Reverse Taylor Anvil Testing of Armour Materials

Final Project Report 2017

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This report aims to design and develop a methodology for conducting Reverse Taylor anvil-on-rod impact tests. The objectives of this project are to conduct Reverse Taylor anvil-on-rod experiments of armour materials (i.e. high strength steels and aluminium) in a verified test setup with verified procedures at various impact velocities. The experiment is to be conducted using the Single Stage Light Gas Gun (SSLGG) in the University of New South Wales’ Impact Dynamics laboratory. The final project report aims to outline the methodology and manufacturing processes to conduct this test as well as comparing results from ANSYS AUTODYN® simulations to experimental results.

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1 PLTOFF, School of Engineering & Information Technology. ZEIT4500
I. Introduction

The aim of this project was initially to develop a working and verified Taylor rod-on-anvil experimental apparatus to conduct testing on various samples to analyse their material properties. Due to resource limitations, the experiment was altered to conduct the reverse Taylor anvil-on-rod experiment. Simulations were conducted through computational modelling in ANSYS AUTODYN® to simulate the experiment and have a benchmark to compare the experimental results to. A test setup was manufactured to enable testing at UNSW Canberra on the SSLGG, utilising the 70mm barrel. The results and discussion of the manufacturing process as well as the conduct of the experiments are also included in this paper.

A. Motivation

The motivation for this project comes from Defence Science and Technology Group – Melbourne (DST Group – Melbourne) who are sponsoring this project. The main objective is to design and develop a methodology for conducting Taylor rod-on-anvil impact tests as well as gaining data that DST Group can use to validate models they have developed.

Having a platform to conduct the testing of various materials will enable DST Group to research different materials and investigate their potential use for ballistic protection. This experiment will also be used to validate computer simulated models DST Group have developed and verify if the simulated results accurately reflect experimental results for specific materials. The potential outcome for this is that defence can research materials using these models, which is both more cost and time effective, and determine certain properties and characteristics of the materials being analysed. The end objective is the potential use of these tested materials in armour protection.

B. Material

DST Group provided the samples, which were analysed in this project. The test samples were BIS80 and 5083-H116 Aluminium. The properties of BIS80 and 5083-H116 Aluminium are listed in Table 1 and Table 2 respectively. The material for the anvil used in this project is BISALLOY Armour Ultra High Hardness (UHH) 600 steel and its properties can be found in Table 3.

<table>
<thead>
<tr>
<th>Properties</th>
<th>BIS80</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical Hardness</td>
<td>255 HB* (26 HRC)**</td>
</tr>
<tr>
<td>0.2% Proof Stress @ 600°C</td>
<td>300 MPa</td>
</tr>
<tr>
<td>Ultimate Tensile Strength in 20 mm @ 600°C</td>
<td>876 MPa</td>
</tr>
<tr>
<td>Elongation in 20 mm @ 600°C</td>
<td>24%</td>
</tr>
</tbody>
</table>

*Brinell hardness number
**Rockwell scale C

Rockwell C hardness testing was conducted over the surface of the BIS80 sample in accordance with AS1815.1 – 2007 Metallic materials—Rockwell hardness test. Each test produced a consistent hardness of 27 HRC, which is what is expected from the material specifications.
Table 2: 5083-H116 Aluminium properties
(Asm.matweb.com 2017; Aluminium Alloy Data Sheet 5083 2013)

<table>
<thead>
<tr>
<th>Properties</th>
<th>5083-H116 Aluminium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness</td>
<td>85 HB* (53 HRB)**</td>
</tr>
<tr>
<td>Ultimate Tensile Strength</td>
<td>317 MPa</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>305 MPa min</td>
</tr>
<tr>
<td>0.2% Proof Stress</td>
<td>215 MPa min</td>
</tr>
<tr>
<td>Elongation in 50 mm</td>
<td>10%</td>
</tr>
</tbody>
</table>

*Brinell hardness number  
**Rockwell scale B

Table 3: BISALLOY Armour UHH600 steel properties (Bisalloy.com.au, 2017)

<table>
<thead>
<tr>
<th>Properties</th>
<th>UHH600 Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness</td>
<td>570 – 640 HB* (55.5 – 59.5)**</td>
</tr>
<tr>
<td>0.2% Proof Stress</td>
<td>1300 MPa</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>2050 MPa</td>
</tr>
<tr>
<td>Elongation in 50 mm GL</td>
<td>8%</td>
</tr>
</tbody>
</table>

*Brinell hardness number  
**Rockwell scale C

The UHH600 steel sample was previously tested and found to have a Rockwell C hardness of 50 (Kelderman, 2015). It was noted that the hardness is lower than what is listed in the material specifications, however for the purpose of this experiment it was determined to still have the properties required to simulate the anvil during the test.

II. Literature Review

A. Taylor Rod-on-Anvil Experiment

The Taylor rod-on-anvil experiment was derived by Taylor, 1948. The purpose of this experiment is that it allows dynamic material properties to be evaluated using a relatively simple and inexpensive testing procedure.

The Taylor rod-on-anvil experiment utilises a cylindrical metal specimen striking a rigid boundary. A metal can avoid plastic strain even if exposed to stresses, which exceed their static yield stress. This can be achieved by subjecting a cylindrical metal specimen to a high stress for a short period of time (Taylor, 1948). During the Taylor rod-on-anvil experiment, the front portion of the specimen will crumple up, while the rear segment remains undeformed. The difference between the initial specimen size and deformed specimen size in conjunction with the impact velocity can lead to an estimation of a minimum possible value for acceleration. This can then allow a minimum value for yield stress to be calculated. However, the actual yield stress will be greater than this initial estimation (Taylor, 1948), and further calculations can be conducted to ensure greater accuracy.

As a cylindrical metal specimen strikes a rigid flat target perpendicularly, a wave of compressive stress will be created at the target face. “The stress at the impact end immediately rises to the elastic limit, and an elastic compression wave travels towards the rear end. The stress in this wave is equal to the elastic limit” (Taylor 1948, p. 289).

If the velocity of the specimen is high enough, the stress wave will separate into two components, the first, leading wave, being an elastic compressive wave, which will move through the specimen at the speed of sound. The second wave is a plastic compressive wave, but will travel at a far lower velocity relative to the leading wave. Due to these high compressive stresses, severe deformation will occur both radially outward from the specimen axis, as well as via axial shortening (House, 1989).

As the leading wave arrives at the free-end of the specimen, it will be reflected as a tensile wave, with equal magnitude to that of the elastic compressive wave. This tensile wave will then move through the specimen until it encounters the slower travelling plastic compressive wave front. When this happens, two key events occur. “First, the velocity of the plastically undeformed portion of the rod will be reduced as the elastic wave moves
through the material. Second, the reflected tensile wave will superimpose with the compressive plastic wave to reduce the overall stress at the plastic wave front” (House 1989, p. 5). As this process continues, eventually both the motion and stress will reduce to zero within the specimen. This will leave a sample with a plastically deformed region that one is able to measure. Figure 1 demonstrates the motion of the plastic and elastic waves travelling within the specimen.

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Figure 1. Plastic and Elastic Wave Motion in the Specimen (House 1989, p. 5).
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The yield stress of a material can be approximated using Taylor’s experiment by measuring the deformed specimen after impact and comparing it to the undeformed specimen prior to impact. A full derivation can be found in Armour: Materials, Theory and Design (Hazell, 2015). It should be noted that the following equation assumes uniform deceleration, which is not completely realistic. However, experimental results indicate this approximation is not far off experimental results (Whiffin, 1948). The equation for yield stress hypothesised by Taylor is listed below in Eq. (1) and Fig. 2 shows where these measurements are taken from.

Yield Stress:

\[
\gamma = \frac{\rho_0 u^2 (L - X)}{2(L - L_1) \ln \left( \frac{L}{X} \right)}
\]  

(1)

The yield stress indicates the stress at the point where a material begins to deform plastically. This point is known as the yield point. Prior to this yield point, deformation is elastic and a material will return to its original shape, however past the yield point, the deformation is plastic and permanent deformation occurs. This is what causes the ‘mushroom’ appearance during Taylor rod-on-anvil experiments in the samples. This mushroom region is where plastic deformation occurs and hence why the samples do not return to their original shape. By knowing the yield stress, indicates the limits to the amount of stress a material can withstand before it will be permanently deformed.

Due to the simplifications Taylor made in his first derivation for calculating the yield stress, Taylor derived a correction factor for more accurate calculations. This correction factor takes into account the variation in deceleration via a set of graphs for multiple correction factors. Whiffin showed that the correction factor was dependent on velocity and that it was approximately equal to 1.12 at a velocity of 100m/s and 1.06 at a velocity of 800 m/s (Whiffin, 1948).

J.B Hawkyard developed equations, which more accurately reflect the final geometry of the specimen than what is predicted by Taylor’s theory. Hawkyard achieved this by utilising “an energy equilibrium equation across the plastic wave” (Hawkyard 1969, p. 313). His equation takes into account strain hardening, which seems to have a significant effect on the final shape of the specimen, post striking the anvil (Hawkyard, 1969). The equation developed by Hawkyard predicts a concave shape for the specimen deformation, whereas Taylor’s prediction was of a convex nature.

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Figure 2. Before and After States. (Hazell 2015, p. 42).
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This experiment developed by Taylor is still valuable in modern science despite being over 50 years old. Taking into consideration the alterations made on Taylor’s first assumptions, the test can be used to validate existing models for various ductile materials. This is “due to the large deformation, large gradients of deformation and stress, unique deformation profiles and very high strain rate that can be achieved in this test” (Sarva, Mulliken and Boyce 2007, p. 2382).

III. Manufacturing

A. Specimen Holder

Due to the need for accurate and repeatable testing, a specimen holder, which can be seen in Fig. 3, was manufactured. The holder ensured the specimen being tested was aligned with the anvil, and multiple tests could be conducted with minimal alterations. Specimens were machined to an L/D of 5, which has been used in previous experiments (Anderson, 2006). Specimens were suspended in a manufactured holding device, which was aligned with the exit of the 70mm SSLGG barrel, which can be seen in Fig. 4. This was achieved via a mounting plate which bolted onto a steel plate within the SSLGG chamber. Two vertical rods were positioned in line with the barrel exit. Laser cut cardboard slides were inserted into the two vertical rods with a semicircle cut out to hold the specimen being tested. The purpose of the laser cut slide was that it was a sacrificial piece of material that could suspend the specimen to be struck by the anvil. These cardboard slides were destroyed in the process of testing and could be readily replaced for subsequent tests. The remaining holding device could then have the slides replaced and a new test could be efficiently conducted, knowing the specimen was correctly aligned.

B. Sabot, Anvil and Specimens

The BISALLOY Armour UHH600 steel was waterjet cut to 60mm diameter anvils with both faces surface ground to a thickness of 8.18 ± 0.01 mm. Multiple measurements of the thickness were conducted to ensure planarity of the anvil using a micrometre. The anvils were recessed into 70 x 110 mm sabots with 0.7 mm of the anvil face protruding from the front. The purpose of the sabots is to increase the velocity of the projectile by creating a seal between the gun tube and propellant (Drysdale, Kirkendall and Kokinakis, 1978). The setup of the anvil and sabot can be seen in Fig. 5.

Specimens were machined to 50 mm lengths with a diameter of 10mm. This resulted in an L/D ratio of 5 which has been used in other experiments before (Cazamias and Bless, 1997). The aluminium 5083-H116, labelled 1 and 2, and BIS80, labelled 3 and 4, prepared specimens can be seen in Fig. 6.
IV. ANSYS AUTODYN® Simulations

The Johnson Cook Constitutive Model (Johnson and Cook 1983) was utilised in the ANSYS AUTODYN® simulations as the strength criteria for the specimens being tested. Equation (2) shows the equation from which the empirical constants $A$, $B$, $C$, $m$ and $n$ are determined. Table 4 lists the parameters used in the simulations.

$$\sigma = (A + B\varepsilon_p^n)(1 + C \ln \varepsilon)(1 - T'/T_m)$$

where $T' = \frac{T-T_{room}}{T_{met} - T_{room}}$

$$\varepsilon = \frac{T_{met} - T_{room}}{T_{met} - T_{room}}$$ (2)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Johnson Cook Function</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A$ (MPa)</td>
<td>Yield Strength of Material</td>
<td>270</td>
</tr>
<tr>
<td>$B$ (MPa)</td>
<td>Strain Hardening Constant</td>
<td>470</td>
</tr>
<tr>
<td>$n$</td>
<td>Strain Hardening Exponent</td>
<td>0.600</td>
</tr>
<tr>
<td>$C$</td>
<td>Strain-Rate Constant</td>
<td>0.0105</td>
</tr>
<tr>
<td>$m$</td>
<td>Thermal Softening Exponent</td>
<td>1.200</td>
</tr>
<tr>
<td>$T_m$ (K)</td>
<td>Melting Temperature</td>
<td>933</td>
</tr>
</tbody>
</table>

Table 4: Johnson Cook Parameters for Al-5083 (Gray III et al. 1994)

A. Simulation Setup

Simulations were conducted utilising a 2D axisymmetric model with Lagrange element meshing. The geometry of the rod was 10 mm diameter and 50 mm in length, which replicates the experimental dimensions. A linear equation of state was used and due to the rod deformation being small enough, a failure model was not required. The simulations were conducted using the properties of Al-5083. The simulations assumed a rigid anvil face and focussed on analysing the final state of the specimens to use Taylor’s yield stress equation and compare the geometry to the results of the SSLGG experiment. Figure 7 shows an example of the simulation setup.

Figure 7. Simulation setup.
B. Results

Table 5: Yield stress estimate utilising Taylor’s formula

<table>
<thead>
<tr>
<th>Material</th>
<th>Speed</th>
<th>Cycles</th>
<th>Mesh size (mm)</th>
<th>Yield Stress (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5083-H116 at 200 m/s for 18000 cycles at 0.25mm Mesh</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>2660</td>
<td>kg/m³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity</td>
<td>200</td>
<td>m/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial Length</td>
<td>0.05</td>
<td>m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Length</td>
<td>0.04455</td>
<td>m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Undeformed length</td>
<td>0.01397</td>
<td>m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yield Stress</td>
<td>275.82</td>
<td>MPa</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

An array of gauges were placed along the top surface of the specimen at 1mm intervals in XY-Space. This allowed the final length of the specimen to be determined post impact as well as the length of the undeformed region. Through analysis of the mesh blocks, once radial deformation was greater than 10 microns, this determined the length of the rod which was undeformed. With this data, the yield stress for a given velocity was able to be determined using Taylor’s equation. Table 5 shows an example of the required parameters to estimate a yield stress using Taylor’s equation.

C. Discussion

As can be seen in Fig. 8, it was noted that the final length of the specimen would oscillate between a minimum and maximum length after a certain duration. Therefore, continuing to increase the cycle length proved redundant. It was also noted that the cycle where the simulation finished had an effect on the results. Depending on the final length of the specimen, corresponded to an undeformed length. For consistency, the simulation was stopped at maximum compression of the specimen when it was at its shortest final length and the corresponding undeformed length was taken at this point. It was noted that if the simulation stopped when the specimen’s final length was at a minimum on the sin curve, which corresponded to a longer final length, the yield stress calculated was significantly higher.

When the simulation was stopped at 15000 cycles for example and the specimen was at its longest final length, the yield stress was calculated to be 303.79 MPa, which is significantly higher than the 275.82 MPa calculated at 18000 cycles when the specimen was at maximum compression.

A mesh convergence was conducted to analyse how altering the mesh size affected the results. As can be seen by the results in Table 6, reducing the mesh size of the specimen also reduced the calculated yield stress using Taylor’s equation. This could be due to the methodology of deciding the undeformed length value in the equation. It was noted that changing this value by 1 mm or more had a significant impact on the calculated yield stress. As the mesh size was reduced, there were more elements that could be examined and therefore a more accurate measurement could be taken. This could explain why reducing the mesh size led to a reduced value for the calculated yield stress.

Table 6: Mesh convergence

<table>
<thead>
<tr>
<th>Mesh size (mm)</th>
<th>Yield Stress (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>277.35</td>
</tr>
<tr>
<td>0.5</td>
<td>276.33</td>
</tr>
<tr>
<td>0.25</td>
<td>275.82</td>
</tr>
<tr>
<td>0.125</td>
<td>273.30</td>
</tr>
</tbody>
</table>

Fig. 8 Final length of specimen vs. time at maximum compression.
V. Single Stage Light Gas Gun

A schematic of the test setup can be seen in Appendix A. Shimadzu Hyper Vision HPV-X2 and Phantom v710 high speed cameras were positioned orthogonally to the test setup to capture the impact between the anvil and specimen as can be seen in Fig 9. A total of three tests were conducted on the SSLGG with test two and three being discussed below. The impact velocities of test two and three were 240 m/s and 241 m/s respectively. The velocities were calculated post-test by analysing the high-speed camera footage. The HPV-X2 was operating at 1,000,000 fps providing 256 frames and a duration of approximately 250 μs. The Phantom v710 was operating at 100,000 fps and was not limited by its recording duration due to the relatively short duration of the experiment.

Figure 9. HPV-X2 and Phantom v710 setup.

A. Results

Analysis on the specimens pre-impact was conducted and it was estimated that the specimens were at an angle of 0.32° and 2.38° to the horizontal for tests two and three respectively. The images used for this calculation can be seen in Fig 10 and Fig 11. Figure 12 and Fig 13 show the plastic deformation of the specimens post impact.
The original ANSYS AUTODYN® simulations were utilised in conjunction with the experimental parameters to replicate the experiment. Changes to the simulation included increasing the impact velocity to 241 m/s and having the specimen at an angle of 2.38° to the horizontal. The simulation was created in three dimensions and simulated the scenario of experiment three as close as possible. The results of the simulation can be seen in Fig. 16.

B. Discussion

Test one data proved invaluable as there was a pressure wave pre-anvil strike, which caused the specimen to become detached from the mount and resulted in the anvil striking the specimen out of frame and with a non-planar impact. Alterations were made to the test setup to minimise the effect of this pre-impact pressure wave. The chamber was separated into two compartments with the main chamber and gun barrel separated by a mylar sheet. The two chambers were then separately evacuated to reduce the pressure difference as the sabot and anvil were fired. O-rings were also added to the sabot to minimise the chance gas escaping around the sabot and leaving the gun barrel first. The specimen was also superglued to aluminium slides opposed to cardboard slides as the aluminium was more rigid and less inclined to move. Coupling this with the superglue meant the impact was very planar with an impact angle of only 0.32°. The issue with using aluminium slides was that it affected the radial plastic deformation on the underside of the specimen and therefore analysis is not valid in this region. However, the top half of the specimen remained unconstrained and its data could be examined.

The third test used a single aluminium slide with the specimen glued with epoxy at the rear. This was done to minimise any interference with the plastic deformation of the specimen when impacted by the anvil. Unfortunately, the effects of the leading pressure wave impacted on the experiment and resulted in the specimen being at a 2.38° angle to the face of the anvil. The effects of specimen yaw have been seen in other experiments (Sarva, Mulliken and Boyce 2007, p. 2391) and the AUTODYN simulations used for comparison took into account the conditions seen in the experiment.
Edge detection software was utilised to compare the profile of the AUTODYN simulation results to that seen in the experiment. The profiles were overlayed to show the similarities between the two results, however it should be noted that edge detection is very complex and as can be seen on the bottom of the experimental sample, damage has occurred due to what is thought to be from the aluminium slide at the rear or contact with the catchment tank. Figures 17 shows the profile of test three’s experimental specimen overlayed on the AUTODYN simulation for test three with the parameters seen in the test. Figure 18 shows the profile of the AUTODYN simulation overlayed on the specimen from test three.

A calculation utilising Taylor’s equation (Taylor, 1948) was conducted to compare the estimated yield stress from the experimental results to that listed in literature for the given material. The values used for the analysis can be seen in Table 7. As can be seen, the estimated yield stress was calculated to be 291.28 MPa. Comparing this to the listed yield stress of 270 MPa (Gray III et al. 1994) indicates that calculating the yield stress with Taylor’s equation is slightly higher than expected. However, the equation is a simple estimate and should only be used as an indication. The data which is more valuable and can be taken away from the experiment is the final profile of the specimen and how the specimen deformed during the experiment. The Phantom v710 recorded the entire deformation of the rod at 100,000 fps. This footage can then be analysed by DST Group in order to determine whether their simulations accurately reflects the deformation that was seen in the experiment.

VI. Conclusion

This project aimed to design a test setup for reverse Taylor anvil-on-rod testing in the University of New South Wales Canberra campus’ Impact Dynamics Lab. The purpose of the project was to record the deformation of DST Group samples, which could then be further studied and examined in order to validate simulation models. Preliminary testing was conducted with deformation seen as was expected from an experiment of this type with radial deformation as well as axial shortening. ANSYS AUTODYN® simulations were created to replicate the experiment and compare the experimental results to the simulation results. The parameters seen in the experiment were implemented into the AUTODYN simulations so a comparison between specimen profiles from the experiments and simulations could be conducted. The setup in the SSLGG allows for future experiments to be completed to test more materials and at different velocities.

Table 7: Yield Stress from experiment three

<table>
<thead>
<tr>
<th>5083-H116 at 200 m/s for 18000 cycles at 0.25mm Mesh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
</tr>
<tr>
<td>Velocity</td>
</tr>
<tr>
<td>Initial Length</td>
</tr>
<tr>
<td>Final Length</td>
</tr>
<tr>
<td>Undeformed Length</td>
</tr>
<tr>
<td>Yield Stress</td>
</tr>
</tbody>
</table>

Figure 17. Test three AUTODYN simulation specimen overlayed with experimental profile.

Figure 18. Test three experimental specimen overlayed with AUTODYN simulation profile.

Figure 17. Test three AUTODYN simulation specimen overlayed with experimental profile.

Figure 18. Test three experimental specimen overlayed with AUTODYN simulation profile.
VII. Recommendations for Future Work

It is recommended that further tests are conducted on the SSLGG with various materials and at various velocities. The implementation of edge detection software to analyse the specimen profiles more accurately would further enhance analysis of the results and could determine trends between simulations and experimental results. Implementing the experimental data into AUTODYN simulation parameters would lead to a more accurate reflection of the profile of the deformed specimens seen in the experimental results. Finally, there were issues triggering the HPV-X2, further development of the setup could mean there is potential of capturing high speed footage of the experiment at high frame rates.

Acknowledgements

I would like to thank DST Group and Dr Shannon Ryan for sponsoring this project. My thesis supervisor’s Dr Juan Pablo Escobedo-Diaz and Professor Paul Hazell for their guidance, support and technical expertise throughout the year. I would also like to acknowledge Dr Andrew Brown for his assistance and advice on the project. Finally, I would like to thank Mr Thomas Thompson and Mr Geno Ewyk for their technical assistance on the project.
References


House, J.W., 1989. Taylor impact testing. KENTUCKY UNIV LEXINGTON.

Kelderman, E., 2015. Mechanical Behaviour of Armoured Steel under High Strain Rate Tensile Loading Conditions. The UNSW Canberra at ADFA Journal of Undergraduate Engineering Research, 8(1).


