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Development of a strain-gage installation method for high-speed impact of strikers on a Split Hopkinson bar apparatus

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Abstract. When designing a split Hopkinson system, the yield strength of the selected pressure bar material determines the maximum stress attainable within deforming samples and also, the maximum striker velocity that is usable to prevent plasticity in bars. In practice, to avoid strain gages stripping, the velocity of the striker is limited by the instantaneous particles acceleration generated in the bars. As a consequence, the full potential of the Hopkinson system can not be used. Therefore, for material having very high yield strength, it is very difficult to induce the required stress wave to create plasticity using a split Hopkinson apparatus. The idea of using an improved method for installing strain gages to withstand very high accelerations is very important for high dynamic loading using the split Hopkinson bar system. This paper compares standard strain gage installation procedures with a new approach. Data obtained for a material showing no plasticity at a normal operating impact velocity range of 22 m/s while showing usable level of plasticity when using a high impact velocity of 37 m/s is discussed.

1 Introduction

Development of new armor materials especially designed to defeat impact dynamic such as high velocity bullet impact and blast loading, requires a dynamic test method developing high strain rate conditions for material characterization. To reach that goal, the Defense Research and Development Canada (DRDC) uses the widely accepted compression split Hopkinson pressure bar (SHPB) technique. However, even with the SHPB technique, characterization of armor material remain challenging due to the difficulty in reaching the sample plasticity regime which requires impact speed of the striker so high that the strain gage barely withstand the acceleration. Experiments at DRDC Valcartier showed that impact speed beyond approximately 22 m/s on Split Hopkinson Pressure Bar lead to strain gage failure. Therefore, to reduce the wasted trials (and material) due to strain gage failure, an improved method of installing strain gage was investigated. The concept consists of varying dimension of connector tab and modifying the soldering of the tab and the strain gage.

2 Split Hopkinson bar set-up

The DRDC Valcartier SHPB system uses a gas gun to propel a 14.3-mm striker bar. The input and output bars both have a diameter of 14.5 mm, a length of 800 mm and are made of maraging steel. Table 1 shows striker, input and output bars properties. The density, modulus of elasticity, ultimate compressive strength and hardness were measured experimentally. Table 1 also shows the Stress-Proof material use as a reference case. The striker calculated maximum safe speed to maintain the instrumented bars below there elastic limit is 96 m/s. Before this investigation, to avoid strain gage failure the safe striker speed impact was limited to a maximum of 22 m/s, which represent only 23% of the full capacity of the system.

Pressure waves traveling into the input and output bars were measured using two strain gages cemented in the middle of each bar, mounted on opposite side of each bar and connected so as to cancel out most of the bending strain in the bars. The strain gages used were Constantan foil model #EA-06-250BG-120 made by Micro-Measurements Div. The gage length was 6.35 mm, while the gage factor was 2.07. The strain limit was ±5% (50 000 $\mu\varepsilon$). Two strain gage conditioner units (RC Electronics model 8000) were used. The A/D digitizer card model used was NI 6133 made by National Instruments. A GPIB data bus (model IEEE 488.1) was used to control the conditioner unit connected to the A/D digitizer card. Software used to control the instruments was designed in-house using LABVIEW software package made by National Instruments. To minimise frictional forces at the bars/sample interface, the Dow Corning G-N Metal Assembly Paste was used as lubricating grease. Striker velocity was measured using 2 independent systems, an Enhanced Laser Velocity System (ELVS) and three IR emitter/detector pairs positioned at the muzzle of the launcher. Reference [1] provides more details of DRDC SHPB system with its calibration.

3 Strain gage bonding work

During the development of an improved method of installing strain gage, the "Vishay Instruction Bulletin 129-8 Surface Preparation for Strain Gage Bonding" was followed to prepare the bars surface as per Ref. [2] and the "Vishay Instruction Bulletin 127-14 Strain Gage Installations with M-Bond 200 Adhesive procedures" was followed to install strain gages [3].

Figure 1 shows a typical strain gages installation. The bondable terminals were installed following the "Vishay Technical note TT-603: The Proper Use of Bondable Terminals in Strain Gages Applications" as per Ref 4. With this installation, failures tend to occur at the connection tabs on the input bar for impact speed above 22 m/s.

As a first option, we try to eliminate the connection tab and solder directly small wires to the strain gage. Small

Table 1. Mechanical properties of Maraging steel (Ma) and Stress-Proof steel.

		unit	Ma	StressProof
Density	ρ	kg/m^3	8064	7805
Modulus of Elasticity	E_b	GPa	182.1	206,8
Ultimate Compressive Strength	σ_u	MPa	2618	745
Hardness		HRA	80	58
Sound Speed	$c_b = \sqrt{\frac{E_b}{\rho_b}}$	m/s	4752	5148
Impedance	$Z = A\rho C_0$	kg/s	6326	6635
Poisson's Ratio	ν		0.3	0.29

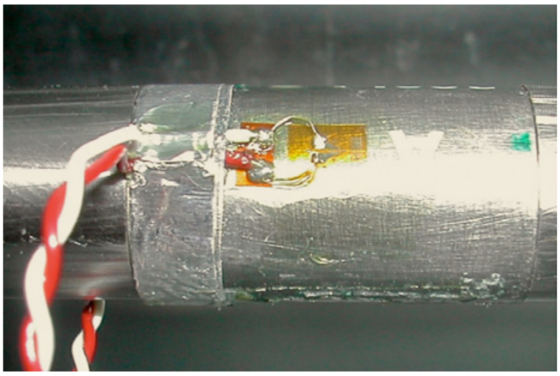

Fig. 1. Standard installation of strain gage before investigation.

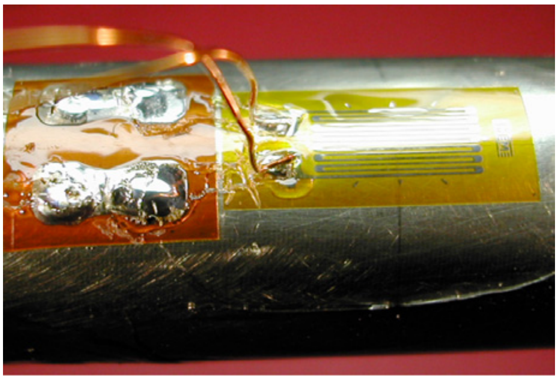

Fig. 2. Thin wires soldered to the strain gage's tab.

Fig. 3. Thin wires soldered to the strain gage's tab after failure.

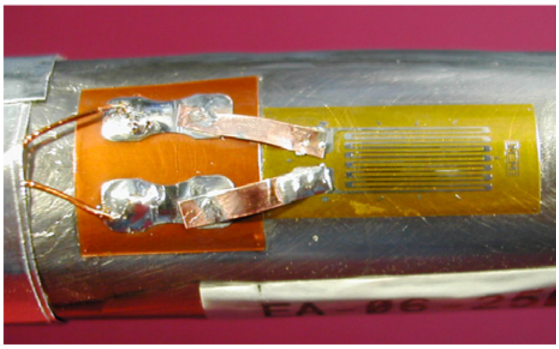

Fig. 4. Copper foil soldered to connection tab and the strain gage's tab with very thin wires.

wires were used in an attempt to reduce inertia during acceleration of the input bar. Figure 2 shows the installation concept. Unfortunately, it failed with no improvement on impact speed (figure 3).

As a second option, very thin copper foils were soldered flat from the connection tab to the strain gage. The way to solder the wire was also modified to reduce inertia during acceleration of the input bar. Figure 4 shows the installation concept. As with standard installation case, the failure occurs at the connection tabs with no improvement on impact speed (figure 5).

As a third option, always keeping in mind the idea of reducing inertia during acceleration of the input bar, thin wires were fixed on larger connector tab with the smallest possible amount of solder on the tab. This installation concept is shown in figure 6. Using this relatively simple technique, it was possible to increase impact speed over 42 m/s without destroying the strain gage or the tab connection. Considering the limitation of the system at 96 m/s, we are now using more than 43% of the capacity of our system, which represent a significant improvement of 20%.

4 The stress-proof material case

Using the above improve installation technique, samples made of stress-proof were evaluated. The material properties are shown in Table 1. Samples dimensions were evaluated to obtain an optimum impedance ratio, which is 9.96 mm diameters and 4.59 mm length. Results for an impact speed of 21.9 m/s, which is close to limit for strain gages failure is shown in Fig. 7. As seen, no plasticity was induced in the sample. The impact velocity was then

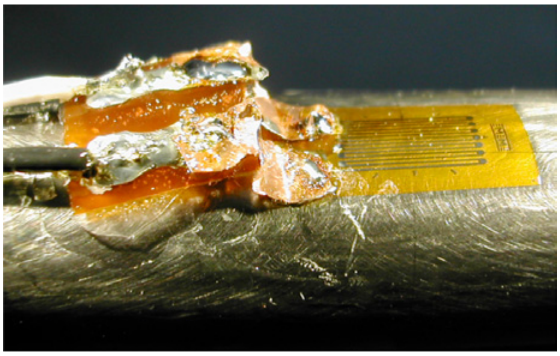

Fig. 5. Copper foil soldered to connection tab and the strain gage's tab after failure.

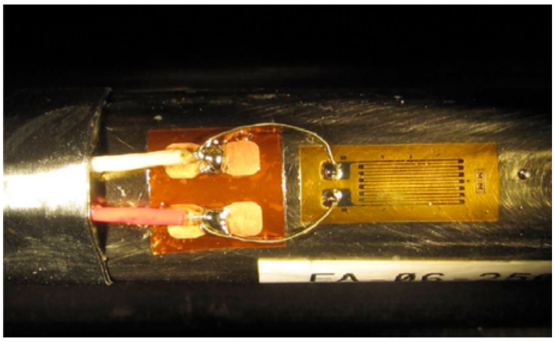

Fig. 6. Connection Tab soldering technique.

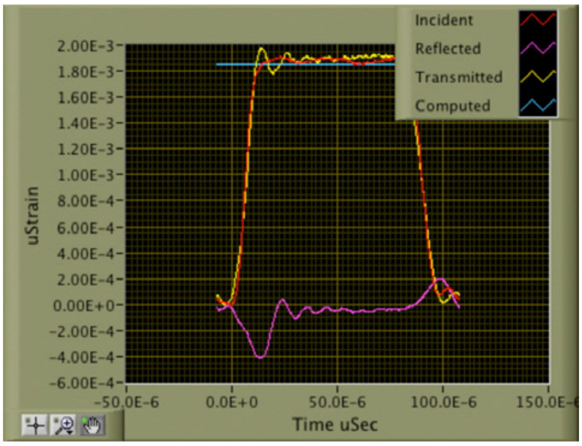

Fig. 7. HSR test result of Stress-Proof. Impact velocity of 21.9 m/s.

increased up to 37.3 m/s to obtain plasticity as seen in Fig. 8.

5 Results and discussion

The DRDC apparatus uses a momentum bar in contact with the output bar. The momentum bar traps almost all the energy propagated by the compressive stress wave through the output bar. Hence, the displacement of the output bar is at its minimum, which explains why strain gage failure on the output bar is rarely observed.

Most of the time, the strain gage failure are observed on the input bar due to the displacement involved during

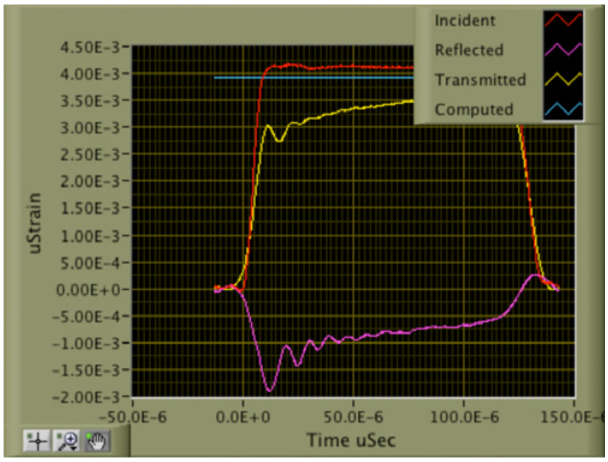

Fig. 8. HSR test result of Stress-Proof. Impact velocity of 37.3 m/s.

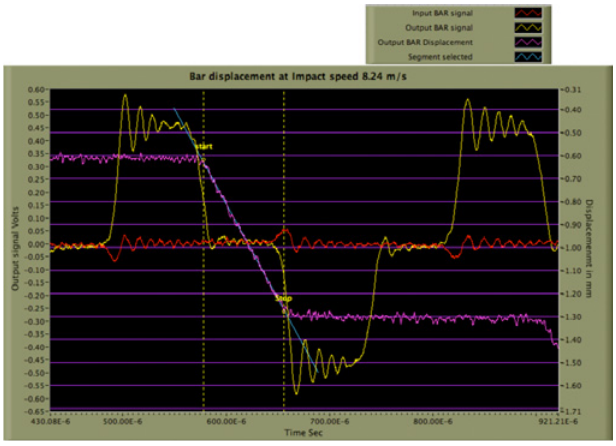

Fig. 9. Output bar displacement and wave traveling.

the sample deformation. In fact, if we try to evaluate the particulate acceleration in the zone of the strain gage, it becomes easy to understand why failure occurs. To estimate that number, we remove the momentum trap at the end of the output bar and place the DRDC ELVS system to measure the displacement. The Fig. 9 shows the waves traveling in the output bar. In this case, we used a striker of 20 cm long. Considering the compressive wave traveling in the bar is twice as long as the striker, the wave length is 40 cm. On our system, the strain gage are fixed in the middle of the 80 cm long bar. By using results from Fig. 9, we can estimate the time required for the wave to travel the 40 cm distance. On the graph, this time is shown by 'start' and 'stop' and correspond to the moment the wave left the strain gage, reach the end of the bar and is reflected back to the strain gage. Having the time and the distance, we evaluate the particulate velocity as 8.2 m/s. Note that the ELVS system place at the end of the output bas has given a velocity of 8.24 m/s, which confirm the evaluation. As for the local acceleration, we need to use the particulate velocity divided by the rising time. In our estimation, we reach 81500 g!

What has been found in this investigation is the vulnerability of the connection tab on the input bar and a lot of attention has to be paid to its installation. There is no issue concerning the strain gage itself if the Vishay Installation Instructions are followed.

Soldering thin lead wires directly to the strain gage leads to failure because the strain gage used has not been designed to withstand acceleration of the lead wire. Using copper foil increased the connection stress between the strain gage and the connection tab and the amount of solder required on the connection tab didn't help either as described below.

The connection tab is the interface between the strain gage and the instrumentations. It must withstand the acceleration and elastic deformation of itself and the inertia of the lead wires connected to the instruments induced by the compressive elastic stress wave in the bar. Increasing the connection tab's bonded surface to the bars helps in withstanding high acceleration. What has been found also, is that solder covering the entirety of the copper surface on the tab creates considerable stress on the substrate. The elasticity of the solder and the bonded substrate is different and hence lead to separation of the connection tab from the bar. Hence, the technique consists of pouring the smallest amount of solder on the tab to fix the lead wires as shown on Figure 6. The smaller the lead wires, better are the chance to reduce the forces required to displace them.

By using this technique, the maximum striker speed impact to avoid strain gage failure has almost doubled and is around 40 m/s. The safe striker speed is around 35 m/s.

6 Conclusion and future work

By using a simple and new strain-gage installation technique, DRDC Valcartier expanded the range of material types to be characterized including several armor types. As future work, it could be possible to improve even more by using this technique with very thin wires used in Figure 2. On the other hand, by using these wires, the users have to change the equations to obtain the strain from the electrical signal by considering the lead wire resistance, which leads to strain gage desensitization (ref. Vishay TN 514).

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