE models were developed with the aim of optimizing the process to cold forming gears according to the "Samanta" principle. Moreover, the identified results are essentially transferable to the conventional forward extrusion process for gear production.

The microstructure of cold rotating gears greatly affects the quality of the gear produced. Therefore, Xinghui et al [4] presented a study to improve the microstructure and texture that occurs during cold rotary forming of toothed bevel gears of 20CrMnTi alloy steel. The grain development of gear teeth is studied through optical microscopy. The results indicate that the grain size distribution is non-uniform from the tooth shape to its centre.

In view of the great importance of forming gears with a final finish and with high quality, ZHUANG Wu-hao, DONG Li-ying [5] carried out a study of the influence of the main factors on the quality of bevel gear forming. Using the finite element (FE) method and the variable control method, the forming variables have influence such as the rotation speed of the upper tool, n, the feed speed of the lower tool, v, the inclined angle of the upper tool, γ, and the friction factor between tools and billet, m, and they found that the flash becomes More uniform with increasing v, increasing m, decreasing n, or decreasing γ.

The gear deformation becomes more uniform as v increases, n decreases, or γ decreases. Finally, a corresponding experiment is performed, which verifies the accuracy of the FE simulation conclusions. Yao Lin, Tao Wu and Guangchun Wang [6] proposed a sequential process for forming large modulus (m > 2.5 mm) fair-tooth gears, where a single-tooth die forms the gear teeth one by one through several passes as a first stage and in In the second stage, another multi-tooth mould refines the pre-shaping of the teeth into the desired shape. The feasibility of this method has been proven. Compared with the whole gear forming process, it shows a reduction in the forming load, simpler tools, and good possibility of manufacturing large-sized gears and large-scale plants.

Forming a fluted column using the axial cold forging process is a difficult topic, so Ning-yu et al [7] used a finite element model using a material model based on the strain rate, so that the metal flow is divided into three different parts, and a three-part assembly method was designed. New dies and dies with variable tooth shape and comparing the differences in metal flow, tooth shape and axial force between traditional axial methods, assembly dies and the new dies. The three-die assembly method resulted in a 31.2% force reduction compared to conventional axial forming. However, the defects of the product were also significant. The quality of the product shape formed by the new mould with changed tooth width was also improved due to the avoidance of defects.

Denis J. Politis et al [8] presented a review of methods that have been developed over the years to reduce labor forces for precision metal forming operations. Cavities on the ends are difficult to fill and require high loads. Methods of reducing the load in forging operations while achieving complete mould filling are important topics. Methods of reducing the load for precision gear shaping have been presented.

The methods reviewed are divided into the categories of (1) material design, (2) tool design, and (3) tool design the operation. Their effects on forging load reduction for fine forging, together with the authors' opinions on the benefits, disadvantages and applicability of each are presented. Flange gears have complex shape and metal distribution during forming along the axial direction suddenly studied by Qiu Jin, Zhiqiang Gu and Jian Hua [9]. They proposed a forging design method in cold orbital forging for complex shaped gears and built a three-dimensional finite element model of cold orbital forging. Cold orbital forging processes were simulated under different geometries and insufficient filling defects were studied. Improving the model and removing defects. The presented design method for forming cold-orbiting flange trusses is also experimentally performed and verified experimentally.

Duy Dinh Van et al [10] studied hot and cold microforging based on simulations and experiments for forming straight-toothed bevel gears made of A5052 aluminium. The study was conducted using the finite element (FE) method and experimental experiments. To improve the hot or cold forging process by giving an accurate description of the material flow, packing conditions, and numerical damage index and comparing it with experimental, the results showed agreement between numerical simulation and experimental analysis of straight bevel gears. Inadequate filling is one of the major disadvantages of traditional forming of closed cold die gears.

Changeling Hu et al [12] presented a study aimed at improving the packing condition of gear teeth. Because die shape is one of the most important forming factors, three design schemes with different die shapes were investigated, the finite element method was used to simulate the cold forging process with an axisymmetric 2D and 3D model, and stress distributions and velocity distributions were studied through another processor. They concluded that corner filling was improved, and well-shaped gears were formed.

Finally, a corresponding practical experiment is conducted, which is mainly used to support and validate the numerical simulation and theoretical investigation. FENG Wei et al [12] presented a study of the effects of the geometric shape of the forming tool on the precision cold forming process of helical gears. Six different metal pieces were used as the forming tool. The geometric shapes were designed using the relief hole principle. The effects of billet geometry on the forming load and the uniformity of deformation were analysed using the three-dimensional finite element method to study the deformation mechanism through the distribution of the flow velocity field and the effective strain field.

Using lead as a model material under the same process conditions used in the FE simulations. The results show that the forming load decreases with the increase of the relief hole diameter d0, but the effect of d0 on the deformation uniformity is very complex. The forming load is lower and the deformation is more uniform when d0 is 10 mm. Lei Shi [13] and others presented the optimal design for the double-action rotary forging process, as the double action leads to greater force being applied to the gears, which improves the quality of tooth filling and thus the quality of the gear produced in this way, based on double-event rotary forging, which led to a reduction in manufacturing costs.

Bernd-Arno Behrens et al [14], [15] Anna Chugreeva et al and others presented a study on the production of hybrid bevel gears containing two different types of steel on the outer surface and on the inner surface using a process that combines forging and welding. Integrated heat treatment of the process was performed. Immediately after shaping. For investigations, material combinations of 41Cr4 with C22.8 (AISI 5140/AISI 1022M) and X45CrSi9-3 with C22.8 (AISI HNV3/AISI 1022M) were applied. To reveal the effect of individual processing steps on the resulting interface, metallurgical examinations, hardness measurements and micro-tensile tests were performed after forming and integrated heat treatment of the process. Recrystallization, grain refinement at the interface, and an increase in hardness and tensile strength were observed in the gears manufactured in this way.

During the precision cold forming process of helical gears, the die is exposed to high forming pressure, which results in elastic deformation of the die that damages it, which is the main factor affecting the dimensional accuracy of the machined gear. Wei Fenga [16] and others introduced the split flow method in forming plastic materials, which is an effective method to reduce the forming force and reduce die pressure during cold precision forming of helical gears. They presented the construction of three-dimensional finite element (FE) models to simulate the plastic billet deformation process during forming using different diameters of die holes.

They found that the deformation increases first and then decreases when the diameter of the vent hole increases. Tooth parts with greater deformation elasticity and the peak value is located in addition. It demonstrates the importance of improving the relief hole diameter and reducing the dimensional inaccuracy in gear machining caused by die elastic deformation. Ping WANG and Xiao Fei DONG [17] presented a new gear forming technology using cold rotary forging for folded internally toothed helical gear based on the structure analysis of automobile starter guide cylinder.

A 3D solid plastic finite element model was an employee. The billet deformation, billet equivalent stress and forming load were studied under DEFORM 3D software environment, then the forming process was applied in the forming experiments, and the simulation results are consistent with the experimental results. The validity of the 3D finite element simulation model was verified. The research results show the efficiency of the proposed cold rotary forging technique in dealing with the problems of manufacturing and shaping these gears.

Wuhao Zhuang et al [18] Fabrício Dreher Silveira Lírio Schaeffer et al [19] presented a development of the forging process used to produce gears and an advanced method for manufacturing bevel gears with fair teeth. They also presented a simulation model of the spur bevel gear under the same conditions in the Deform software platform. -3D. To improve the distribution of metal. The results show that compared with traditional cold forging of bevel gears, the advanced cold forging can increase the degree and uniformity of plastic morphology and improve the accuracy of gear teeth.

Abdel Tawab et al [20] presented the polysizing method for producing sleeves with internal threads, considering that this method is close to the internal circular seal for producing modified threads, using a mathematical model and studying the sizing variables on the filling ratio of the threaded sleeve. The results showed the convergence of the mathematical model with the practical results. J. Cai et al [21] and others address die design aspects in the gear forming process and alternative tool designs that can be used on a press with only one moving slide and ejection system.

The effects of different designs on metal flow and load requirements are studied through experiments and finite element simulations. The effects of friction on loads and the flow of metals are discussed. M. L. Elves et al [22] developed a tool system to produce parts such as gears. The overall probe uses conventional gears. Basic research is conducted using existing virtual prototyping techniques based on the element method. The use of such techniques provides a better insight into the mechanics of forging during the forging process, but a later stage can be developed in order to put the proposed forging concept on an industrial basis.

Moulds are exposed to high contact pressures and temperatures during the moulding process that greatly affect the lifespan of the moulds M. Deplaned and A. Groseclose [23]). They studied the use of mould material quality, hardness, and coating to increase the life of the mould. Using finite element analysis (FEA) based methods were also used to estimate abrasive and plastic wear over the life span. Tae-Wan Ku [24] proposed a two-stage cold forming process to manufacture a drive shaft with internal splines using extrusion. In the design process, the mould is designed using a volume division system of the desired target shape, after which, the initial circular mould is selected. AISI 1035 carbon steel was selected as the raw material, and spherical heat treatment was adopted. Considering the results, the results indicate that the proposed two-stage cold forging process can be well applied to produce the toothed drive shaft.

Wuhao Zhuang et al [25] presented an investigation that the microstructure and mechanical properties of cold rotating gears are of great importance in improving their service performance. They also presented the development of a three-dimensional FE model of hard plastic to simulate cold rotary forging, and the results of this led to improving the performance of bevel gears. Duy Dinh Van and Duc Quang Vu [26] presented a study that, through 3D numerical simulation, studied some geometries of work pieces and tools to find the optimal parameters. The results obtained from the simulation method determined that a cylindrical work piece with a tapered end and die bottom with convex profile will increase the material flow velocity, improving cavity filling, uniform pressure distribution in the forming sample, and forming products without defects. Which ensures geometric accuracy.

Grzegorz Samołyk [27] used orbital shaping in which one die performs a complex oscillating motion. To ensure the required load is reduced and to allow cold forming of the work piece is a bevel gear. The results of this method led to the production of conical gears made of aluminium alloy. Devanathan. R and Vela Murali [28] Sundar Singh Sivam et al [29] X. HUANG et al [30] and M. E. Plancak and [31] presented a numerical study and simulation of the rotary forging process to produce bevel gears.

The orbital cold forging process is used, which is an innovative process in manufacturing. In this method, one of the moulds is tilted To a certain angle and perform a complex swinging movement with specific paths. As a result, the contact area between the mould and the work piece is reduced and it is constantly moved. The history of various variables such as stress and tension has been studied [32]. The results provide valuable guidance for better understanding the morphology characteristics of orbital rotary cold forging Abdel Tawab et al [33] used steel balls in two forming processes, the process of expanding the end of pipes and the process of producing a gear with straight teeth using the pressure of steel balls inside a mould that forces the metal to fill the void of the mould, forming a gear. Rajab Kamal et al [34] and Ayman A. Abd-Eltwab et al [35] and [36] presented a study on the production of parts. using a simple shaping tool based on ballizing technque.

It can be seen from the previous review that; the process of forming the gear was need more investigated. The process of rotary forging with balls (Ballizing process) is proposed here to manufacture a solid gear. In this paper, a new method for forming threaded parts using a rotary forging process with a new tool is proposed. The experienced Brazilian cold forging manufacturer has developed a process to produce gear parts using ballizing process.

2 Materials and Methods

2.1 Test Rig and Used Device

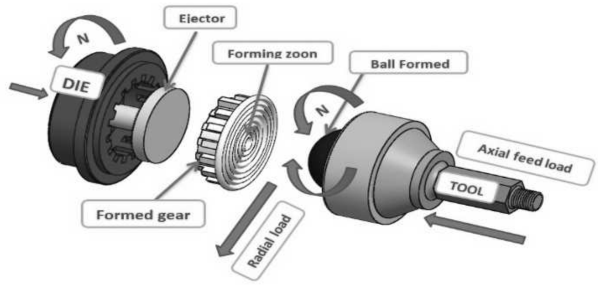

Fig. 1 *Schematic of the rotary forging process*

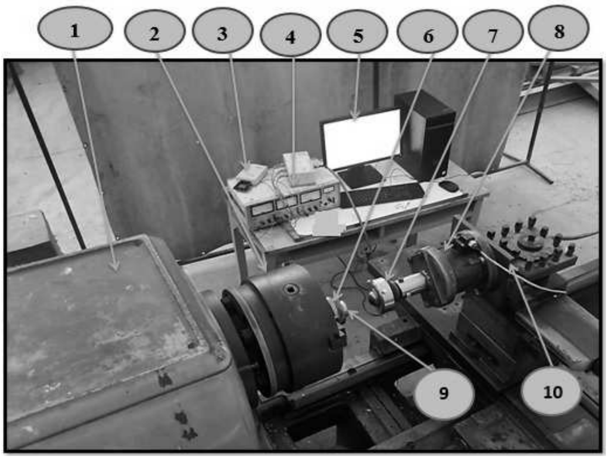

Fig. 2 *Experimental set-up of the rotary forging process*

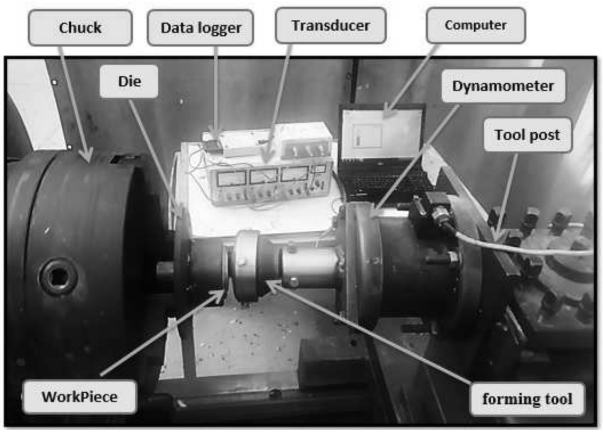

Fig. 3 *Experimental set-up of the rotary forging process during deformation*

Experiments were conducted using sets of dies and forming tool with different sizes, two different groups were built to conduct the experiments. Preparing the laboratory equipment for the experiments of this research began by designing the forming equipments.

First, the idea of the work was explained and illustrated in Fig. 1 The idea of manufacturing gears and toothed parts using the rotary forging method is based on applying the forming load through the forming tool (free forming ball) while the die rotates. The forming ball applies pressure on the sample as it rotates, and with the rotation the tool advances, causing compression in the sample. This compression leads to a decrease in the length of the sample combined with an increase in its diameter. This increase in the diameter fills the grooves of the teeth.

Fig. 2 and 3 shows two photographs of the laboratory equipment, which consists of: 1- a lathe machine as a forming machine, 2- the lathe chuck, 3- the data logger with the operating system (acquisition system), 4- the transducer, 5- a computer to record the results, 6- the forming die. 7- Forming tool, 8- dynamometer, 9- specimen, 10- forming tool holder.

As for Figs. 4 and 5, they show a SolidWorks visualization of the parts and assembly of the process in various stages of manufacturing, starting with the installation of the sample in the die, and the adjustment of the variables of the forming process and the rotation of the sample, the forming tool advances, forming the sample into a cylindrical shape to produce gears or parts with external teeth. Fig. 5 shows the sample before and after the forming process.

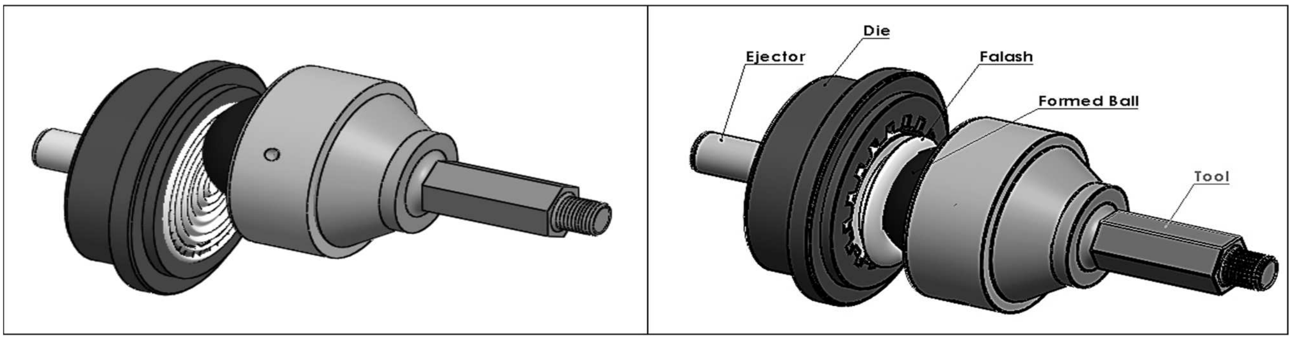

***Fig. 4** Schematic of the rotary forging process during deformation stages*

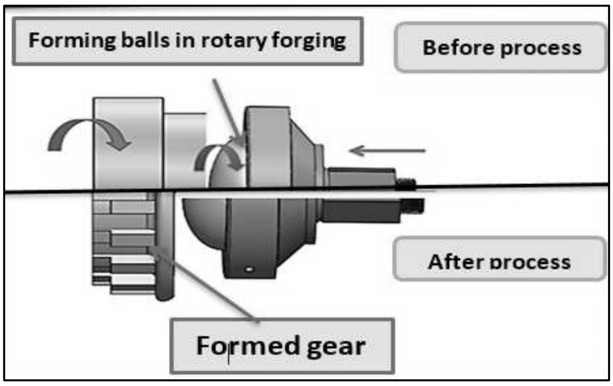

***Fig. 5** Schematic of the blank before and after deformation*

2.2 Forming Tool

Preparing the forming tool used in this work requires a design that allows the forming ball to rotate freely around its centre. The ball takes its free movement from the movement of the specimen by the contact between the specimen and the ball during the process. The free rotation of the forming ball reduces the friction which affects the forming process. Die rotary motion is operated by the lathe chuck.

Fig. 6 used to describe the forming tool parts as follows: a picture of the tool assembly; a Solidworks drawing for the tool assembly consists of a complete assembly and a section view to show the assembled parts. Balls with diameters of 30, 40, 50 and 60 mm were used with a one holder for the four diameters mentioned 1 and 2 in the section view to hold the balls. Each ball has a cover mentioned 3 in the section view to hold the ball inside the holder without obstructing its free movement. This assembly is positioned as a forming tool on the lathe carriage at an angle of $0_{\circ}$ so that its axis is exactly symmetrical with the die. One forming tool of one size was used to make the gear in this manner.

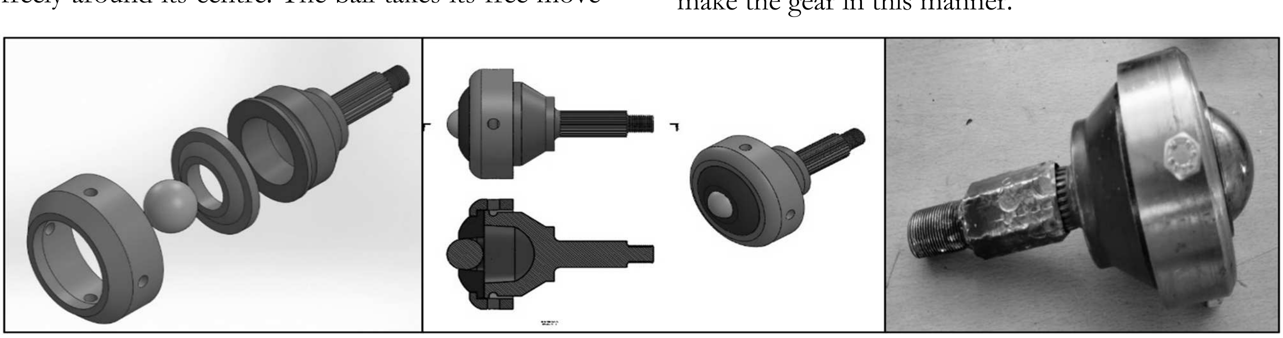

***Fig. 6** Schematic of the forming tool in rotary forging process*

2.3 Forming Dies

The forming dies used in this work consist of four different sizes as shown in Fig. 7 with an inner diameter of 25, 44, 55, and 66.5 mm. These dies are internal gears with straight teeth, approximately 50 mm long, and are fixed in a holder to secure the gear and attach it to the lathe chuck. As the die is placed on the lathe, it is positioned exactly axially with the lathe rotation axis and with the forming tool axis. The die also includes a small square hole that prevents the sample from slipping inside the die and contributes to maintain the rotation process of the specimen with the die. After the forming process, this part is used in cooperation with the forming gear to extract the specimen, using light knocks on the sample ejector and thus it is extracted from the die. Each die contains an ejector part corresponding to the dimensions of the die.

2.4 Forming Samples and Materials Used

The forming specimens are from Lead material and were produced by casting in a specific casting mold to get the required dimensions. The specimens has an outer diameter equals to the inner diameter of the forming die. It is securely fixed to the die and has a protruding portion of square section that is placed into the hole in the die to prevent the sample from slipping during rotation. The specimen rotation speed is adjusted to be equal to the die speed. All preform samples have a classification according to the die size. There are four sizes available used to produce gears made with the same cylindrical sizes as the dies, but without teeth. Teeth are formed during the formation process. Lead material was chosen for the samples in this work, due to the excellent research properties of lead. The melting point of lead is 237 °C, and the crystallization temperature of lead is room temperature, so using lead as forming samples at room temperature is similar to hot forging, but it is done under normal room conditions without heating. In addition, lead is a heavy material with a density of 11.3 g/cm3, which requires high forming strength, so a suitable machine must be selected to withstand these loads. Fig. 8, used to identify four different sizes of samples which are used in the production of solid gears of different diameters, also experiment preparation steps showen in Fig. 8. The hight of the specimen part which are inside the die is set to be 15 mm, and the length of the distinct part of the sample that comes out of the die is chosen so that it changes with the variables of the forming process. Its dimensions were chosen to be double the size of the teeth that must be filled to form the gear. The diameter of the specimen part which fixed inside the die is depending on the die diameter as mentioned before that there are four dies used.

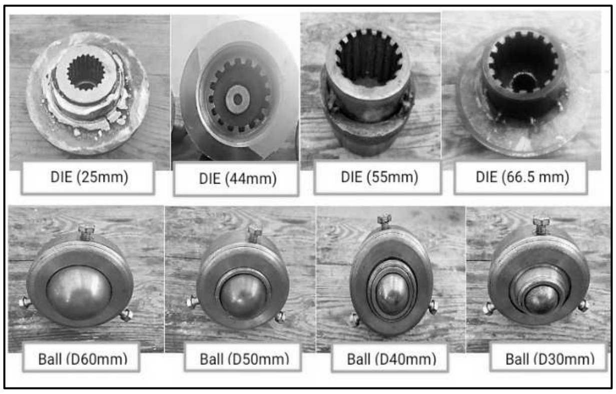

Fig. 7 *The dies and forming balls used in rotary forging process*

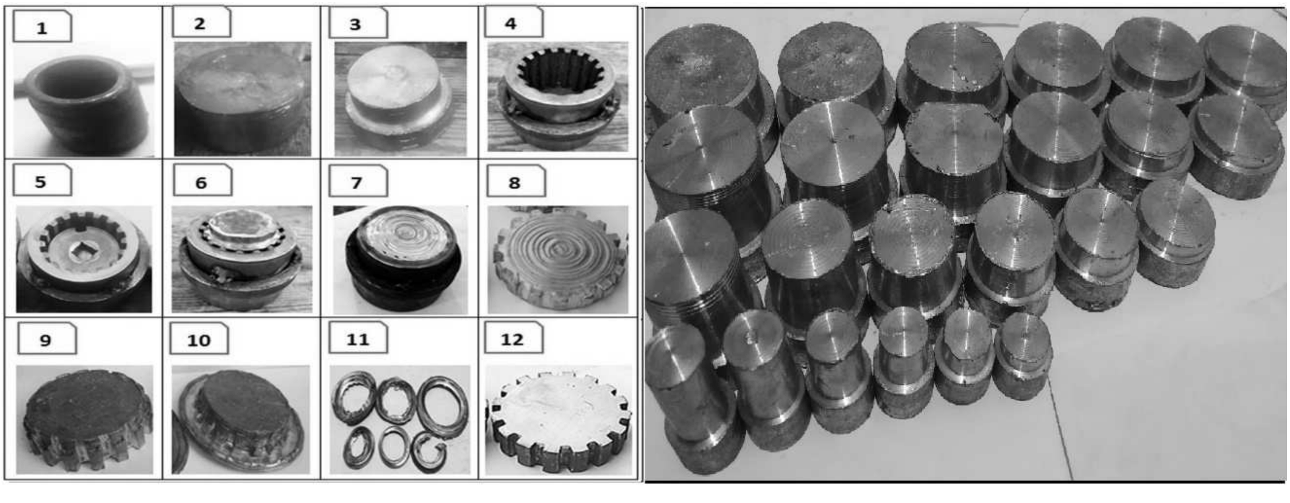

Fig. 8 *The blanks used in rotary forging process and experiment preparation steps*

2.5 Measuring Devices and Their Calibration

A dynamometer is used during the forming process to measure the forming force required for the process in the three axes. This data is collected and transferred to the transducer and then to the computer using the data acquisition system. The readings are recorded as an electrical voltage in millivolts. This value is sensed via a bridge of resistors connected to each other by strain sensors installed inside the dynamometer. Four strain sensors are installed in each direction. By measuring the potential difference generated as a result of applying the forming force and by calibrating the dynamometer, we can determine the value of the force in newton resulting from this small change in voltage. After completing the sample forming, it is cleaned, and any excess material is removed. The sample is then prepared to obtain a final shape. Next, the filling percentage is measured by the sample weight and compared to the theoretical weight of the fully formed sample. The sample volume is calculated using a height of 15 mm along with the volume of the tooth. The total theoretical weight is calculated using the density of the sample metal. The filling ratio of the completed sample is then calculated by knowing the actual weight of each sample and dividing it by the theoretical weight.

2.6 Experiments and Measurements Program

Two sets of experiments were selected to study the factors affecting gear forming using rotary forging. In the first set, the effect of volume ratio on the filling of the teeth was studied. The specimen volume must be more than the required gear volume to insure the filling of the teeth cavity in the die. The specimen volume selected to be from 1.03 to about 2 times the die volume. Six volume ratios were available differed by the height of the excess part of the specimen outside the die as this height was 5, 10, 15, 20, 25, and 30 mm with a diameter less than the inner die diameter by about 10mm.

The second group was selected to check the effect of the forming ball diameter, rotational speed, and feed rate on the filling ratio and forming load with the four available die size as follows: ball diameter of 30, 44, 50, and 60 mm; rotational speed of 8, 10, 12.5, and 16 RPM; Feed rat of 0.013, 0.08, 0.16, and 0.2mm/rev; die diameter of 25, 44, 55, and 66.5 mm.

2.7 Steps of the Experiments and Measurements Program

All specimens are prepared with the required dimensions before starting the forming process. The sample to be formed is well fixed inside the die, and the rotation and feed rate of the forming machine is adjusted. All connections and fittings are connected, and the forming tool is tightened in place and well positioned. After that, data recording is started using the Data Logger program and the machine is turned on. During the forming process and at the end of the journey, the machine is stopped and the results recording program is disconnected, and the sample is removed and prepared to measure the filling percentage. All experimental data are collected according to the previously designed experimental program, and the data are recorded for processing and extracted in the form of curves using Excel programs.

3 Results and Discussions

The results of the research are discussed at this part in three parts. The first part discussing the samples appropriate size. The second part discussing the different parameters affects the process. The last part is about the product quality.

3.1 The Appropriate Size Required for Experimental Samples

Figs. 9 (a) to (d) shows the values of the filling ratio percentage in the first set of the experimental program to determine the best value for the appropriate specimen volume ratio of the die volume before forming. The aim of these experiments is to determine the values that allow the best possible filling of the die cavity to form a complete gear or tooth-like part suitable for use. The relationship between the filling ratio and the length of the part outside the die appears at different speeds and the number of dies of different sizes. These experiments are carried out with a feed value of 0.013 $mm.rev^{-1}$ and a ball diameter of 44 mm. It is clear from the Figures. that the curve follows the same trend with different speeds. Each die has a sample size in which the best filling ratio occur. The filling ratio changes with different length sizes outside the die. When the length is less than the maximum point, less and incomplete filling occurs and is insufficient to fill the entire die cavity. When long samples exceeding the specified maximum value are used, the filling level is lower. This can be due to the difficulty of the metal flow filling the teeth cavity in the die, even though a larger quantity of the required metal is available.

Another way in which metal flow leads to the formation of an unwanted part also occurs, causing metal to build up far from the gap to be filled in the die. This results in less opportunity for the gaps in the die to be filled with metal and thus the resulting gear is incompletely filled.

The relationship between the filling ratio and the length of the part protruding outside the die was studied in four dies of different sizes, and the same trend as before was observed. It turns out that there are repeated values for the length of the part protruding outside the die. For example, in the die with a diameter of 25 mm, the best filling ratio value of about 85% was achieved when using a sample length of 14 mm, and in the tool with a diameter of 44 mm, the best sample length was 16 mm with filling ratio of about 95. In the die with a diameter of 55 mm, the best length of the sample was 18 mm with 96% filling ratio, and finally in the die with a diameter of 66.5 mm, the best length of the sample was 21 mm with about 80% filling ratio. This relationship can be seen in Figs. 10, 11, 12 and 13.

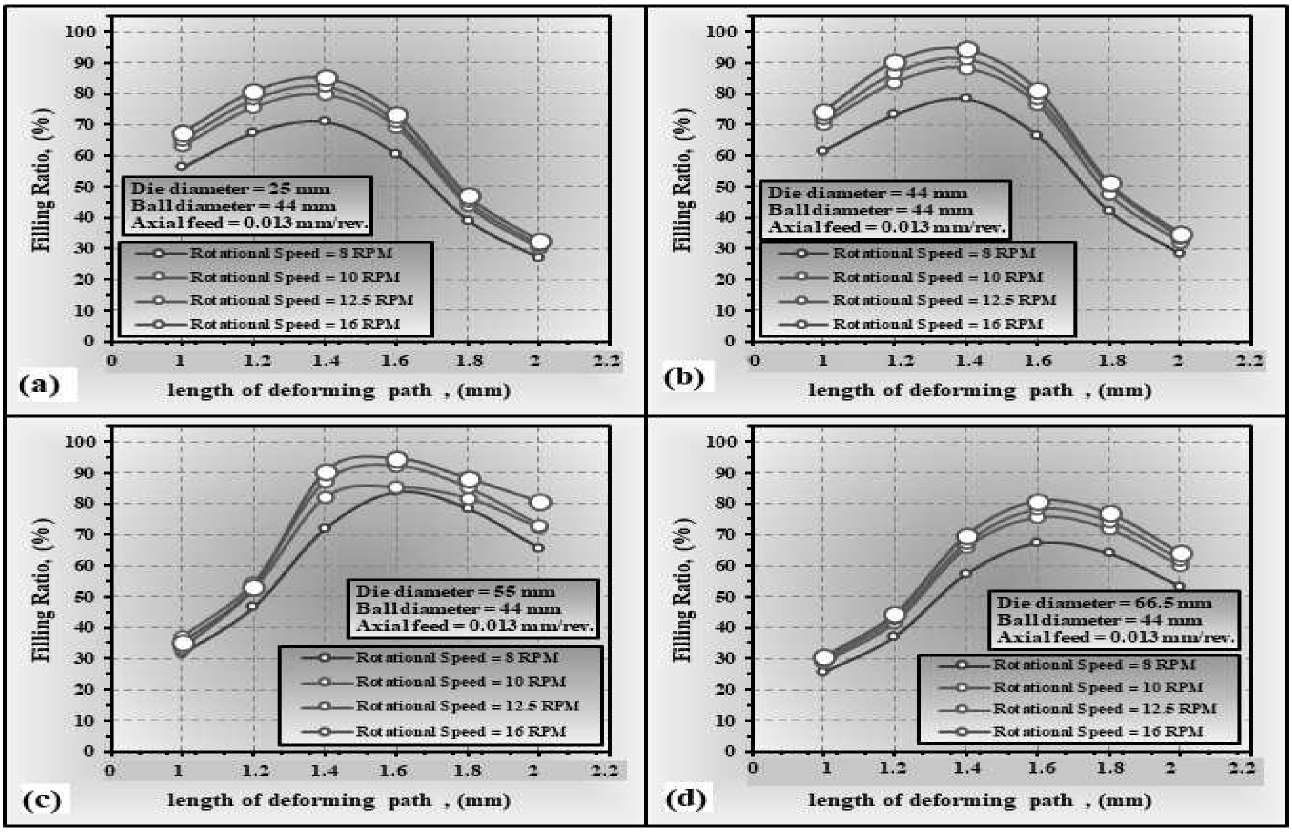

Fig. 9 *Filling ratio against length of deforming path at different rotational speed for die diameters 25, 44, 55 and 66.5 mm*

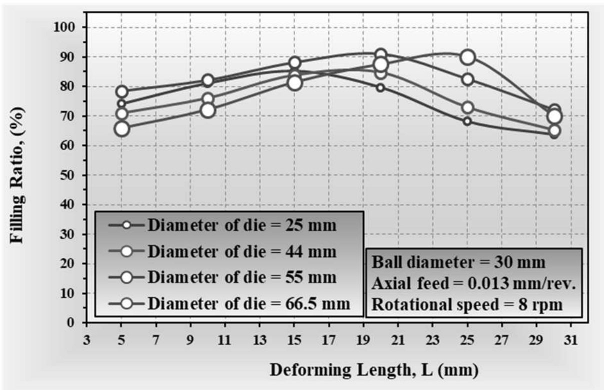

Fig. 10 *Filling ratio against length of deforming at different die diameters and ball diameter 30 mm*

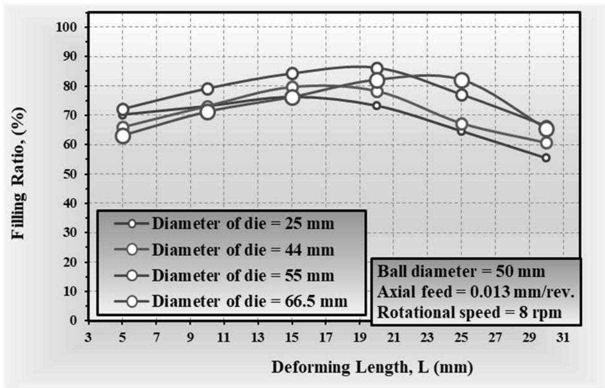

Fig. 12 *Filling ratio against length of deforming at different die diameters and ball diameter 50 mm*

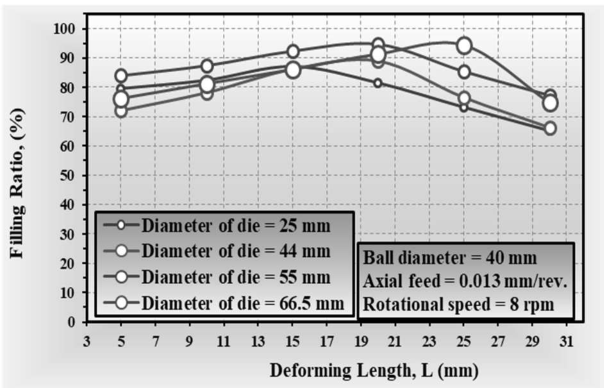

Fig. 11 *Filling ratio against length of deforming at different die diameters and ball diameter 40 mm*

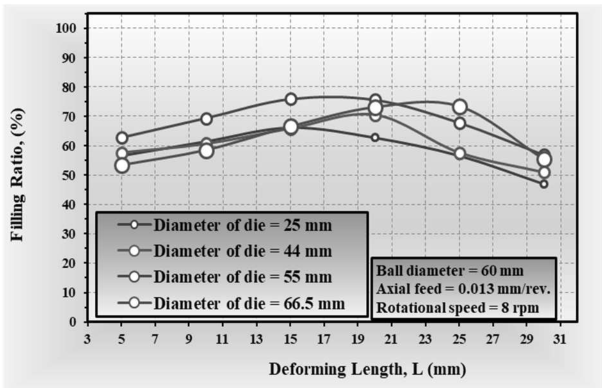

Fig. 13 *Filling ratio against length of deforming at different die diameters and ball diameter 60 mm*

3.2 Study the affect parameters on the filling ratio and forming load

By looking at Figs. 14 it can be observed that the ball diameter affects the filling ratio in all cases of die diameter with the same trend. It can be concluded that the ball with diameter of 40 mm can fill the die cavity more than any other diameter. This can be due to this diameter does not cause a built up material or flash metals outside the die cavity.

It can be concluded from Fig. 15 that it shows the same effect of the ball diameter on the filling ratio. Also, it can be shown that the increase in the rotational speed decreases the filling ratio.

Fig. 16 and 17 illustrates that any increase in the forming ball diameter increases the forming load and this is due to the increase in the contact area between the forming ball and the specimen. Also, a large die diameter requires more loads, and this is due to the fact that it needs more metal to be pressured in the die cavity which needs more loads.

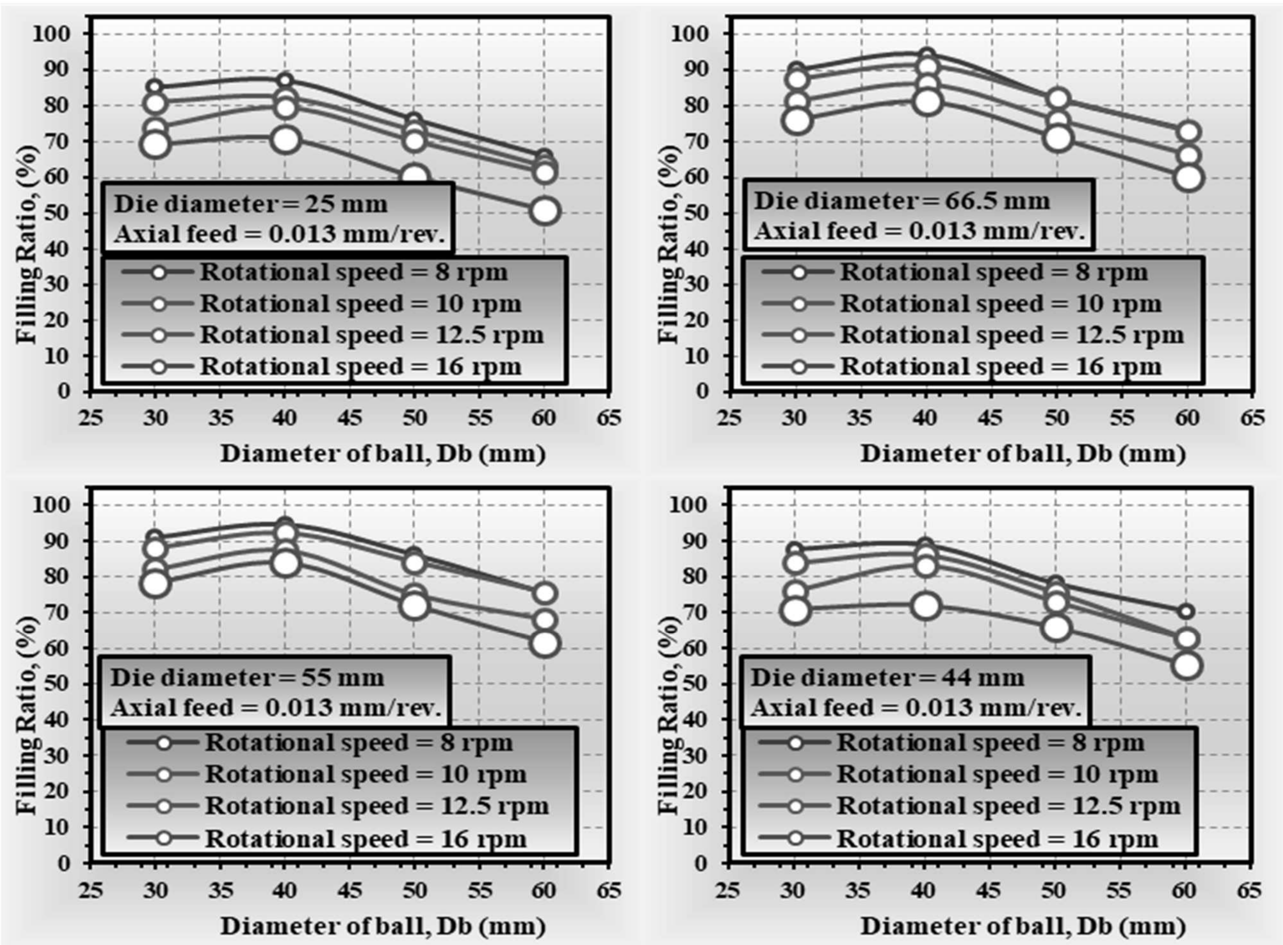

Fig. 14 *Filling ratio against ball diameter at different rotational speed for die diameters 25, 44, 55 and 66.5 mm*

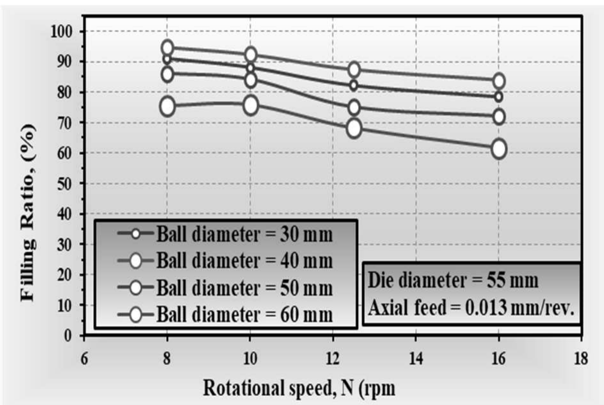

Fig. 15 *Filling ratio against rotational speed at different ball diameters and die diameter 55 mm*

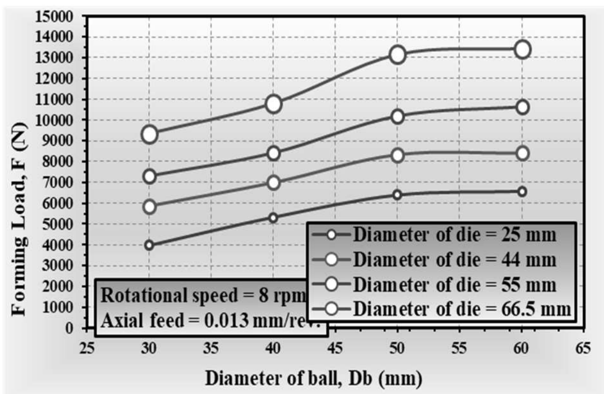

Fig. 16 *Forming load against ball diameter at different die diameters and rotational speed 8 rpm*

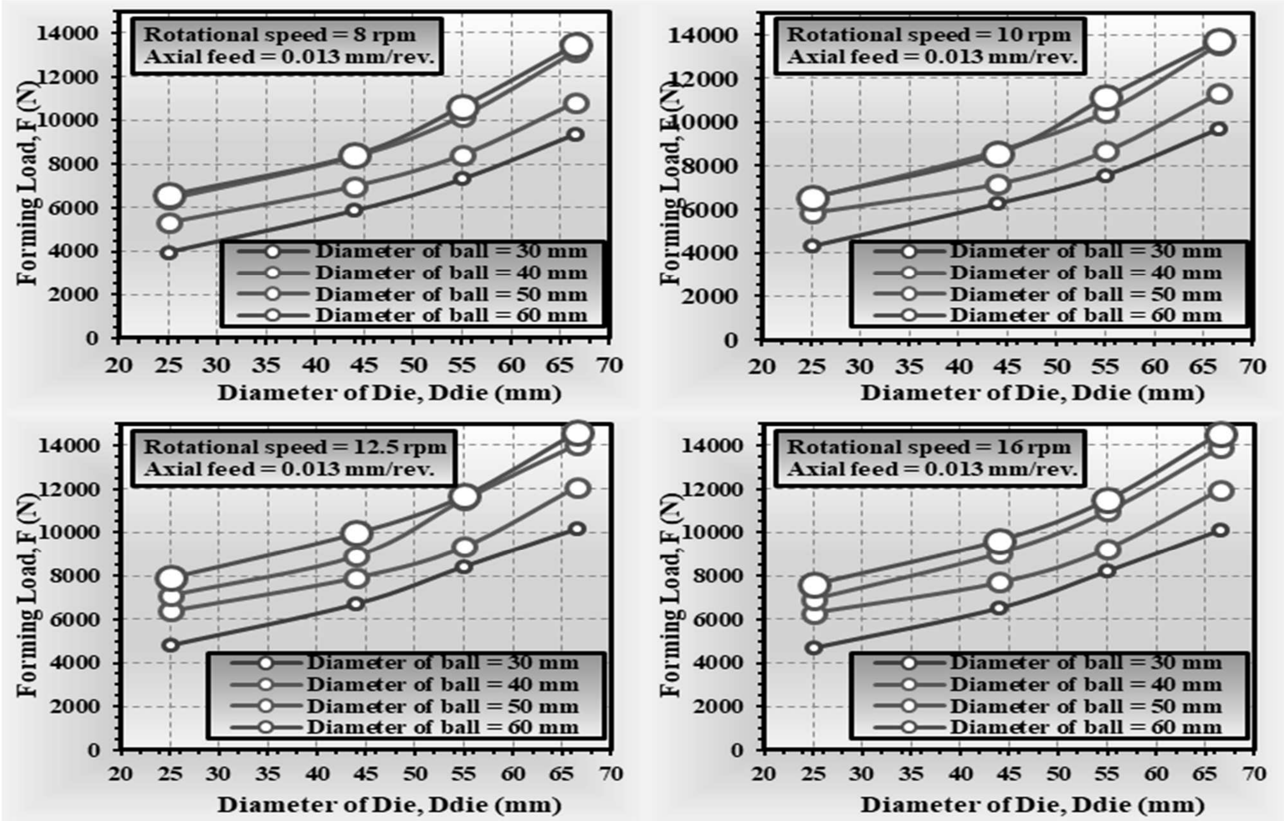

Fig. 17 *Forming load against die diameter at different ball diameters and rotational speed 8, 10, 12.5 and 16 rpm*

3.3 Gears produced by rotary forging

Fig. 18 shows gear specimens produced using the rotary forging process in two sets of experiments. From Fig. 18, it is clear that the gear samples produced with lower quality suffer from the phenomenon of metal built up, as it prevents the filling of the die cavities and thus reduces the value of the filling ratio, which leads to the production of incomplete gears.

Fig. 18 *Formed gears by rotary forging process*

While in Fig. 19 to 22 the formed gears are clearly displayed, and the quality of the gear, the shape of the teeth, and the completeness of their filling can be seen.

Fig. 19 shows successful gear samples with the four different diameters. Fig. 20 illustrates the successful gear samples before and after removing the flash material for different groups of samples. Fig. 21 demonstrates a group of successful gears with different rotational speeds. While Fig. 22 displays successful gears for die diameter of 55mm with different parameters.

Fig. 19 *Successful formed gears by rotary forging process*

Fig. 20 *Successful formed gears at different parameters*

Fig. 21 *Successful formed gears at different parameters*

***Fig. 22** Successful formed gears at different parameters*

4 Conclusions

The present study has reached several important conclusions regarding the production of solid gears and teeth parts using by rotary forging as follows:

- The ballizing technique has been shown to be successful in producing gears and toothed parts with processes similar to rotary forging by using a lathe as a forming machine with low forming load and good teeth cavity filling.
- The best appropriate dimensions of the sample were determined at the best filling ratio, as it was found that the ideal size of the sample should be equivalent to 1.2-1.4 times the volume being filled. The tooth completion rate reached more than 95% at a gear length of 15 mm.
- Variables in the forming process, such as rotation speed, ball diameter, and die diameter, showed a clear influence on the forming load and the tooth filling ratio. The best value for measuring the die was determined to be 55 mm in diameter, the best value for the ball was determined to be 40 mm in diameter, and the best value for the rotation speed was 8 revolutions per minute

Author Contributions

The contribution of the authors is as follows; Ayman Ali Abd-Eltwab and Mohamed N. El- Sheikh designs the main idea. Walid Elsyed Ayoub, Essam Khalaf Saied, Nouby M. Ghazaly and Ayman Ali Abd-Eltwab are prepared the test-rig component and made experimental works. Gomaa A. A., Essam Khalaf Saied and Ayman Ali Abd-Eltwab, wrote a draft copy, collected the data and analyzed it. Gomaa A. A., Ayman Ali Abd-Eltwab, Nouby M. Ghazaly and Mohamed N. El- Sheikh review and revised the manuscript.

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The authors declare no conflict of interest.

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