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Experimental and numerical investigation of processes that occur during high velocity hydroforming technologies: An example of tubular blank free bulging during hydrodynamic forming

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ABSTRACT

Frequent use of hydroforming in automotive and aerospace industries requires intensive research of all aspects of this relatively new technology. In this paper we have studied the characteristics of aluminum tubular blank free bulging during hydrodynamic forming; both experimentally, and through numerical finite element analysis using LS-DYNA. We obtained the quantitative description of a pressure wave in working liquid, which directly relates to the load on the blank. The finite element analysis examined how a computationally efficient simulation model could be achieved, to replicate the experimental testing results. It was intended to correlate the simulation with experimental results; we were successful in demonstrating that the simulation can achieve an acceptable level of correlation with the experimental results.

1. Introduction

Hydroforming is a manufacturing process employed for the purposes of shaping ductile metals into lightweight, structurally stiff and robust components with complex geometries, using a fluid medium to form a component through the application of high internal pressure [1]. Internal pressure is usually obtained by various means such as hydraulics, viscous mediums, elastomers, and polyurethane [2]. Three types of hydroforming can be distinguished: shell hydroforming, sheet hydroforming and tube hydroforming. Tube hydroforming is a well-known technology, which has become a viable method for mass production with the use of internal pressures of up to 6000 bar [3]. This process has gained wide application in the aircraft, aerospace and automotive industries [4–6].

Hydrostatic pressure forming has several advantages when compared to the conventional manufacturing method which uses a combination of stamping and welding. These advantages are: part integration, weight reduction, improved structural strength and stiffness, lower tooling cost, fewer secondary operations, high accuracy and high materials utilization. Despite these advantages, hydrostatic pressure forming has some significant disadvantages such as slow cycle time and high equipment cost [7].

Currently, there are various impulse or high velocity hydroforming technologies available whereby the work piece material attains forming speeds in excess of 100 m/s [8]. Strain rates during impulse forming range from 10^2 to 10^4 s^{-1} and typical forming times are usually in the range of microseconds or milliseconds [9]. Like conventional hydroforming, in impulse hydroforming the force is applied via a solid, fluid or gaseous working medium and thus, only one die is required, however unlike the quasi-static case, Pascal's principle is no longer valid. Instead of a homogeneous pressure distribution in the fluid, here a pressure impulse propagates through the fluid as a pressure wave, or shockwave. This pressure wave accelerates the workpiece in its propagation direction. The shockwave initiation mechanisms distinguishes the methods as follows: electrohydraulic forming, explosive forming and propellant forming, hydro-punching and hydrodynamic forming. Each has a specific set of technological capabilities, advantages and disadvantages, which determines the effective application of each method.

Due to high strain rates, in comparison to conventional forming technologies, the high velocity forming technologies have several advantages, for example: increased formability for several materials, reduced wrinkling and springback effects, and the adiabatic

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character of impulse forming allows for exploitation of the forming heat more efficiently than in quasi-static forming operations [9,10]. Typical disadvantages are: high acoustic emissions and increased demands on the process measurements.

In this paper an investigation of high velocity hydroforming an example of hydrodynamic forming was conducted. The essence of the hydrodynamic forming method is to convert the energy of gas expansion, by means of a piston, into the significant increase in pressure of a liquid contained within a forming chamber to form a blank. To impart the required speed to the piston, either the energy of compressed gases, or the explosion energy, or the energy of combustion products of some air–fuel mixtures can be employed. The pressure, set up in the working liquid, may considerably exceed the initial pressure of the gas, which ensures the safety of the manufacturing process by the localization of high pressure within the hydraulic chamber and the reduction of pressure inside the gas chamber [11]. This method makes it possible to manufacture parts in a non-sealed forming chamber without any rubber seals in gaps between the tooling elements. Leakage is limited though these gaps automatically when impacted by hydraulic shock due to a considerable rise in the hydraulic resistance.

Melnychuk [12] described the key parameters of hydrodynamic forming as follows:

- The piston's maximum velocity at the moment of its impact on the working liquid for different hydrodynamic forming devices is 50–250 m/s.
- Pressure pulse duration in liquid is 10^{-4}–10^{-2} s.
- The maximum achievable pressure in the forming chamber of different hydrodynamic forming devices is 300–500 MPa.

The features and advantages of the hydrodynamic forming method allow it to be applied to a wide range of production processes. Among the main processes of sheet forming are blanking and drawing process, bulging of tubular parts, tube reduction process, perforation, bending of tube requiring acute radii, and permanent joint assembly operation (movable and fixed joints), to name a few. Application of hydrodynamic forming technology is most appropriate in aerospace industry for the production of complex parts from tubular blanks requiring high-pressure for their forming. The most common hydrodynamic forming technology is the bulging process for production of rims and aircraft high durability pipelines elements. Basically they include various types of pipe fittings, stub ends, movable joint elements, pipeline compensators, and the like.

Today, numerical simulation provides an effective means of studying high velocity hydroforming processes. In this research, we performed numerical simulation of an aluminum tubular blank free bulging, to study the blank behavior under hydrodynamic loading, using the LS-DYNA finite element analysis system. This software allows finding the correct solutions for highly nonlinear and explicit multi-physical problems. We compared the calculated results with experimental values of permanent hoop strain in nine sections of tubular blank, and hoop strain versus time dependence in its two sections. Processes occurring during hydrodynamic forming are common to all types of high velocity hydroforming. Strain rates and the mere forming duration are approximately similar for all types of high velocity hydroforming. So the proposed model can be supplemented to investigate other high velocity hydroforming processes, with the only consideration being the initiation mechanisms of the shockwave.

2. Experimental procedure

Free-bulge expansion is a well-known experiment. To conduct free-bulge testing of circular cross-sections, several design

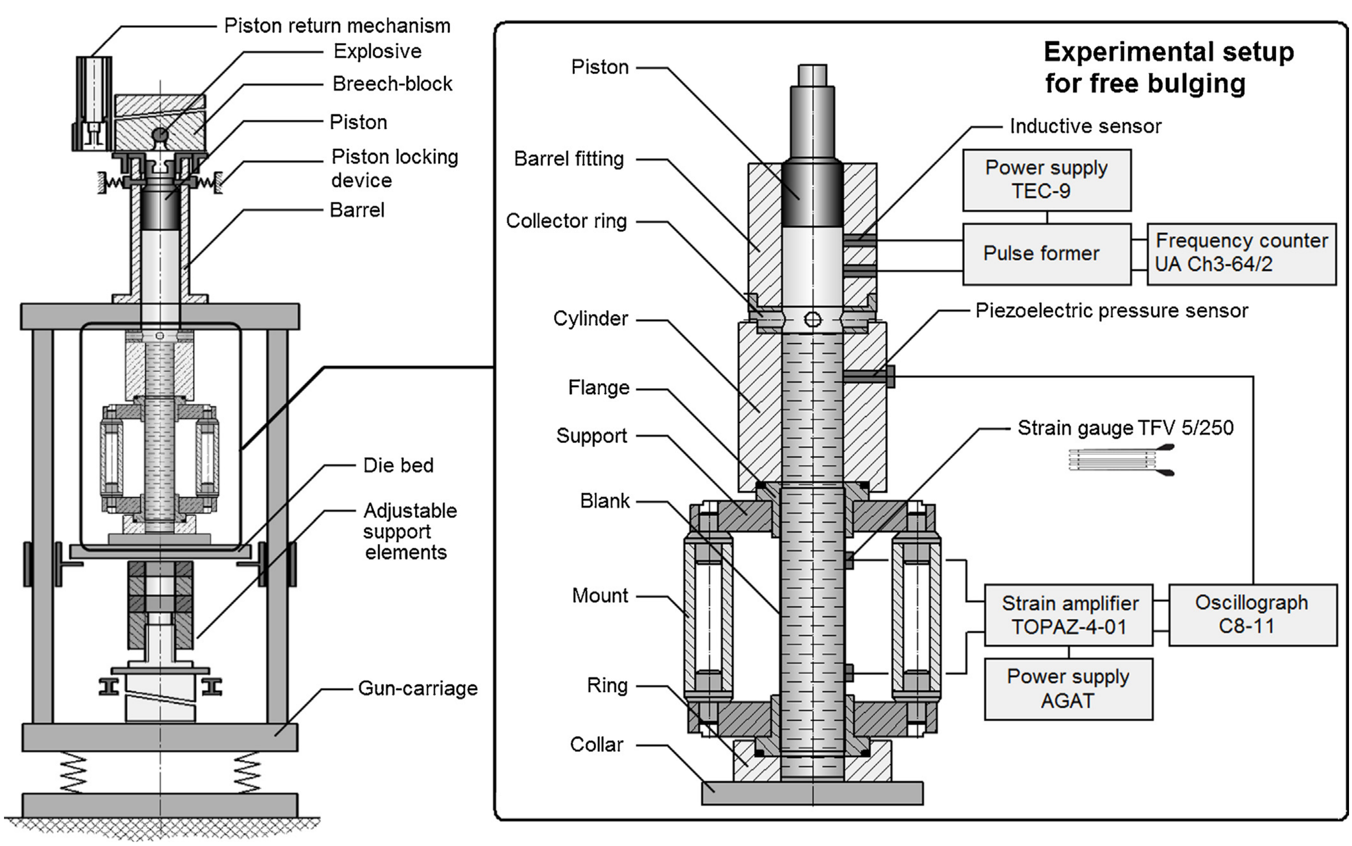

Fig. 1. Device for hydrodynamic forming and experimental setup for free bulge experiment.