REVIEW OF RUBBER BASED SHEET HYDRO-FORMING PROCESSES

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Abstract

Rubber based forming process is a versatile metal fabrication process used in commercial aerospace, automotive and defence applications. It is well suited for prototyping and production of small quantities of sheet metal parts. Rubber based forming employs a rubber pad contained in the rigid chamber or flexible diaphragm as one tool half, requiring only one solid half to form a part to final shape. The solid tool half is similar to the punch as in conventional process. The rubber exerts nearly equal pressure on all workpiece surfaces due to its incompressibility. The multi-directional nature of the force from the rubber pad produces variable radius during forming and thus enhances uniform elongation of the workpiece. The process exploits the benefits of flexible rubber punch and produces the complex shaped sheet metal components with minimal spring back and profile deviation. Parts with excellent surface finish can be formed with no tool marks and severe variations in the metal thickness, as occurs in conventional forming processes, is reduced considerably. Some of the very popular processes under Rubber-pad forming are Guerin process, Marform deep drawing process, Verson Hydroforming process, SAAB rubber diaphragm process and Maslennikov's process. The paper discusses in brief about these processes and presents literature review of various developments occurred in this field.

***Keywords*:** Rubber-pad, Forming, Hydroforming, Sheet metal

1. Introduction

Rubber forming adopts a rubber pad contained in a rigid box acting as a die and requires the use of a single metallic punch. The elastomer incompressibility is exploited deforming at constant volume it exerts a hydrostatic pressure on the sheet metal [1]. As the punch advances, and the rubber acts somewhat like a hydraulic fluid in exerting nearly equal pressure on all workpiece surfaces as it is pressed around the form block or punch [2]. Such a technology possesses several advantages: it requires a single punch, and a rubber pad replaces many dies of different shapes. The punch, more conveniently loaded, can be realised with cheaper materials. The bending radii change progressively during forming process. Material thinning is reduced. The same tool set-up can be used to stamp different materials and different thicknesses [1]. Due to low hardness of the rubber pad, the sheet metal does not suffer from wear when compared to deep drawing. However, since the amount of pressure exerted by rubber is limited by the strength of rubber itself, forming of sheet metal parts with small forming radius may not be possible and the wear of the rubber is an issue in larger quantity manufacturing [3]. E. Battikha and D.J. Browne (1992) also suggested using this process for prototype development or for low-volume production. The other disadvantages are lower forming pressure and consequently large amount of wrinkles and low production rate.

2. Chronological Development of Rubber pad Forming Processes and their Classification

The origin of Rubber Pad forming can be traced back to 19th century when Adolph Delkescamp in 1872 employed rubber pad for cutting and shearing of thin sheet. In 1912, Leonard Beauroth used a rubber bulging technique to form metal barrels. However, it was three patents of Henry Guerin in 1938, 1939 and 1940 that led to wide introduction of rubber forming techniques [3]. Later on Guerin process was modified and improved to develop Marform deep drawing process. Hybrid processes such as Verson-Wheeler, Verson Hydroform and SAAB Rubber Diaphragm techniques were developed to exploit the benefits of pressurized fluid and hyper-elastic nature of rubber diaphragm. The various processes are being discussed in brief in following section.

2.1 Guerin process [4]

The Guerin process is oldest and simplest rubber pad forming process. Aluminum alloys, Austenitic Stainless Steels and titanium alloys can be shallow drawn using this process. The schematic diagram of Guerin process is shown in figure 1. As the ram descends, the rubber presses the blank around the form block, thus forming the workpiece. The rubber-pad retainer fits closely around the platen, forming an enclosure that traps the rubber as pressure is applied. The pressure produced in the Guerin process is ordinarily between 6.9 and 48 MPa.

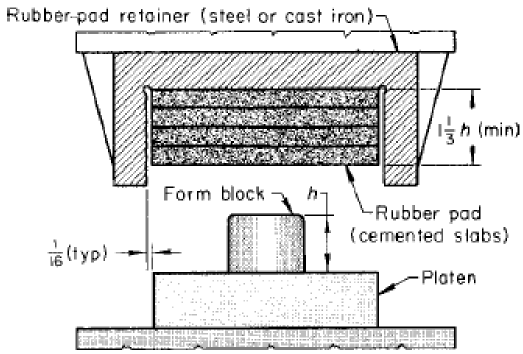

Fig1: Set up for rubber forming by Guerin Process

This process is however limited to forming moderately shallow, recessed parts, having simple flanges and having simple configuration due to lower strength of rubber.

2.2 Marform Process [1]

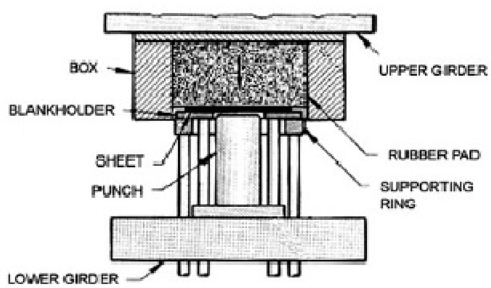

Fig 2: Marform Process [1]

In Marform process, deep-recessed parts with either vertical or sloped walls can be formed [5]. The set up details are shown in figure 2. Compared with Guerin process, tooling includes a steel blankholder supported by a hydraulic actuator equipped with a valve controlling pressure.

2.3 Verson Hydroform Process [4]

In this process, hydraulic pressure under control would act on rubber membrane covering the blank. Verson Hydroform process is different than other processes in the sense that it contains the die cavity which is partially filled with hydraulic fluid. The forming pressure is balanced by fluid pressure. Figure 3 shows the schematic details of this process. More severe draws can be made by this method than in conventional draw dies because the oil pressure against the diaphragm causes the metal to be held tightly against the sides as well as against the top of the punch.

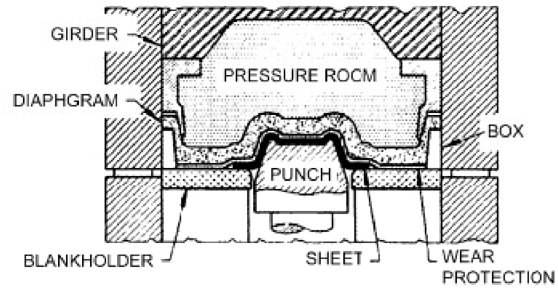

Fig 3: Verson-Hydroform process

2.4 Maslennikov's process [6]

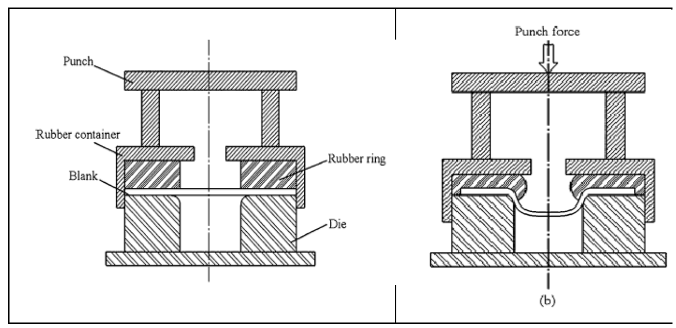

Fig 4 : Maslennikov's process

In 1957, Masennikov introduced a punch less drawing technique using annular technique. Maslennikov's process is a deep drawing technique that uses annular rubber pad to draw very deep cups. As can be seen in the figure, the punch squeezes the rubber ring and makes it deform radially inward. It develops a radial frictional force between the rubber ring and the blank and causes the blank to draw inside the die cavity. [6]

Other important rubber forming techniques are SAAB rubber diaphragm, Verson-Wheelon and bulging technique.

3. Literature Review

Most of the research work is limited to the Guerin process, its numerical simulation, friction coefficient studies and computer aided modeling probably because of its simplicity and greater utility. Thiruvarudchelvan **S., [**7-8] in his review paper stated that rubber use as flexible tool started at the beginning of the 20th century in bulging processes but only in the sixties with the introduction of the polyurethanes such elastic means began to be largely used due to their much higher hardness and resistance to wear and to chemical attacks by lubricants. After polyurethanes became available combined elastic and solid die forming developed fast and was the subject of research in many countries. Process investigated using this technique included; blanking, bending, extrusion, deep drawing and tube forming [9]. Al-Qureshi developed a theoretical analysis for predicting the total ram movement for a piercing operation using rubber pad and found a remarkably good agreement between theory and experiment [10].

The significance of polyurethane as flexible tool has been reiterated by many academic researchers. N.Alberti , A. Forcellesez, L. Fratini and F. Gabrielliz (1998) have described Urethane as a polymer which shows non linear elastic stress-strain behavior [11]. Such elastomers are often referred to as rubber-like materials even though no natural rubber exists showing a pure elastic behavior. Moreover, it should be noticed that the elastomers show an initially random orientation of the long-chain molecules and as a consequence the materials can be assumed isotropic; as the deformation increases the molecules orient themselves following the stretching direction: nevertheless the elastomers can be considered fully isotropic all along the deformation path. The poly- urethane rubber is a hyperelastic material, and generally it is assumed as nearly incompressible during deformation [12]. Xiao Wang [13] proposed that rubber is similar to the liquid which has good flow property. If compressed in one direction, it will expand in the other direction, and delivering pressure. Geiger and Sprenger (1998) has conducted a study on the characterization of polyurethane pads and experimental bending using elastomer pads [14].

This unique property of poly-urethane generated lot of academic and industrial interest in rubber-based forming processes. Several numerical investigations using Finite Element Method and corresponding experimental investigations have been carried out in last 3 decades. The notable among them is Sala(2000) who proposed a numerical and experimental approach to optimize aluminium alloys rubber forming. He used Guerin rubber-forming process to fabricate an aluminium alloy fuselage frame belonging to AerMacchi MB-339 trainer aircraft. David and Emil [15] presented an experimental study of the rubber forming process in order to produce sheet metal components. They investigated the capability of the process and optimized the process parameters to ensure defect-free products by using a 100 t double-acting hydraulic press. Husnu and Akdemir [16] studied the significant parameters associated with FFP (flexible forming process) by numerical simulation with a commercially available finite element package. Their investigations showed the effectiveness of finite element in process design. Sala G [1] also optimized the process with numerical simulation and experiments. Lei Chen (2014) studied straight flanging and springback of aluminum materials in rubber forming process [17]. The experiments were carried out in a Quintus Fluid Cell Press at the maximum available pressure of 140 MPa (1400 bar). He concluded that the springback can be eliminated with r/t < 2. The increase of pressure and time in rubber forming has little effect on the springback when the blank is coinciding with the die. In another study, Kwon et al.[18] have investigated the flexible bending of a structural aluminium frame using rubber. From the experimentally bent profiles, a parametric study for process design was performed. Yamashita et al [19] carried out numerical simulation of a cup drawing process using dynamic explicit finite element code DYNA3D and studied the effect of the forming parameters, such as dimension and hardness of the rubber ring, frictional coefficient of the interface between the sheet and the rubber ring and mechanical properties of the sheet, on the sheet deformation is investigated and concluded that the numerical simulation may be helpful in determining the forming conditions for the sheet metal drawing by Maslennikov's technique

Literature survey indicates that friction has remained one of the important process parameters to be studied during numerical simulation. PENG Lin-fa (2009) highlighted the influence of friction on material formability and product quality. In similar study Maziar [20] and Dirikolu [16] concluded that the friction condition cannot change the forming limit strain of the sheet metal but can change the distribution of stress and strain, which can affect the defects in the metal forming. PENG et al (2009) carried out finite element simulation using the Coulomb friction model and Maziar et al (2009) presented the theoretical friction model to investigate the effects of various friction coefficients on the blank thinning and stress distribution in the rubber forming. Dirikolu and Akdemir (2004) investigated the parameters associated with rubber pad forming such as the rubber hardness, blank material type, contact friction and so on, through simulation by using the commercial software ANSYS. They also analysed the use of different types of lubricants at the blank and its interfaces. Wax (Vestoplast 703) was found to be the best lubricant for the process. Maziar Ramezani (2009) made an exhaustive study in friction models and proposed to use static friction and kinetic friction models instead of coulomb's friction model.

In recent years, Rubber pad forming has been used to form micro and meso features. Peng Lin-fa [21] established a finite element analysis (FEA) model to study sheet forming process using soft punch at micro/meso scale. The forming parameters (material grain size, friction and hardness of soft punch) related with the forming process are detailedly investigated. It is found that sheet metal with small grain size is prone to obtain high formability. Lager friction coefficient between the sheet and the rigid die may make the sheet thinning quickly that decreases the formability, while the friction between the sheet metal and the soft punch does not play an important role. The hardness of soft punch is not a decisive parameter to the final quality of the workpiece. Chul Kyu Jin (2014) used rubber forming method is used to fabricate titanium bipolar plates for proton exchange membrane fuel cells. The size of the channel is 0.8 mm (width) x 0.4mm (depth) and rib width of 1.4 mm [22]. On similar line, Yanxiong Liu (2009) numerically investigated, using ABAQUS, the rubber forming process to fabricate metallic bipolar plate for proton exchange membrane fuel cells [23].

4. Simulation Study using ABAQUS

Abhishek Kumar, S.Kumar (2014) carried out simulation of the micro-channel similar to that studied by Yanxiong Liu (2009) for fabrication of metallic bipolar plate. Material is Pure Aluminum instead of SS 304. Rubber material of 70 shore hardness is used as die. The simulation result is shown in figure 5.

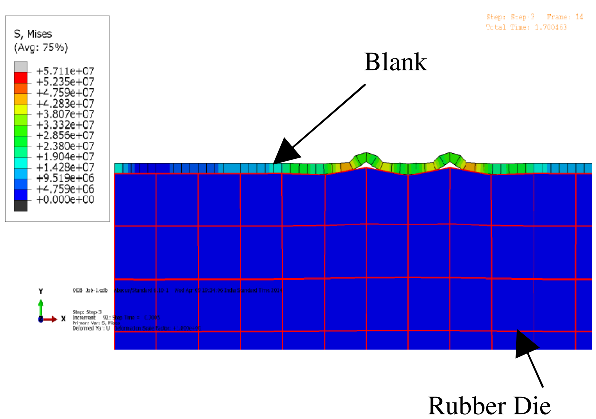

Figure 5: Von Mises stress plot after forming

Results indicate that rubber die is capable of sustaining forming loads and defect free product can be obtained. Thus simulation of rubber pad forming process is verified using ABAQUS. It yields encouraging results and can be extended for complicated shapes.

5. Conclusion

Rubber based forming process falls into the flexible forming methods category. Although the process is quite old but only during last two decades, it has generated lot of enthusiasm among intelligentsia and academic groups. Guerin process has remained the most understood technique. However, there is lot of scope for research in other variants of rubber forming processes such as Marform, Verson-Hydrofrom and SAAB rubber Diaphragm processes. The Investigations in terms of improvement in Forming Limit Diagram using rubber pad forming is still unexplored.

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