

## A COMPARATIVE COST ANALYSIS BETWEEN CONVENTIONAL AND PROGRESSIVE DRAW DIE

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**Abstract:** Progressive die technology is very important in sheet metal forming. These kinds of dies have amount of advantage especially for mass production for comparing conventional deep drawing processes. Progressive dies, which needs have experience to be designed can be easily machined with new developed CAD-CAM technologies. In this study, a progressive die designed for a certain part, which is used in building sector and then manufactured. A commercial steel sheet was chosen as a test material which in widespread used in automotive and kitchenware industry. Then an analysis which has all details about die cost, material cost and workmanship cost were made in order to compare and see the differences between the progressive deep drawing process and conventional deep drawing process. Besides, different punching types around the part were explained with figures. Experiments shown that progressive draw dies provides 4 times more production compared to conventional deep drawing dies. Thus, they are better in terms of energy consumption and workmanship cost.

**Key words:** Deep Drawing, Progressive Die, Cost Analysis.

### 1. INTRODUCTION

Sheet metal products are frequently used in industry. In this issue tool design plays a critical role. In sheet metal forming, a thin blank sheet is subjected to plastic deformation using forming tools to confirm to a designed shape. Deep drawing is one of the major industrial sheet metal forming processes. It is used to manufacture a variety of products such as pans food containers, kitchen sinks and automotive fuel tanks. The design and control of a deep drawing process depends not only on the workpiece material, but also on the condition of the tool-workpiece interface, the mechanics of plastic deformation, the equipment used and the control of metal flow (Moshksar, 1997). Therefore it is important to optimize the process parameters to avoid defects in the parts and to reduce manufacturing cost.

Due to limitations related to the properties of the blank sheet material, several drawing stages may be needed for the required shape and dimensions. Until

the 1990s the process design for multistage deep drawing was conducted expert's judgement and trial-error stages (Abdelmaguid, 2012). After then, many researchers studied the multistage deep drawing process by means of the finite-element (FE) method. Min et al (1995) used rigid-plastic FEM to analysis the multistage deep drawing of circular cups. Kim et al (2002) was carried out for a multistage deep drawing and ironing process of a rectangular cup with large aspect ratio using the results of the finite element analysis. Choi et al (2002) investigated the development and application of intelligent design support system for the deep drawing process of the circular cup. Several applications were also shown to prove the performance of the mentioned system. Kim and Hong (2007) studied a multistage deep drawing process of a circular cup from molybdenum sheet. Faraji et al (2010) aimed to improve the process parameters for multistage cylindrical shell by using finite element simulation. Research works are quite less containing to minimize the number of drawing stages which directly leads to minimization of manufacturing costs. Recently Ramirez et al (2010) and Abdelmaguid et al (2012) proposed approaches for optimizing the number of drawing stages in order to minimizing the total process cost.

On the other hand, for mass production of stamped parts which do require complicated in-press operations, progressive dies are used due to its high productivity, high precision and relatively economic cost in terms of per piece of product. One of the advantages of this type of press is the production cycle time. Depending upon the part, productions can easily run well over 800 parts/minute (Kalpakjian, 2006). Progressive dies have a special role in various methods of sheet metal production. Progressive dies, which can be used instead of several simple dies, containing a series of stations that perform one press operation after another in series. A progressive die gradually forms a part as it moves through the die, and the last operation separates the part in sheet metal

working. Progressive stamping can encompass punching, coining, bending and several other ways of modifying metal raw material, combined with an automatic feeding system. The feeding system pushes a strip of metal through all of the stations of a progressive stamping die. Each station performs one or more operations until a finished part is made. The final station is a cut off operation, which separates the finished part from the carrying web.

The design of progressive dies is a complex and highly specialized procedure (Ismail, 1996). The quality of product achieved by traditional or modern methods depends on the experience of designers. Computer aided design technologies have been used to improve the design effectiveness of progressive dies since 1970s. Usage of CAD systems reduced the design lead-time from days to hours (Kumar, 2008). The intermediate shapes and to predict the formability of each step from the final shape to initial blank is the most important parameter for the designers. Because it is not possible to apply FEM incremental approach to simulate the sheet metal forming at each step (Jian et al, 2002). Formerly Schaffer (1971) developed progressive die design by computer system and then Fogg and Jaimeson (1975) considered further parameters on a die design and improved the Schaffer's software. Then Nakahara et al (1978) and Shibata and Konimoto (1981) developed a CAD/CAM system in order to help designers for nest the parts on the strip and design layout. The computer aided die design system (CADDs) developed by Prasad and Somasundaram (1992) has one module for the strip-layout for progressive die. Choi performed many studies on CAD systems for blanking or piercing of stator and rotor parts by progressive dies (1997 a-b, 1998). In another study, Choi and Kim (2001) implemented data conversion, modeling and post-process modules in the integrated CAD system for the blanking of irregular shapes. A CAD system of a progressive die has been developed by Park (1999) for the grid parts of the Braun tube electron gun by applying the parametric auto design method. Lee et al (2002) used FEM analysis for blanking process simulation and predicted the amount of deflections and spring back. The die center of force has been determined by Lin and Chen(2003) using a simple mathematical model. The sheet metal forming process with progressive die by cut-off type feeding system has been investigated by Sim et al (2004). In the mentioned study DEFORM programming was used in order to prevent the defect of die design and making. Kumar and Singh (2004) performed a low cost knowledge base system framework for progressive die design. The system was divided into different modules for major activities of progressive die design and each module of the proposed

framework was designed to interact with the user through the user interface. Draw processes of a dome shape bulb shield were modeled and analyzed by Sheng et al (2007) by a commercial FEM base programme called DYNAFORM. According to Sheng the simulation not only predicts accurately the strain and thinning distribution but also helps to identify the root causes of surface distortion. Kumar and Singh (2007) carried out a material selection rule based expert system for selecting progressive die components. In another study, Kumar and Singh (2008) presented a production rule-based expert system for automation of strip-layout design process. Production rules were coded in AutoLISP language by Kumar to construct knowledge base of the system. Zhibing (2008) developed for blank design and formability prediction of complicated progressive die stamping part. In the mentioned study some finite element aspects in the inverse approach (IA) were firstly recalled. A software has been developed in order to automate the nesting of different parts according to minimum scrap strategy by Ghatrehnaby and Arezoo (2009). Ghatrehnaby performed a mathematical model to analyze and process the parts in order to present the best nesting template. Kumar and Singh (2011) developed an automated design system for design of progressive die.

There was no good enough comparing with all details to compare about the cost and stage between the classical and progressive die design even though so many design works were made for progressive die. In this research, DIN EN 10130-2006 (IF) steel sheet with low carbon and high quality formability and a thickness of 0.6 mm. has been used as a test material for axisymmetric deep drawing process. The first cost analysis is about the cylindrical part which is made progressive die with clover punching system. The following cost analysis is about that if the same part was made conventional deep drawing, how the result would be. Eventually the cost analysis was made with all details so as to compare these production types.

## **2. EXPERIMENTAL STUDY**

### **2.1. Material**

As explained above, DIN EN 10130-2006(IF) (Turkish grade ERDEMIR 7114-DC04 quality) was chosen as test material for good deep drawing formability. This material can be used in automotive industry, white goods, kitchenware, radiator and air-condition equipments and durable consumer goods. Also it can be used when toughness, ductility and strength requested. Mechanical properties and chemical composition of material is shown in Table 1 and Table 2 respectively.

Table 1. Mechanical properties of 7114 IF

Material	Yield Strength (MPa)	Tensile Strength (MPa)	Fracture Elongation (%)
DIN EN 10130-2006	210	270-350	38

Table 2. Chemical composition of 7114 IF in wt%

Material	C	P	S	Mn	Ti
DIN EN 10130-2006	0.012	0.012	0.007	0.018	0.068
	Nb	Si	Cr	Ni	Mo
	<0.002	0.007	0.025	0.031	<0.005

## 2.2. Equipment and Tool Set-up

The quality of the die design mainly depends on the designer's skill, experience and knowledge. Although there are several CAD/CAM systems for help in drafting and analysis in die design process, human expertise is still needed to arrive at the final design.

As a first step in the planning of manufacture of a sheet metal part, it is suggested to control of the design features in order to avoid the manufacturing defects such as tearing or wrinkling and section weakness. Basic components of a progressive die are die block and gages, stripper plate, punch plate, punch, pilot, die-set and fasteners. Sheet thickness, sharp edge direction and die material affect the size of die block. Sheet thickness also affects the die gages. As known, strippers are of two types: stationary and movable. The size of stripper plate depends on the size of die block. The punch plate is used to fix and support the punches and should have sufficient thickness in which a function of punch diameter. Other dimensions of punch plate are usually same as of die block. Selection of the kind of die-set depends upon the type of operation, part quantity and desired accuracy. In progressive die operations selection of materials depend on functional requirements in order to avoid the die failures. To obtain longer die life tool steels are being widely used for progressive dies. They can be machined easily in original situation and they became very hard by applying suitable heat treatment.

Deep drawing experiments were carried out on a 125 metric ton capacity eccentric press. For the multistage deep drawing process, firstly a cylindrical part as shown in Figure 1 which having 20mm. inner diameter and 40mm. in height was chosen. The diameter of the resultant cylindrical cup after each stage of the multistage deep drawing process has to be selected such that no failure occurs. The determined stages of deep drawing process are schematically illustrated in Figure 2 and the experimental set-up is shown in Figure 3.

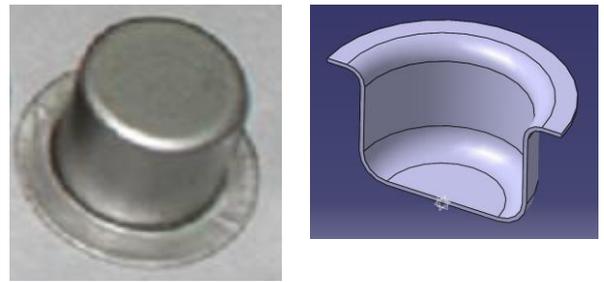


Fig. 1. Photographic and schematic representation of workpiece

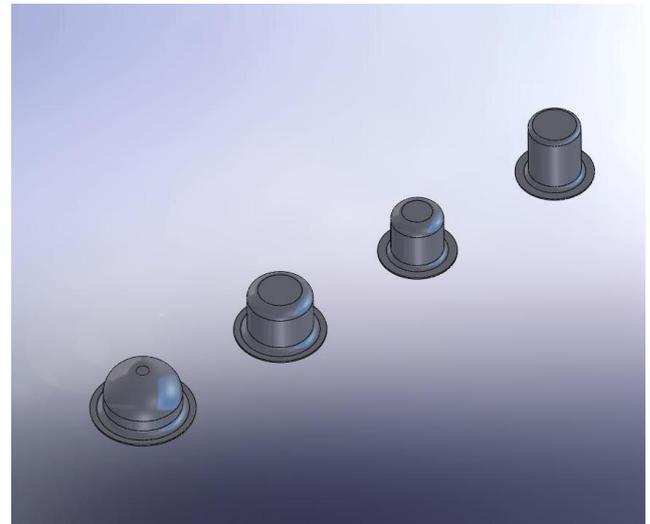


Fig. 2. Determined stages of drawn cup

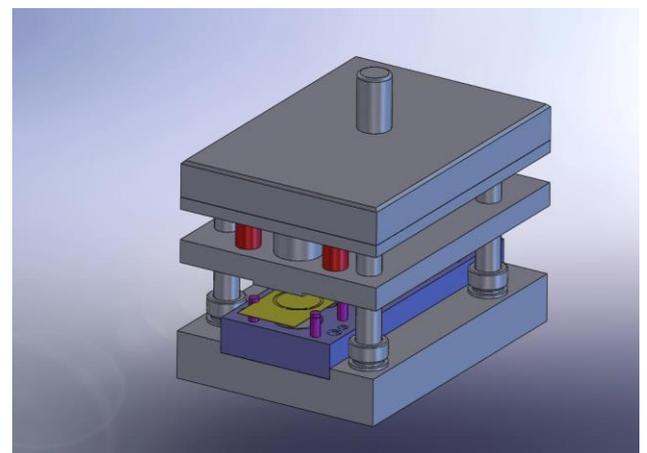


Fig. 3. Schematic representation of die assembly

## 3. PUNCHING

Punching operation must be done in order to obtain circular geometric piece from square geometry band at progressive dies. Because, as the sheet metal has got square profile at every station, it will be drawn at different loads. Therefore, radial tensile loads and stresses at the corners and the edges will be different and will lead to wrinkling. Depending on the size and number of stages of the parts to be drawn various punching methods may be used, which can be listed as follows.

### 3. 1. Internal Punching Model

In this method, external parts of the band, the areas at inter-stations (not the sections to move inside the shield) are cut as seen in Figure 4. It is used generally at deep drawing operations that are non-circular shape. Nevertheless, there occur deformations albeit small at the deep drawing operations. The die runs smoothly.



Fig. 4. Photographic view of internal punching model

### 3. 2. External Punching Model

This process is given in Figure 5 and is a method which may lead to inconveniences at the drawing operations and which therefore cannot be preferred.



Fig. 5. Photographic view of external punching model

### 3. 3. Clover Model

The portion which was discharged at the operation of such type of deep drawn the scrap is not thrown from the band as burrs. By cutting the sheet metal and inserting one inside the other it ensures it to remain connected at the several points to the band and the piece. This is a good method to provide that the band may move easily within the die shield. It does not restrict sheet movement and the die works smooth. The designed clover model in the lower die for the presented study is given in Figure 6a and drawn strip is given in Figure 6b.

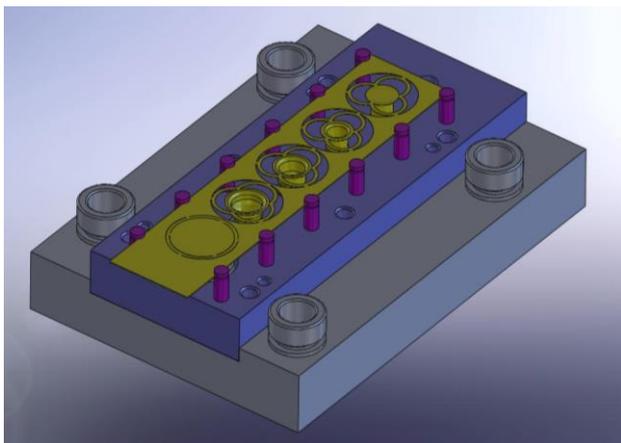


Fig. 6a. Clover model in the die



Fig. 6b. Clover model on the strip

## 4. COST ANALYSIS

The part which is to be manufactured, in strict compliance with its dimensions, can be manufactured at 3 stages through conventional deep drawing method. These pieces which will be used at the construction sector will be manufactured as 1.000.000 pieces/year and die service life will be expired in 3 years. Accordingly please find hereunder the cost analysis between the pieces drawn as shown in Figure 1 by conventional deep drawing method at three stages and manufacturing of same through progressive die whose manufacturing was made.

### 4.1. Die Cost

#### 4.1.a. Die Cost of Conventional Deep Drawing Process

The parts which are completed to be drawn at three stages need 4 pcs of die. These dies are respectively blank operation die, the 1<sup>st</sup> drawn die, 2<sup>nd</sup> drawn die and 3<sup>rd</sup> drawn die. Price quotations for these 4 dies received from three different companies are as follows:

**First Company:** 1 blank operation and 3 drawn die: 12.000 €

**Second Company:** 1 blank operation and 3 drawn die: 14.500 €

**Third Company:** 1 blank operation and 3 drawn die: 17.500 €

Eventually, the best price is 12.000 €. Throughout the service life of die production of 3.000.000 parts has been planned, accordingly the cost of die per piece is 0.004 €.

#### 4.1.b. Die Cost of Progressive Deep Drawing Process

The number of stages at the progressive deep drawing dies cannot increase the number of die, but enlarge dimensions of them. Production of one die is sufficient for a part to be drawn at 3-stages. Price quotation has been requested from 3 companies for 1 progressive deep drawing die. They are as follows:

**First Company:** 1 progressive deep drawing die: 20.000 €

**Second Company:** 1 progressive deep drawing die: 22.000 €

**Third Company:** 1 progressive deep drawing die: 26.000 €

As the production of progressive deep drawing die is challenging, the number of companies that will produce it is also less. Manufacturing of such kind of

dies depends upon technical facilities in addition to experience. Our cost for die manufacture in reference to the Company who offered the best price is 20.000€. Throughout the service life of die production of 3.000.000 parts has been planned, accordingly the cost of die per piece is 0.0066€. Eventually, the cost of the deep drawing progressive die is 65% more than the cost of the conventional deep drawing die.

#### 4.2. Material Cost

Depending on the finished dimensions of the part as given in Figure 1 the blank diameter is determined as 70.2 mm. The price of 7114 quality DKP material is 0.7 €/kg.

##### 4.2.1. Material Cost of Conventional Deep Drawing Process

Band width and pitch for 70.2 mm of blank diameter and 0.6mm of sheet thickness have been determined as 74 mm. Material weight is calculated as 0.0256 kg. and then the cost is calculated as,  $0.0256 \times 0.7 \text{ €} = 0.018 \text{ €}$ .

##### 4.2.1. Material Cost of Progressive Deep Drawing Process

For the same blank diameter and sheet thickness, considering that the band should not be subjected to deformation, the safe band width and pitch have been determined as 80 mm. Material weight is calculated as 0.0299 kg and then the cost is calculated as,  $0.0299 \times 0.7 = 0.021 \text{ €}$ . Eventually, the material cost for using progressive die is 17% more than the material cost for using of the conventional deep drawing die.

#### 4.3. Workmanship Costs

##### 4.3.1. Workmanship Cost of Conventional Deep Drawing Process

It has been stated earlier that the part which will be formed in the conventional die operation will be produced at three stages and total 4 operations together with blank cutting process will be made. A PLC controlled eccentric press with ram stroke of 40 per minute will be used for blank formation. Within an 8 hour working period, after removal of breaks, there remains 6.5 hours of net working period. If we consider also the loss of average 20% loading period, the beneficial and productive working period for such a press is 5,2 hours. About 12.500 blanks are punched within this time zone. Monthly average cost of a worker to the Company is 500 € and works 20 days per month. Thus, daily cost of a worker is 25 €. Accordingly, the workmanship cost per piece for cutting die is found as  $25/12.500 = 0.002 \text{ €}$ . Deep drawing operations however will be made by hydraulic press with capacity of 20 strokes per

minute. Inasmuch as the fact that in the course of such operations loading of material to the die is to be made manually, even under the best conditions a loss of loading at the rate of 50% occurs and which means however 10 strokes per minute. With a press which makes 10 strokes per minute daily 3.120 parts are produced. Cost per piece of a worker who is paid 25 € daily will be  $25/3.120 = 0.008 \text{ €}$ . As the production of cup parts at the finished dimensions has been secured at 3-stages, the total cost in the drawing operations will be  $3 \times 0.008 = 0.024 \text{ €}$ . Thus total workmanship cost per piece at the conventional die production is  $0.024 + 0.002 = 0.026 \text{ €}$ .

##### 4.3.2. Workmanship Cost of Progressive Deep Drawing Process

Deep drawing operation with progressive die is made by an eccentric press with 40 strokes per minute and the band is driven from the roll to the shield under PLC control, as seen in Figure 7. Likewise, when we subtract breaks and 20% loss of load time, the beneficial working period is 5.2 hours. Similarly production of about 12,500 pieces of finished parts is made within the mentioned working hours. As a worker costs 25 € per day, workmanship cost per piece is calculated as  $25/12500 = 0.002 \text{ €}$ . In respect to costs of workmanship, the progressive deep drawing die has got 1200% more advantages than the conventional deep drawing die process. What's more, for the conventional process 3.120 finished parts are produced per day, on the other hand for the progressive die about 12.500 pieces can be produced per day.



Fig. 7. A PLC controlled eccentric press used in the experiments

#### 5. TOTAL COST AND RESULTS

Costs for both processes have been given for 1000 finished parts in the Figure 8 comparatively. While

total cost of a piece which is produced by means of conventional deep drawing process is 0.048 €, total cost of a piece which is produced by means of progressive die method is 0.03 €. As it is seen also from the figure, the progressive die has got quite a big advantage in terms of the workmanship. Total advantage however is 37.5% in favor of the progressive die. In this method which provides advantage of 0.018 € per piece, a total gain of  $0.018 \times 3.000.000 = 54.000$  € can be achieved until expiry of service life of the die.

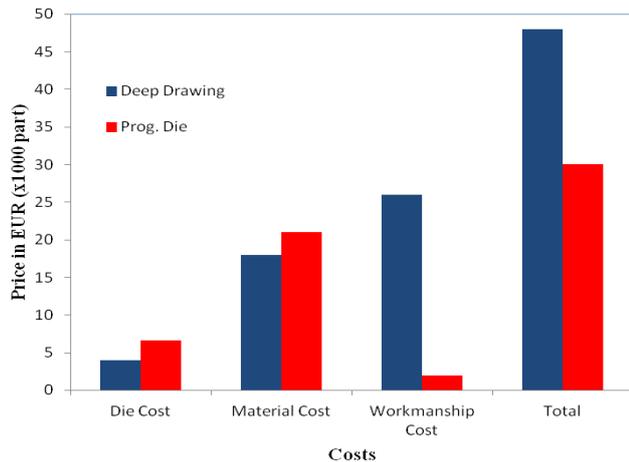


Fig. 8. Comparative costs for two manufacturing process

Cost analyses in detail of both methods however have been provided in Figure 9 and Figure 10. As shown in Figure 9, 54% of total cost calculated for a drawn part in the conventional deep drawing process consists of the workmanship. Cost of material is at the rate of 37.5% and cost of die however is only at the rate of 8.5% of the total cost. Accordingly, while the cost of die for the conventional deep drawing process is fairly insignificant within the total cost, the biggest cost share belongs to the workmanship cost.

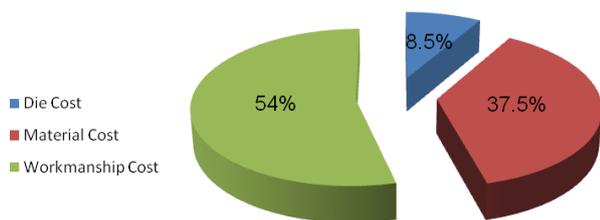


Fig. 9. Percentages of cost components for conventional deep drawing die

Similar analysis has also been made for the progressive die process and rates have been presented in the Figure 10. The biggest cost share for such kind of die process implementation belongs to the material at the rate of 71%. While the cost of die, whose design and manufacturing is difficult, is 22%, the workmanship share however is only 7%. As it is seen,

the portion in which the progressive die is the most advantageous and where the total cost is pulled down is the workmanship gain.

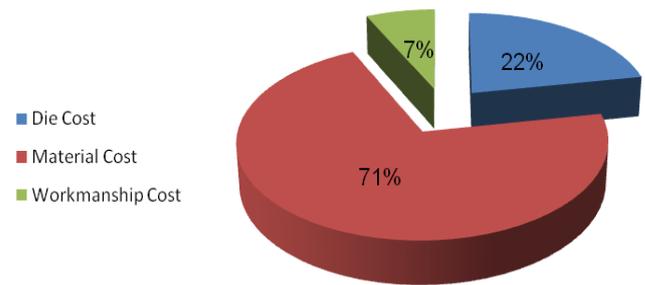


Fig.10. Percentages of cost components for progressive draw die

## 5. CONCLUSION

Nowadays, energy is the most important requirement. Progressive draw dies provides 4 times more production compared to conventional deep drawing dies. Thus, progressive draw dies are better in terms of energy consumption. The other competition parameters in manufacturing sector are human resource and workmanship cost. In this study it is observed from experimental results that more production is obtained by less workmanship when progressive dies are used. In addition, progressive dies are more compatible with automation compared to others so it is more safety.

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