

Gas Detonation Forming by a Mixture of H₂+O₂ Detonation

Morteza Khaleghi Meybodi, and Hossein Bisadi

Abstract—Explosive forming is one of the unconventional techniques in which, most commonly, the water is used as the pressure transmission medium. One of the newest methods in explosive forming is gas detonation forming which uses a normal shock wave derived of gas detonation, to form sheet metals. For this purpose a detonation is developed from the reaction of H₂+O₂ mixture in a long cylindrical detonation tube. The detonation wave goes through the detonation tube and acts as a blast load on the steel blank and forms it. Experimental results are compared with a finite element model; and the comparison of the experimental and numerical results obtained from strain, thickness variation and deformed geometry is carried out. Numerical and experimental results showed approximately 75 – 90 % similarity in formability of desired shape. Also optimum percent of gas mixture obtained when we mix 68% H₂ with 32% O₂.

Keywords—Explosive forming, High strain rate, Gas detonation, Finite element analysis.

I. INTRODUCTION

THE use of explosives for metal forming has been well known for many applications in the past [1]. A specialized method within this forming processes works with explosive gas mixture like oxygen and hydrogen. The gas detonation forming of metal plates is a dynamic production process based on the pressure energy produced instantaneously by the shock wave inside a combustion chamber [2]. The process takes place in a few milliseconds and impulsive forces are utilized in the deformation of circular blanks. The strength of detonation pressure is controlled with the amount of impulse gas inside a chamber. Since the process takes place inside a closed-control volume, it is impossible to observe the deformation of blank during process. The process simulation based on the finite element method is used to investigate the deformation mechanisms and examine effect of the detonation pressure on the work piece [3]. The advantage of using gaseous medium is the possible automation due to an easy filling and a clean combustion.

Compared with the conventional explosive forming process, the gas detonation forming process is more advantageous in commercial use for the following reasons:

- 1) Since commercial fuel gas is used as the energy source, possible danger is minimized and, thus the GDF process can be used in ordinary factories.
- 2) Both the ultimate pressure level and the period of duration for applying the ultimate pressure can be set almost independently to each other.
- 3) Automation of the GDF process is relatively easy and the process is suitable for repeated operation.
- 4) The work plate and the apparatus do not come in contact with water and thus GDF process is advantageous in terms of rust prevention.
- 5) The sound level of the GDF process is low.
- 6) The investment cost and operation cost of GDF process are relatively low [2].

In this study we use a gas detonation forming apparatus to obtain some experimental data and after that we use the Finite element Analysis to compare our experimental data.

II. EXPERIMENTAL WORK

Experimental tests were carried out in Guilan University's GDF apparatus (Fig. 1). This apparatus consists of different parts such as ignition system, Oxygen and hydrogen cylinder, valves, manometer and an explosion chamber made of special seamless carbon steel pipe that is a thick cylindrical tube with 4.5 cm thickness and 53 cm length.



Fig. 1 GDF apparatus

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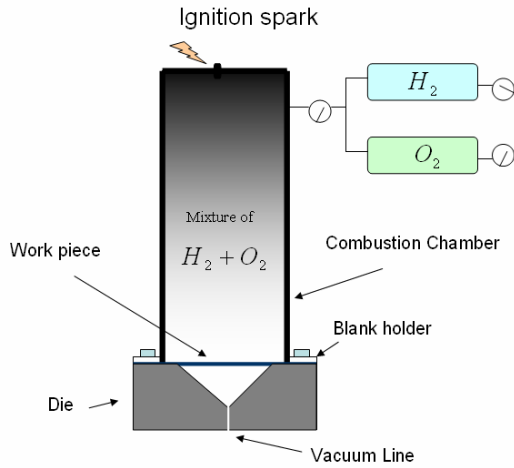


Fig. 2 A conceptual drawing of GDF apparatus

First of all Oxygen and Hydrogen have been used with a ratio of 1/1, while after many tests a mixture of 68% Hydrogen + 32% Oxygen was distinguished as the best result (Fig. 3). Gas is ignited by a spark plug.

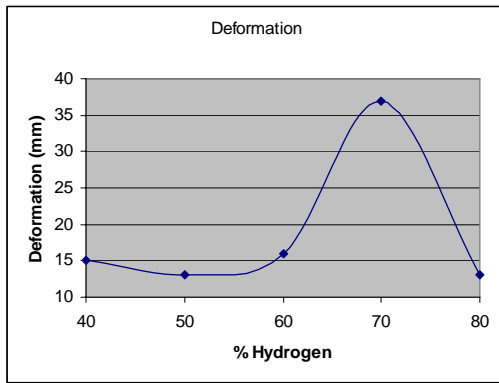


Fig. 3 Effect of Hydrogen percent in formability

Some circular steel plates were used as work piece with 1mm thickness and 16cm diameter. Also Die angle was 90 degree and the mechanical properties of the steel blank are given in Table I.

III. EMPIRICAL CONSTITUTIVE EQUATIONS

There are a number of equations that have been proposed and successfully used to describe the plastic behavior of materials as a function of strain rate and temperature. At low (and constant) strain rates, metals are known to work harden along the well-known relationship (called parabolic hardening) [4].

$$\sigma = \sigma_0 + k\varepsilon^n \quad (1)$$

Here σ_0 is the yield stress, n is the work hardening coefficient and k is the pre-exponential factor. The effect of temperature on the flow stress can be represented by:

TABLE I
MECHANICAL PROPERTIES OF MILD STEEL BLANK

Elastic modulus, E (G Pa)	210
Poisson ratio	0.29
Density (kg/m ³)	7890
Yield Stress (M Pa)	217

$$\sigma = \sigma_f \left[1 - \left(\frac{T - T_r}{T_m - T_r} \right)^m \right] \quad (2)$$

Where T_m is the melting temperature, T_r is a reference temperature at which σ_r , a reference stress, is measured, and T is the temperature for which σ is calculated. This is simple curve fitting, and the equation above increases in concavity as m , an experimentally determined fitting parameter, is increased. The effect of strain rate can be simply expressed by

$$\sigma \propto \ln \dot{\varepsilon}$$

This relationship is observed very often at strain rates that are not too high. Johnson and Cook [5] and Johnson et al. [6] used these basic ingredients and proposed the following equation:

$$\sigma = (\sigma_0 + B\varepsilon^n) \left(1 + C \ln \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0} \right) \left[1 - (T^*)^m \right] \quad (3)$$

This equation has five experimentally determined parameters (σ_0 , B , C , n and m) that describes fairly well the response of a number of metals. The terms T^* is calculated as:

$$T^* = \frac{T - T_r}{T_m - T_r} \quad (4)$$

where T_r is the reference temperature at which σ_0 is measured and $\dot{\varepsilon}_0$ is a reference strain rate (that can , for convenience , be made equal to 1). Johnson and Cook tested a number of materials and obtained these parameters which are given in Table II for Steel 1006.

TABLE II
MECHANICAL PROPERTIES OF MILD STEEL BLANK

σ_0 (MPa)	B (MPa)	n	C	Melting T (K)	m
217	234	0.643	0.076	1811	1

IV. EXPLICIT DYNAMIC SIMULATION MODEL

Nowadays, numerical simulation by means of finite element analysis (FEA) is an established tool for investigation of complex forming processes. But due to the coupled field problem, containing a mechanical, fluid mechanical the simulation and optimization by FEA is not as easy as for conventional forming operation. The GDF process is a

transient dynamic deformation process and the process simulation is the finite element solution of dynamic equilibrium equations. In the combustion chamber, the detonation gas is the only agent that deforms the steel blanks and forces the material to flow into the die cavity [7]. The first assumption in the process model is the elimination of detonation gas from the computational model and replacing the complex shock wave propagation with the measured pressure in the chamber as boundary condition acting on one side of the sheet. A 3D simulation model including the steel blank, Die and blank holder was constructed and the FE solution of dynamic equilibrium equations was performed using the explicit time integration method. The geometry of die, blank and blank holder is shown in Fig. 4. The die and blank holder surfaces are modeled as analytical rigid segments. The blank is modeled with S4R shell elements. The boundary conditions were considered as perfectly clamped as the real situations in experiments.

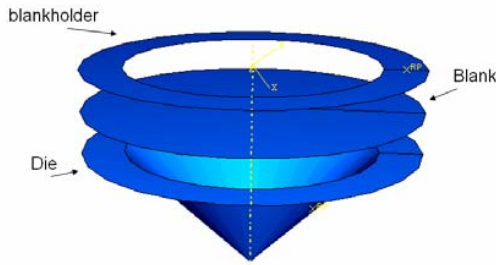


Fig. 4 3D Finite Element model

V. RESULTS AND COMPARISON OF EXPERIMENTAL AND THEORETICAL MODELS

In this study the die with 60 mm in depth was used. It was observed that the steel sheets in some primary tests did not fill the die cavity completely, but after reaching to an optimum percent of gas mixture which was 68% H₂ + 32% O₂, the die was filled by steel blank efficiently. Also initial charged gas pressure was 5 bar so initial hydrogen pressure before detonation was 0.7*5=3.5 bar and initial oxygen pressure before detonation was 0.3*5=1.5 bar. Fig. 5 shows the experimental and numerical results comparatively.

The sheet could not fill the die cavity efficiently in conditions that the average pressure was below 0.75 MPa and the efficient forming could not take place [8].

As you see, Fig. 6 shows a comparison between stresses on different radiuses. Whatever we move from centre of the blank to the edge, stresses are reduced. Also fig7 shows variations of thickness strains which are calculated in experimental by equation:

$$\epsilon_t = \ln (T/T_0).$$

Fig. 8 shows the variations of Hoop strain in different radiuses which are calculated in experimental by equation:

$$\epsilon_d = \ln (D/D_0).$$

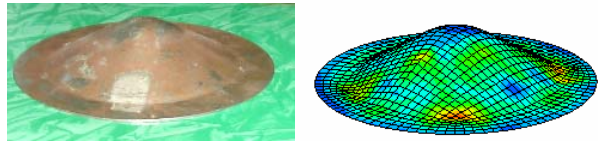


Fig. 5 Comparison between experimental and numerical

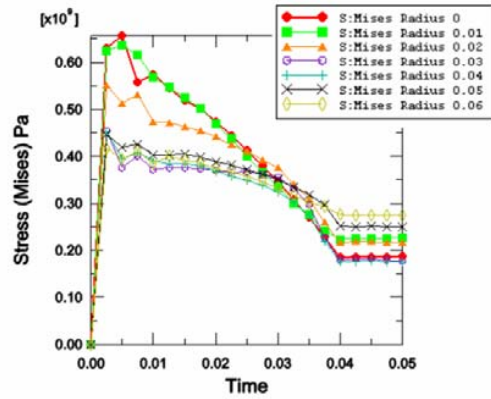


Fig. 6 Comparison among stresses

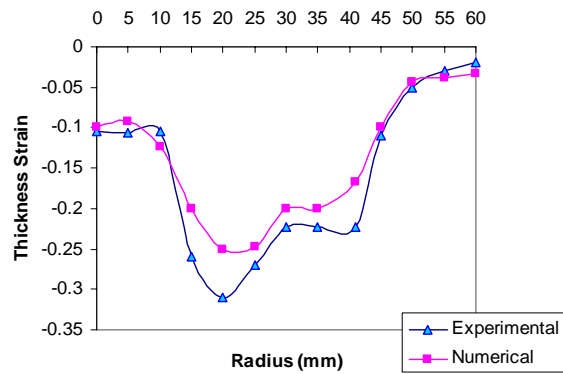


Fig. 7 Thickness strain comparison

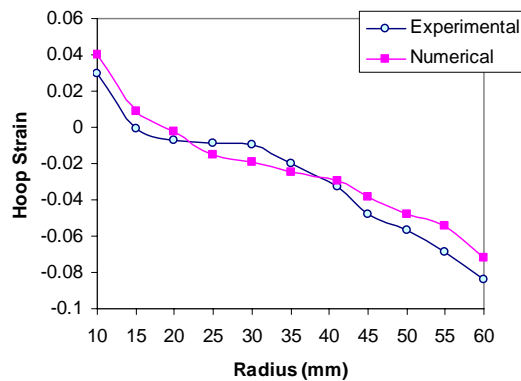


Fig. 8 Hoop strain comparison

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