Measurement of impact velocity of cladding metal by photonic Doppler velocimetry (PDV)

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Abstract:

Explosive welding is a process of reliably joining two different metals often difficult to join by other techniques. The process results depend on number of parameters out of which the most important one is the cladding metal velocity at the time of impact on the cladded one. This contribution focuses on development of methodology for determination of impact velocity during the welding process. The use of Photonic Doppler Velocimetry (PDV) was tested for this purpose with different types of probes under different angles. Well tested combination in which copper plate is accelerated and welded to the steel baseplate was chosen for conducted experiments.

Keywords: Acceleration by detonation; explosive welding; collision of metals; PDV; Photonic Doppler Velocimetry

1 Introduction

The process of explosive welding is used for joining two or more different metals often difficult or expensive to join by other techniques. The mechanism of welding process is based on high velocity impact of explosively accelerated metal plate to metal baseplate under suitable angle. The explosive with low detonation velocity, often in range from 2 to 3.5 km/s, is placed on top of the accelerated metal. The low but stable detonation velocity is important, because higher detonation velocity would generate strong shock wave that could damage the accelerated plate by spall or destroy the weld due to a shock reflection. For this reason the most commonly used explosives in Czech Republic are Semtex S25, S30 and S35 or ANFO in the mixture with some inert [1].

At the impact point of the accelerated plate on the baseplate pressures of tens of gigapascals are reached. In this pressure region metals behave as fluids [1]. If the collision angle is in the range of 5-20° unstable jet is formed at the impact point resulting in formation of a typical wavy interface [2]. The scheme of this process is shown in Figure 1 where β is the flyer plate dynamic bend angle, v_0 is the accelerated plate velocity and v_k is the weld formation speed which is for parallel arrangement the same as the detonation velocity. The detailed formation mechanism of the wavy interface is described by Bahrani, et al. [3].

For determination of the welding conditions it is necessary to know the collision velocity. This can be done by number of methods including the high-speed camera, shorting pins, VISAR or PDV.

In our experiments we decided to test suitability of the PDV technique for determination of the entire velocity profile of the accelerated metal plate during the welding process. The overall goal is to develop technique that would allow anyone to measure impact velocity during industrial welding process. In this paper we present our first results obtained in trials with Cu plates being welded on steel.

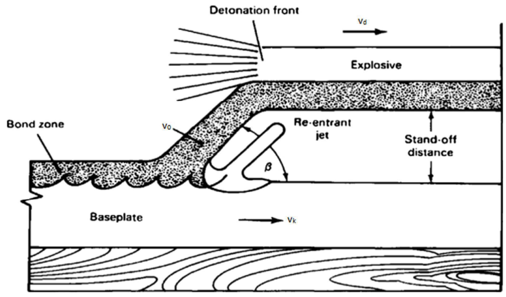

Figure 1: Flyer plate deformation during the welding process [4]

2 Experimental

2.1 Experimental arrangement

The experiment was conducted in parallel geometry with 4 mm standoff distance. A 2 mm thick copper was chosen as the material of the accelerated plate. The copper plate size was 159x124 mm with sides bent upwards forming 20 mm deep tray. This was filled with Semtex S25 powder explosive (two centimeters thick layer). Detonation velocity of this explosive is 2050 m/s at density 1.1 g/cm^3. The copper tray filled with the explosive and placed on wooden supports ensuring proper standoff distance is shown in Figure 2 on the right. The explosive was initiated by standard detonating cord containing 12 g of PETN per meter. A stainless steel baseplate 100x100 mm and 12 mm thick is shown in figure 2 (left). Four holes for the optical probes were drilled through this plate. These holes were drilled under two angles - 75° and 80°. Two probes were used for each angle for to check the reproducibility of the signal in one shoot.

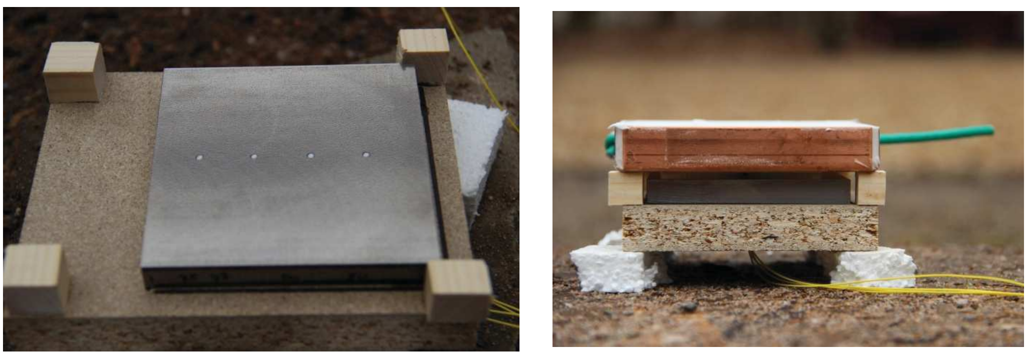

Figure 2: Arrangement of the plates, steel plate with the probes on the left, entire setup on the right

The steel plate was placed on 16 mm plywood support. This low impedance material prevented the weld from being damaged or destroyed by tensile stresses. The plywood support also served as a holder of four 16 mm high wooden spacers on which rested the copper tray 4 mm above the steel plate. The schematic arrangement of the probes is shown in Figure 3.

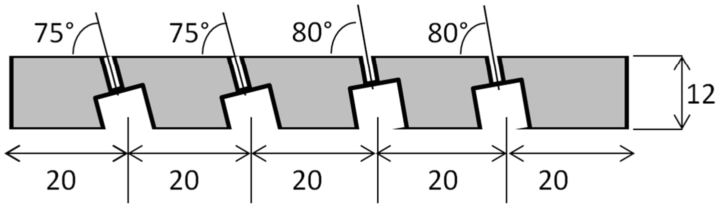

Figure 3: Scheme of the probes setup with for determination of the impact velocity during the process of metal welding.

2.2 Velocity measurement technique

Photonic Doppler velocimetry (PDV) was used for the measurements. PDV is a laser interferometric technique for measuring velocities of moving surfaces up to tens of kilometers per second [1]. The light emitted by fiber laser is divided to two paths, the first called a reference arm takes the unshifted light to the coupler where it combines with the shifted light from the measurement arm. At the end of the measurement arm of every channel is an optical probe which emits the light to the point of interest on the surface of the moving object and acquires the reflected light. The movement of the object results in slight shift in frequency. This Doppler shifted frequency is combined with the original laser beam from reference arm yielding a new beat frequency. The evaluation of velocity is based on determination of the beat frequency at particular time. Many methods exist to do that but Fourier or wavelet transforms are the most common ones. The schematic of Photonic Doppler Velocimeter is shown in Figure 4 on the left and the photo of the device used in the experiments on the right.

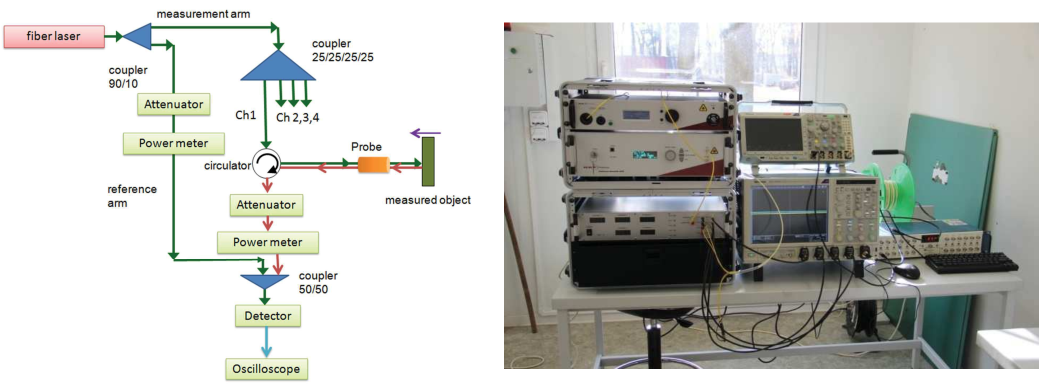

Figure 4: Schematic and actually used 4 channel Photonic Doppler Velocimeter

3 Results

An example of velocity profile obtained by probe under 80° angle is shown in figure 5 on the left. The velocity profile has an expected shape with gradual increase in velocity and it should end at the time when the copper plate hits the steel baseplate and destroys the optical probe. The distance travelled by the plate is shown in Figure 5 on the right, which is an integral of the velocity curve. Based on this curve we know that the copper plate fly-off distance was only 3.4 mm which does not correspond to the standoff gap of 4 mm. We are missing a part of the signal corresponding to the distance of 0.6 mm before copper plate hits to the steel plate. The reason why the signal ends before the impact can be that the jet gets in a way of the light emitted from the probe. The other possible explanation is that the shock wave in the air travelling between the plates can hit the probe before the copper plate.

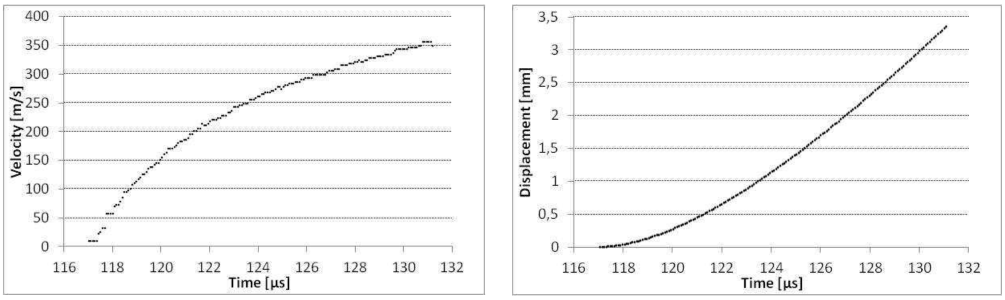

Figure 5: Results of impact velocity measurement: velocity vs. time (left), distance vs. time (right)

The collision angle was calculated from the data in figure 5 using simplified approach. It took into consideration that during the 13 µs the copper plate flew the distance of 3.4 mm and that the detonation velocity of the Semtex S25 is 2050 m/s. The calculated collision angle was 7.4°.

An ideal range of collision angles exist for various combinations of the welded metals. In general angles between 5-20° result in desired wavy weld [5]. An optimal angle to measure the velocity of accelerated copper plate is perpendicular to the surface of the plate as it hits the steel base plate. Setting this angle exactly would however result in loss of the signal in the early stages of the plate acceleration. The direction of the metal acceleration and hence the deflection angle also changes. The velocity vector is in the early stages practically perpendicular to both surfaces and only gradually changes as the acceleration process progresses. The probe we are using is a wide angle one and therefore captures the reflected light even when it comes back under an angle. The use of collimating probes will increase the accuracy of the evaluation.

Further experiments with various angles and probes will therefore follow with the goal to optimize the measurement setup for industrial application.

4 Conclusion

This work demonstrates initial trials using PDV measurement for determination of velocity profile of detonation accelerated metal plate during the metal welding process. The knowledge of the impact velocity is useful to calculate the collision conditions. Setup with simple and cost effective probes was successfully tested and the direction of further experiments set up. Further experiments will investigate the effect of the probe angle, its position with respect to the baseplate surface and utilization of different optical probes with the goal to eliminate the noise distracting the light path just before the collision.

Acknowledgments

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