Research Progress in Mechanical and Manufacturing Engineering Vol. 4 No. 1 (2023) 495-503
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RPMME

Homepage: http://penerbit.uthm.edu.my/periodicals/index.php/rpmme
e-ISSN : 2773-4765

A Numerical Analysis of Recycled Aluminium Alloys Reinforced with Alumina Oxide Subjected to High Velocity Impact

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DOI: https://doi.org/10.30880/rpmme.2023.04.01.057
Received 15 July 2022; Accepted 26 January 2023; Available online 1 June 2023

Abstract: Developing superior recycled aluminium as a replacement for primary sources, a variety investigation must first be done to determine the material's mechanical behaviour. Aluminium oxide, often known as α-Al_2O_3, is a chemical compound made up of aluminium and oxygen with the formula α-Al_2O_3. A previous experimental test on the deformation behaviour and fracture mode of recycled aluminium alloy AA6061 reinforced alumina oxide during Taylor impact tests at 191 ms^{-1}, 209 ms^{-1}, 220 $ms^{-1}$and 231 ms^{-1}. In this research project, the deformation behaviour and fracture mode are investigated numerically with implementing Johnson-Cook material model. The parameters are calibrated using experimental data. The results proved that the characterized model is capable of reproducing the mushrooming shape of the ductile fracture mode.

Keywords: Recycled Aluminium Alloys, Alumina Oxide, Taylor Impact Test, Fracture Modes, Finite Element Analysis

1. Introduction

The growing desire for more fuel-efficient automobiles to reduce energy consumption and pollution is a problem for the automotive industry. Aluminium characteristics, such as its high strength-to-weight ratio, good formability, corrosion resistance, and recycling capacity, make it an ideal option for replacing heavier materials (steel or copper) in vehicles in order to meet the automotive industry's requirement for weight reduction.

Because of the increased expense of raw materials [1], only limited research has been done to strengthen aluminium matrix composites with boron carbide. Furthermore, the silicon carbide

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aluminium reinforcement can aid to boost micro-hardness due to it hard effect, while diminishing the tensile characteristics renders the matric fragile due to the presence of reinforcement elements. Reinforcement with Al_2O_3 can increase the ultimate tensile strength, according to Lajis et al. [2] Within the method of mixing between the machining chips first undergo cleaning and drying processes of recycled aluminium alloy with Al_2O_3.

The main objective of material modelling is to create models that are widely used. Applicable and rather easy to define. General constituent models must have the following characteristics: they must be capable of expressing key elements of material behaviour, be simple in mathematical and computational terms, and require suitable experimental effort to get material parameters [3]. This research is significant because it provides an overview of the numerical analysis of the deformation behaviour of recycled aluminium alloy AA6061 reinforced alumina oxide deformation behaviour when subjected to high velocity impact. The findings on fracture mode prediction will aid in the development of recycled aluminium alloy AA6061 reinforced alumina oxide for industrial applications.

2. Materials and Methods

2.1 Recycled AA6061 Reinforced Alumina Oxide

Recycling is a modern method of minimising the enormous amount of waste produced every day. The extraction of bauxite, the purification of alumina using the Bayer process, and cryolite-based molten salt electrolytes are all energy-intensive steps in the basic processing of aluminium [4]. Aluminium oxide is a chemical compound of aluminium and oxygen with the chemical formula Al_2O_3. It is the most commonly occurring of several aluminium oxides, and specifically identified as aluminium (III) oxide. The purpose of the experiment was to see how the cylinder specimen would react to various collision scenarios at various speeds. The initial step was to give the geometry a substance. Using the mechanical properties stated in Table 1, the recycled aluminium alloy AA6061 reinforced alumina oxide was chosen for the entire body.

Table 1: Mechanical properties of Recycled Aluminium Alloy AA6061 reinforced alumina oxide [2]

Mechanical Properties	
Young Modulus, E	66.05 GPa
Yield Strength	177.64 GPa
Ultimate Tensile Strength (UTS)	315 GPa
Elongation	20.5%
Density, ρ	2.69 g / cm^3
Poisson's Ratio, V	0.33
Melting point, T_m	Approx. 580°C

To calibrate the material constant in the Johnson-Cook (JC) [4][5] model for recycled aluminium alloy AA6061 reinforced alumina oxide impact simulations, a multi-variable parameter fit produce was performed by using the results of the Taylor impact experiments data performed by another researcher. The Johnson-Cook material model is used to characterize the dependence of the yield stress σ on the plastic strain ε_p, rate of plastic strain $\acute{\varepsilon}_p$and temperature *T*, as follows,

$$\sigma_{eq} = [A + B(\varepsilon^p)^n][1 + Cln\dot{\varepsilon}^*][1 - (T^*)^m] \qquad \text{Eq. 1}$$

The Johnson-Cook material parameters for recycled aluminium alloy AA6061 reinforced alumina oxide, obtained by Taylor impact test are given in Table 2.

Table 2: Parameter Johnson-Cook model

Parameter Johnson-Cook Model	
A	214.9972 MPa
B	963.43002 MPa
N	0.829
C_1	0.0362
m	0.3004
T_m	855.15 K

2.2 Methodology

The initial geometry model of cylinder specimen and rigid wall are created in LS PrePost software. The cylinder specimen and rigid wall are modelled by using element and mesh tools. Table 3 shows the dimension of cylinder parts. The models are exported, combined and assembly in LSDYNA explicit finite element code as shown in Figure 1.

Table 3: Dimension of cylinder part

Dimension	
Diameter	8.45 mm
Length	15 mm

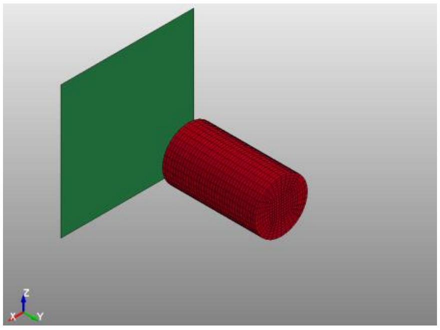


Figure 1: Model of cylinder specimen and rigid in LS PrePost software

Taylor impact test has been simulated using LS DYNA to predict the deformation and fracture modes of the cylinder specimen at after different impact velocities of 191 ms^{-1}, 209 ms^{-1}, 220 $ms^{-1}$and 231 $ms^{-1}$with the experimental test results. LS DYNA is a general-purpose finite element software used for solving static and dynamic responses of structures with large deformation. Several material models are available to predict deformation and fractures and among them Johnson-Cook model has been used for high velocity impact simulation. It incorporates high strain rates and large strains which are expected in high velocity impact cases.

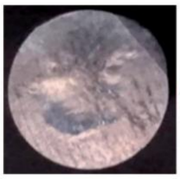
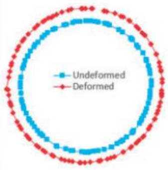
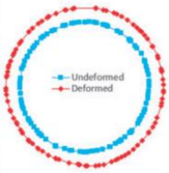
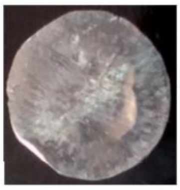
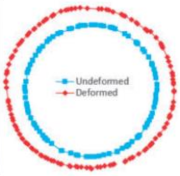
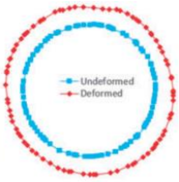
3. Results and Discussion

The section begins with the creation of a finite element model that will be used with the LS DYNA software. The comparison of outcomes between numerical analytic data and experimental test data is then shown, followed by a discussion of this research.

3.1 Experimental Results

The Taylor impact test had experimentally performed by other researcher using cylinders made of the recycled aluminium alloy AA6061 reinforced alumina oxide with a length of 15 mm and a radius of 8.45 mm. The experimental test had carried out with three different impact velocities at 191 ms^{-1}, 209 ms^{-1}, 220 $ms^{-1}$and 231 ms^{-1}respectively. The rigid wall had smooth surface and there was low friction condition during the impact test. Table 4 shows footprint deformation after the different impact velocities.

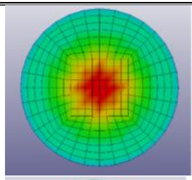
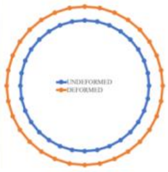
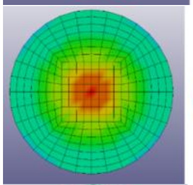
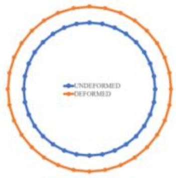
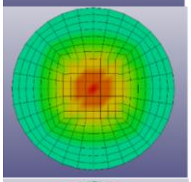
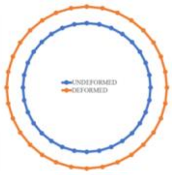
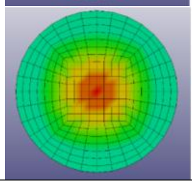
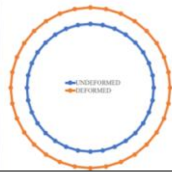
Table 4: Experimental results of recycled AA6061 reinforced alumina oxide

Impact Velocity (ms^{-1})	Final Length (mm)	Final Diameter (mm)	Photographs and the digitised locus of deformed specimen footprint	Fracture Modes
191	14.55	10.29	 	Mushrooming
209	13.55	10.33	 	Mushrooming
220	13.05	10.69	 	Mushrooming
231	12.80	10.95	 	Mushrooming

3.2 Numerical Results

The Taylor test has simulated in LS DYNA software, based on the experimental test data. Geometric model of the test contains a cylinder with the specified dimensions, impacts to a rigid body. 10 mm gap is considered between the cylinders and rigid wall in the simulations. Rigid body is assumed in the simulation, as impact wall is more rigid than cylinder made of recycled aluminium alloy AA6061 reinforced alumina oxide. Taylor impact is used with vary of initial impact velocity to observe the cylinder specimen reaction and impact occurred in a perpendicular form with rigid body in a very short time. Hence, it shows that the heat transfer is very low and the process is neglected.

Table 5: Numerical results of recycled AA6061 reinforced alumina oxide

Impact Velocity (ms^{-1})	**Final Length (mm)**	**Final Diameter (mm)**	**Photographs and the digitised locus of deformed specimen footprint**		**Fracture Modes**
191	13.28	10.22			Mushrooming
209	13.05	10.45			Mushrooming
220	12.92	10.60			Mushrooming
231	12.78	10.76			Mushrooming

3.3 Comparison Between Numerical Analysis with Experimental Test

The plotted graphs in Figure 2 shows the comparison between the data obtained from the experimental test and the numerical analysis on the final diameter of the tested cylinders. From the graph that has been compared, the final diameter for cylinder specimen after impacted by initial impact velocities has been plotted. From the observation, the graph shows that final diameter is increased when the initial velocity increased but suddenly decreased when initial velocity impact reached to 231 ms^{-1} for experimental tests. Meanwhile for numerical analysis graph shows increment trend since the initial velocities impact increase. By all of this comparison, the trend for graph of experimental tests and numerical analysis are different curve trending shape was obtained.

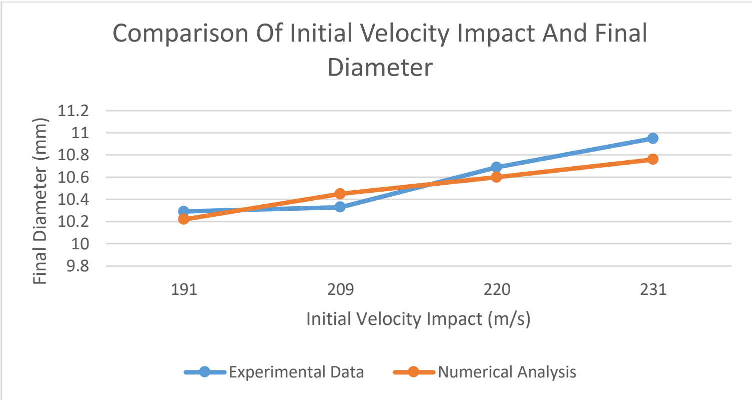


Figure 2: Comparison of Initial Velocity Impact and Final Diameter Graph

Table 6 shows the comparison between the data obtained from the experimental test and the numerical analysis on the coordinate of each node of footprint after the impact. From the table that has been compared, the footprint for cylinder specimen after impacted by initial impact velocities has been plotted. From the observation, the table shows that size of footprint is increased when the initial velocity increased. By all of this comparison, the trend for footprint of experimental tests and numerical analysis are slightly different shape was obtained.

Table 6: Footprint Comparison of Experimental Test and Numerical Test of Recycled AA6061 Reinforced Alumina Oxide

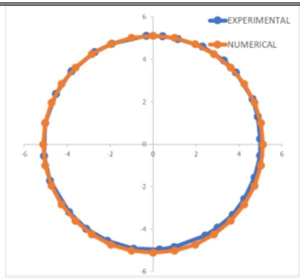
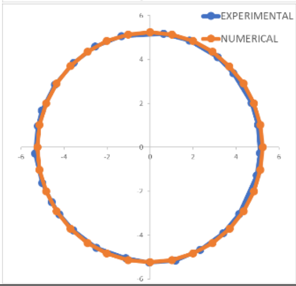
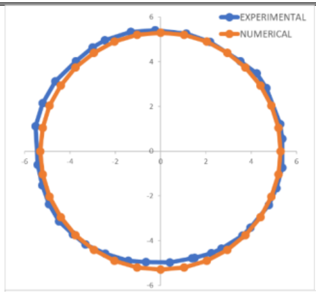
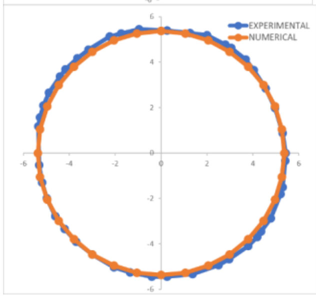
Impact Velocity (ms^{-1})	Footprint Comparison of Experimental Test and Numerical Test
191	
209	

Table 6. Continued.

Impact Velocity (ms^{-1})	**Footprint Comparison of Experimental Test and Numerical Test**
220	
231	

From the graph that has been compared in Figure 3, the final length for cylinder specimen after impacted by initial impact velocities has been plotted. From the observation, the graph shows that final length of the cylinder specimen will be decreased since the initial velocity increased. The graph shows the decrement trend for both of experimental tests and numerical analysis. The final length for experimental test after highest initial velocity impact of 231 ms^{-1}has been decreased to 12.80mm and for numerical analysis length has been decreased to 12.78mm. The differences between this experimental test and numerical analysis are 0.02 mm.

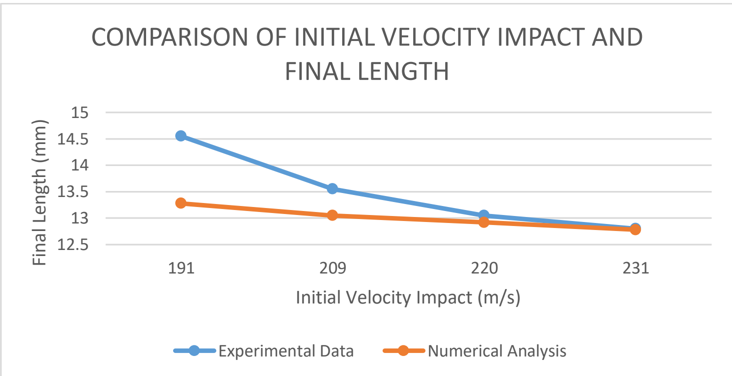


Figure 3: Comparison of Initial Velocity Impact and Final Length Graph

3.4 Discussion

The objective of this project on recycled aluminium reinforced alumina oxide is to show that when the Taylor Impact test fails, better investigations and descriptions may be done by combining the Johnson-Cook material model into numerical analysis. The Taylor impact test has simulated in the LS DYNA finite element code by using the application of Johnson Cook damage. The cylinders made of recycled aluminium alloy AA6061 reinforced alumina oxide in the test were thrown for four different velocities of 191 ms^{-1}, 209 ms^{-1}, 220 $ms^{-1}$and 231 ms^{-1} to a rather rigid body. Because of quick hit, the effects of heat transfer and friction were neglected. Following the numerical analysis, the deformation behaviour of the cylinder was numerically obtained at various velocities and compared to experimental tests.

From the comparison of cylinder specimen shapes obtained in the experimental test and the numerical analysis for the final diameter. The consistency between experimental observations and numerical analysis simulations indicates that the Johnson-Cook material model parameters can describe the large strain mechanical deformation behaviour of recycled aluminium alloy AA6061 reinforced alumina oxide undergoing high impact velocities. All four deformed specimens at a velocity of 191 ms^{-1}, 209 ms^{-1}, 220 $ms^{-1}$and 231 ms^{-1} from the experiments are reproduced by this model but still have some of error on the size of dimension.

Furthermore, the cylinder specimen of numerical analysis is within 0.7% error of the experimental test data. Meanwhile, at the initial impact velocity of 209 ms^{-1}, 220 $ms^{-1}$and 231 ms^{-1}, the result shows the cylinder specimens of numerical analysis are within -1.2%, 0.9% and 1.9% of error from the experimental test data respectively.

From the comparison of initial velocity impact and final length that shown in Figure 3, we can see that final length of the cylinder specimens for both numerical analysis and experimental test have been reduced to 13.28mm and 14.55mm at impacted velocity of 191 ms^{-1}. It reveals that cylinder specimen of numerical analysis is within 12.7% error of the experimental test data. Meanwhile, at the initial impact velocity of 209 ms^{-1}, 220 $ms^{-1}$and 231 ms^{-1}, we can observe that the cylinder specimens of numerical analysis are within 5.0%, 1.3% and 0.2% of error from the experimental test data respectively.

4. Conclusion

As a conclusion, this research objective considers successfully achieved which to study the deformation behaviour and the fractures mode of the recycled aluminium alloy AA6061 reinforced alumina oxide undergoing several velocity impacts by using Taylor impact test. In this study, the deformation and fracture characteristics of recycled aluminium alloy AA6061 reinforced alumina oxide was simulated numerically during Taylor impact tests with Johnson-Cook material model parameters calibrated by various material properties experiments. Lastly, numerical analysis simulation with implemented the Johnson-Cook material model results show that this research successfully captured the prediction of behaviour of footprint and side profile of cylinder specimens made from recycled aluminium alloy AA6061 reinforced alumina oxide as observed before in experimental test. The numerical analysis results clearly seen that deformation and fracture modes in the mushrooming shape was developed in the deformed cylinders near to impact area with initial impact velocity of 191 ms^{-1}, 209 ms^{-1}, 220 $ms^{-1}$and 231 ms^{-1} similar to experimental tests conducted beforehand.

Acknowledgement

Authors wish to convey a sincere gratitude to the Ministry of Higher Education (MOHE) and Universiti Tun Hussein Onn Malaysia (UTHM) for providing the financial means during the preparation to complete this research under Fundamental Research Grant Scheme (FRGS) –

FRGS/1/2020/TK02/UTHM/02/5, Vot K331, and UTHM Contract Research Grant – Vot H276, respectively.

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