Review on various experimental methods in Warm Hydroforming of Sheet Metals

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ABSTRACT

Hydroforming is a key technique for the forming of various complex geometrical sheet metal parts. When the sheet metals formed in the hydro forming formability for the material plays an important role. To improve the forming effectiveness of the lesser formability materials, warm hydro forming is found to be apt method. In this paper, various methods used in warm hydro forming and the observation made by various researchers are presented. The scopes for further improvements in this warm hydro forming process are also presented.

KEY WORDS: warm hydroforming, sheet metal, formability, Tube bulging.

1. INTRODUCTION

In order to achieve the better formability of light weight components in automobiles, the new production techniques such as hydroforming, warm forming, and warm hydroforming are used in recent years. The warm hydroforming process has become an evolving technology in recent years to decrease the weight of automotive body structure and reduce the number of process steps. So that the cost of end product may be reduced and the customer will be benefited

It is important that both the tool and sheet metal have to be heated continuously in the controlled manner for warm hydroforming process. Thus, it is useful to keep temperature control around the tooling setup as uniform as possible. This is an elementary requirement for a well proved scientific investigation of the warm hydroforming process. The temperature must have to be changed and the control must also facilitate to realize different temperatures. Even though there are a lot of advantages, it has some limitations also such that slightly inflammable materials and materials which develop poisonous steam at these temperatures should not be used.

The formability can be improved in warm hydroforming due to two important factors of temperature and through thickness normal stress. The thermomechanical treatment by warm hydroforming is a potential method for the products manufacturing of aluminum alloy with high strength and good formability.

The following reasons are also for the popularity of warm hydroforming process:

- A high forming geometrical accuracy as essential for the automated body shell work.
- A high torsion and bend stiffness of the components.
- The possibility to produce variable cross sections along the longitudinal axis of the component.

In this paper, the various experimental methods followed by researchers are reviewed and presented to enhance the knowledge of the warm hydroforming.

Methods of warm hydro forming: Based on the intensive study of the research works in warm hydroforming, the following potential experimental methods which improve the formability and geometrical accuracy are identified, reviewed and presented in this section.

Method I: In this method, detailed design and construction of warm hydro mechanical deep drawing (WHDD) process setup was developed and experimentally validated to perform small-scale industrial production with all essential control on heating, cooling, and sealing systems as shown in figure.1.

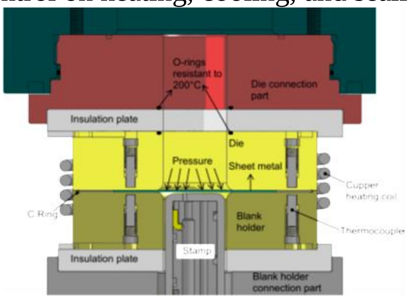

Figure.1. WHDD tooling design

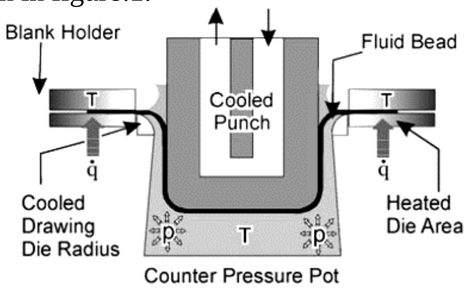

Figure.2. Process principle of hydro-mechanical deep drawing at elevated temperatures

In this system, a copper coil is used to heat the sheet material from the flange region to achieve the preferred temperature in the die. An automatic control of the heating and cooling systems was done using a PLC system to maintain the required temperature of the dies. Another work reported a technology that associates the different effects used in hydro-mechanical and warm deep drawing to decrease the drawing force and to increase the transmittable drawing force in the deep drawing process of aluminium sheets by heating the flange and by using a counter pressure as shown in the figure.2.

Similar to the method I another researcher developed an experimental set up to heat the die. The temperature of upper and lower die were monitored and controlled individually using separate cartridge heaters and thermocouples as shown in figure.3.

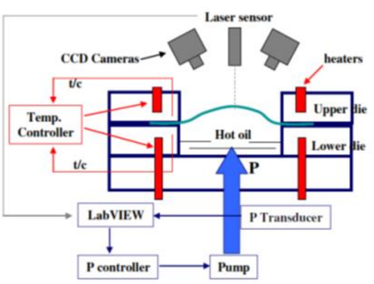

Figure.3. Schematic diagram of the warm bulge test setup

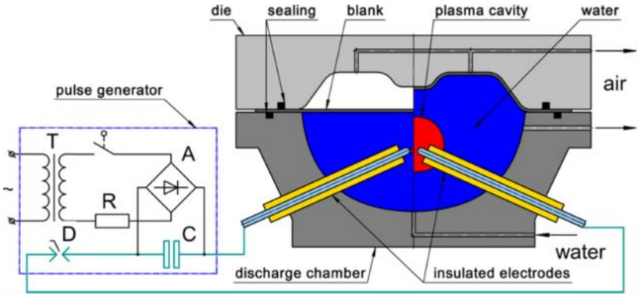

Figure.4. Schematic of sheet metal forming using method 2

The above said warm bulge test setup was used to characterize the material behavior of Al5754 using both tensile and hydraulic bulge tests under both room and warm temperature conditions.

Method II: This method was developed initially done in 1968 for early laboratory experiments and initial low volume industrial applications for sheet metal forming. During this process, a high pressure, high temperature plasma channel is produced between the electrodes using high voltage discharge of capacitors. The resulting shock wave in the water filled chamber was initiated by the expansion of the plasma channel. It propagates toward the blank at high speed. Then the sheet metal is formed in the required shape and size of the due to the mass and momentum of the water in the shock wave as shown in the figures 4 and 5.

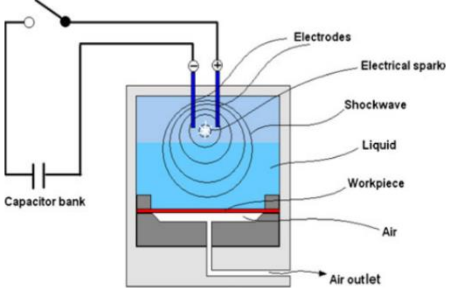

Figure.5. Shock wave generation in method 2

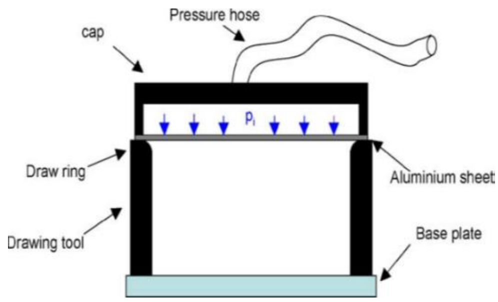

Figure.6. Principle of the experimental tool for the Method III (sheet metal and the tool are heated in a furnace)

Method III: As explained in the introductory section, to maintain the uniform temperature, the whole die setup is placed in the furnace as shown in the figure.6. This method is used to increase the formability of the aluminium alloys during the hydroforming process. The complete die set along with the sheet metal is heated in a curing furnace. The temperature is controlled with the available furnace control. The several measurement points were provided within the tool at which the temperature is controlled continuously.

Method IV: To achieve better uniform heating, this combined heating method as shown in the figure.7 was developed and tested.

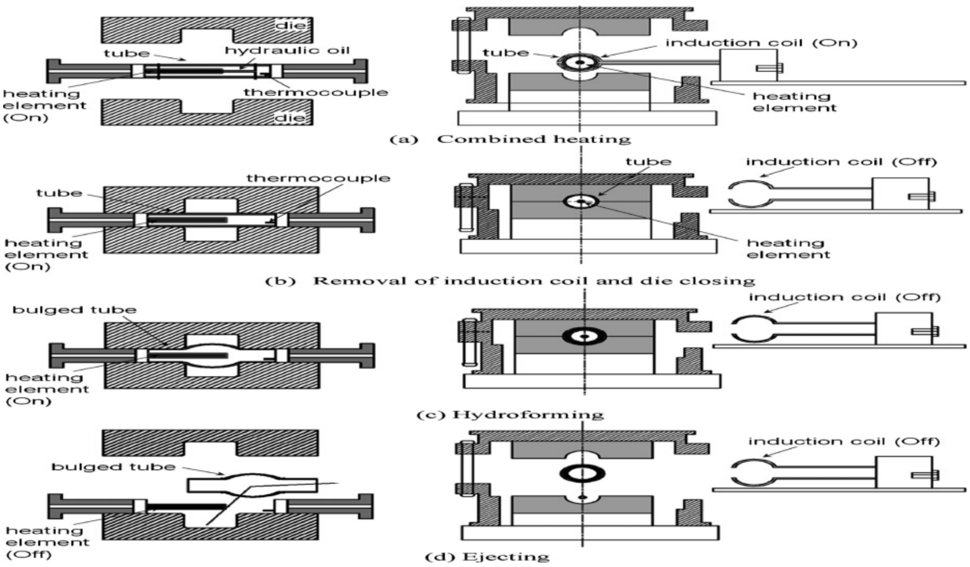

Figure.7. Schematic drawing of method 4 (combined heating system)

In this method, the ends of the tube are sealed horizontally by hydraulic press. Initially the upper frame is opened. Then the upper die is held up. This will prevent interference between the die and the induction heating coil. The induction-heating coil is placed around the tube. A thermocouple inside the tube monitors temperature (Fig. 7a). The heating coil is retracted and the dies are closed (Fig. 7b). The tube is hydro formed using internal pressure and axial feeding (Fig. 7c). The hydro formed tube is removed from the die (Fig. 7d).

A combined heating system consists of an induction coil and a heating element. It has been applied to the warm hydroforming of aluminum alloy tubes. For the speedy heating of tubes, the designed induction heating system is used as a main heating source. The heat generated by the induction coil is unevenly distributed across the tube. To overcome this difficulty, an additional heating element was introduced inside the tube. So that the heat lost to the tooling is reduced. This will increase the temperature uniformity.

Process parameters: The following fish bone diagram (Fig. 8) shows the various factors that affecting the efficiency of the warm hydro forming. These factors are to be considered carefully because the part formability, part quality and process robustness are based on these factors. The warm hydroforming process variables categorized into four major groups namely material, tribological, die & tool and loading process. Mechanical property of the material, anisotropy, thickness of the blank are identified as material variables. Lubricant, surface condition, dirt, coating and roughness are well-known tribological variables. Die &tool variables are consisting of corner radius, alignment, punch speed, draw beads, surface finish, die and expansion. Hydraulic system, sealing, blank holder force, temperature distribution, hydraulic pressure and fluid temperature are coming under loading and process variables.

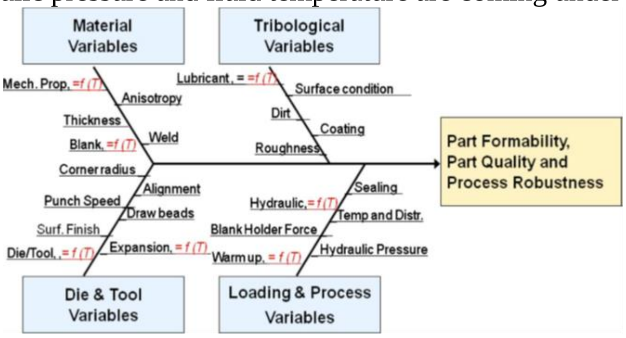

Figure.8. Variables affecting the part formability, part quality, and process robustness in warm hydroforming

The various process variables and control strategies are discussed and developed to get the benefits such as process development, less trial and error and high dimensional accuracy as shown in figure 9. Die temperature, punch temperature, hydraulic medium and die temperature can be controlled but the response on deformation is slow. To overcome this issue hybrid approach with DOE and adaptive isothermal FEA as a strategy. Because of this strategy the optimal temperature distribution can be obtained.

Hydraulic pressure, blank holder force and punch speed are the important control variables which show the fast response on deformation. To obtain the optimal loading profile the adaptive FEA with fuzzy control algorithm serves as a good strategy.

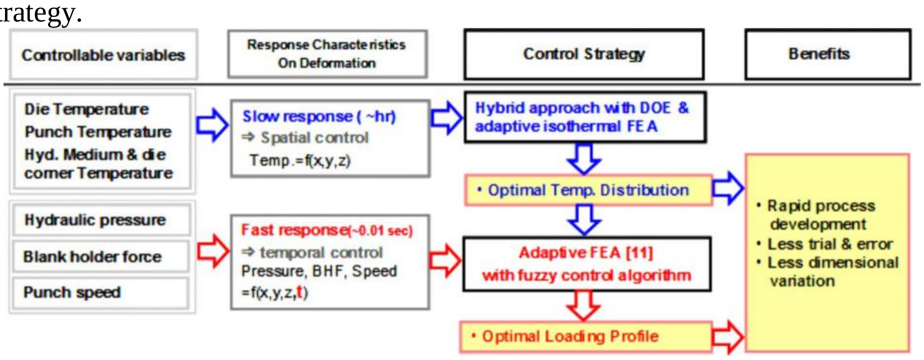

Figure.9. Process control strategy for the warm hydroforming

Observations:

In method I: The first method was experimented and the performance of each subsystem was confirmed through repeated test runs as well as through part quality measurements. This investigation provided a platform for new researchers and manufacturers with a set of design and process strategies to develop similar systems. The thickness distribution of the formed cups were measured and compared for rolling direction and transverse direction. The various observations summarized as follows:

- The most apt material for the insulation and to keep the die hot for longer time was reported as calcium silicate-based composite plates which has temperature resistance of 1200˚C and compressive strength of 48 MPa

- For a successful hydro-mechanical deep drawing process the fluid pressure and blank hold force (BHF) should be set accurately as per the punch position at particular velocities.
- For the selected AA5754 material, temperature levels are reported to be between 185˚C and 305˚C. In this study, it was found that at 260˚C maximum deviations of around 0.08 MPa for the fluid pressure and 1.7 kN for the BHF.
- The fluid pressure, the blank holder force (BHF), the punch speed and position were found as independent of each other and fine-tuned.

Magnesium alloys have limitations in their formability at room temperature. Anyhow above 225˚C it can exhibit good formability. To overcome this issue Kurz (2004), developed a warm hydro deep drawing process and reported that using developed model the temperature can be decreased by the use of deep drawing process. For the numerical simulation various experimental studies were conducted to detect the essential system parameters, such as, Temperature dependent friction coefficients and heat transfer coefficients, temperature and strain rate dependent flow curves. The experiments show that the developed hydromechanical deep-drawing process with thermal support has the potential of clearly widening the forming limits in deep-drawing. Also proven that FE simulations suitable for experimental studies and the FE results are matched with the results of numerical calculations.

The effects of the temperature and the pressure of the sheet metal formability of aluminum 5052 and 6061 were studied in a closed-die hydroforming. At 200˚C, an increasing pressure leads to an increase of about 77-93% in the cavity filling ratio for Al 5052 and 60-83% for Al6061. A similar observation is made for an increasing temperature at low pressure value (10 MPa), but not at high pressure level (20 MPa). The findings of the FE modeling compared with closed-die hydroforming experiments based on the material flow stress curves from both bulge and tensile tests at different temperature, pressure and strain rate conditions. Those results show that both bulge and tensile tests are in good agreement with experimental measurements in terms of predicting the part profile, cavity based on the flow curves.

It was found that greater deformation without failure can be achieved up to 60% strain by variable strain rates during warm hydraulic bulge while reducing the stress levels significantly. It was also observed that more than 200˚ C, the effect of pressurization rate became more distinct for increasing the cavity filling and decreasing thinning at slow pressure rates when both experimental and FEA predictions were considered together.

In method II: The second method was conducted experimentally, a model was developed by performing two experiments and validated the model using LS-DYNA. The first experiment was conducted with an axisymmetric cylindrical chamber. The second experiment was conducted in a conical chamber. For the both methods the pressure was measured using pressure sensor and membrane pressure measuring methods respectively. Results obtained from the experiments exhibited well quantitative correlation with the simulation model to forecast the amplitude of the pressure waves and their distribution.

The developed simulation model incorporates

- energy deposition of the plasma channel
- Expansion of the channel and propagation of pressure waves in the water filled chamber.
- Used to simulate multistage hydroforming of intricate geometry automotive part.
- Investigation of the results exposed the complex nature of multistage hydroforming process

In method III: In the third method, the whole die set along with the blank is kept in the furnace. Chosen the material AlMg3.5Mn for this study because it has wide application in automotive industry. For example, in the rear axle of the BMW 5 and 7 series vehicles is made up of AA5182. At room temperature, this chosen material has an elongation after fracture of about 22%. In this study, experiments are performed at higher temperatures to investigate the formability, the microstructure before and after the forming, the wall-thickness distribution and the strain distribution.

The following results were observed:

- A concept for the thermal hydroforming is developed.
- A forming tool for sheet metals is recognized.
- The experiment provided the optimal temperature and an optimal radius between drawing tool and base plate for finding the optimal height of the drawing tool.
- The cycle time of 15 seconds per part confirms the potential for high volume manufacturing
- On the outset, this method has lot of potential technologically as well as for business management reasons.

In method IV: It is a well-known fact that the uniform and effective heating of the blank is necessary for ease in warm hydroforming process. To achieve these there is combined heating in this fourth method. The advantages of the combined heating method are increased hydro formability and making more uniform bulging in the tubes. The following points are observed

- The important process parameters such as internal pressure, axial feeding and heating conditions have also been successfully optimized.

- Heating rate is more with uniform temperature distribution in comparison with the other methods such as using induction heating or a heating element alone.
- Because of temperature uniformity, the circumferential bulge heights of formed tubes are more uniform.

2. CONCLUSIONS

Warm hydroforming of sheet metals is emerging technique for forming complex parts which has lesser formability. Almost all aspects of warm hydroforming technology require full attention of researchers for better understanding of its details. Development in this technology seems to follow similar developments like other metal forming processes. Even though some works carried out and reported in this area some other key areas like spring back of the blank, dynamics of the fluids and comparison on effectiveness of the various fluids used in this are need to be investigated.

REFERENCES

Bruno E.J, High Velocity Forming of Metals, American Society of Tool and Manufacturing Engineers, Dearborn, MI, 1968.

Chachin V.N, Electrohydraulic Treatment of Structural Materials, Naukai Technika, Minsk, 1978, 80–87.

Chen Y.Z, Liu W, and Yuan S.J, Strength and Formability Improvement of Al-Cu-Mn Aluminum Alloy Complex Parts by Thermomechanical Treatment with Sheet Hydroforming, JOM, 67 (5), 2015, 938-947.

Choi H, Koc M, and Ni J, A study on warm hydroforming of Al and Mg sheet materials: mechanism and proper temperature conditions, Journal of Manufacturing Science and Engineering, 130 (4), 2008, 041007.

Groche P, Huber R, Dorr J, and Schmoeckel D, Hydromechanical deep-drawing of aluminium-alloys at elevated temperatures, CIRP Annals-Manufacturing Technology, 51 (1), 2002, 215-218.

Kim H.S, Koc M, and Ni J, Determination of proper temperature distribution for warm forming of aluminum sheet materials, Journal of manufacturing science and engineering, 128 (3), 2006, 622-633.

Koc M, Agcayazi A, and Carsley J, An experimental study on robustness and process capability of the warm hydroforming process, Journal of manufacturing science and engineering, 133 (2), 2011, 021008.

Koc M, Mahabunphachai S, Carsley J.E, Barlat F, Moon Y.H, and Lee M.G, Numerical and experimental investigations on deformation behavior of aluminum 5754 sheet alloy under warm hydroforming conditions, In Aip Conference Proceedings, 1252 (1), 2010, 107.

Kurz G, Heated Hydro-Mechanical Deep Drawing of Magnesium Sheet Metal, Essential Readings in Magnesium Technology, 2004, 389-393.

Lang L, Cai G, Liu K, Alexandrov S, Du P, and Zheng H, Investigation on the effect of through thickness normal stress on forming limit at elevated temperature by using modified MK model, International Journal of Material Forming, 8 (2), 2015, 211-228.

Li D, and Ghosh A, Tensile deformation behavior of aluminum alloys at warm forming temperatures, Materials Science and Engineering: A, 352 (1), 2003, 279-286.

Mahabunphachai S, and Koc M, Investigations on forming of aluminum 5052 and 6061 sheet alloys at warm temperatures, Materials & Design, 31 (5), 2010, 2422-2434.

Mamutov A.V, Golovashchenko S.F, Mamutov V.S, and Bonnen J.J, Modeling of electrohydraulic forming of sheet metal parts, Journal of Materials Processing Technology, 219, 2015, 84-100.

Melander A, Delic A, Bjorkblad A, Juntunen P, Samek L, and Vadillo L, Modelling of electro hydraulic free and die forming of sheet steels, International journal of material forming, 6 (2), 2013, 223-231.

Michael K, Herbert B, David H, Anjali K.M, and Silva D, Enhancing the formability of aluminium components via temperature controlled hydroforming, Journal of Materials Processing Technology, 167 (2/3), 2005, 363-370.

Turkoz M, Halkaci H.S, Halkaci M, Dilmec M, Avci S, and Koc M, Design, Fabrication, and Experimental Validation of a Warm Hydroforming Test System, Journal of Manufacturing Science and Engineering, 138 (4), 2016, 045001.

Yi H.K, Pavlina E.J, Van Tyne C.J, and Moon Y.H, Application of a combined heating system for the warm hydroforming of lightweight alloy tubes, Journal of materials processing technology, 203 (1), 2008, 532-536.