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# Fit Mix Effect Modelling of Physio-Mechanical Properties of Experimental Al-Zn-Mg-Cu Alloy Stir-Cast from Recycled Beverage Can

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**Abstract.** The unique properties of aluminium and its alloyability with metals and non-metals made it one among most studied materials. It has vast areas of application in the automobile and aerospace industries. More than 97 % of aluminium used in beverage cans (BCs) are recoverable. Bulk of efforts were channelled to reuse of BCs to produce another can. Casting of a new Al-Zn-Mg-Cu alloy from BCs, adoption of Fit Mix Effect (FME) to model the physical and mechanical properties of the novel alloy were lacking in previous studies. Ingots were cast from BCs and spent batteries. Weight percent (Weight wWt. %) Zn were alternated between 4, 4.5 and 5 to produce nine (9) sections. Tensile and hardness pieces were heat treated. Largely, S3 delivered the peak UTS of 362.935 MPa, hardness of 113.06 Hv, 1.38 mm elongation and density of 2.8001 g/cm<sup>3</sup>. The empirical properties were used in delivering the FME model after fitting. The model was significant ( $P=0.991$ ) and fully represent the properties of this alloy. Further studies may adopt this model to predict the properties of similar alloy and validate with experimental outcomes. Simulation of the properties are equally open for further investigations. Simulation of the properties are equally open for further investigations.

## 1. Introduction

The addition of Zn, Mg and heat treatment improve the mechanical properties of 7xxx aluminium alloy [1-3]. Basically, the formation of hardening precipitates like  $MgZn_2$  are composition and heat treatment dependent. The build-up of the GP zones at room temperature supports the makeover of the metastable  $\eta'$  phase and lastly the  $\eta$  phase during over-ageing [4-6].

The latter support stability and dispersal of the particles. The strength-to-weight ratio of this alloy earned it a top-notched place in the aluminium alloy family [7,8]. This 7xxx alloys find application in the aerospace and automobile industries [1,7]. It is evident that the bulk of studies conducted on the 7xxx alloys obtained commercially available alloys [9-12]. Whereas the recycling of BCs were done solely to recover aluminium [13, 14] or for can production within the same cycle [15,16]. The casting of new X7475 alloy from BCs and the development of fit mix model to predict the physical and



mechanical properties after artificial aging remain unique and unexplored in the past. In this current study, the aim was to cast an experimental 7xxx alloys from BCs utilizing stir casting process and develop a model to mimic the density, hardness and UTS of the alloy after artificial aging. The justification was to effectively manage resources and optimize the properties through the FME model.

## 2. Materials and experimental

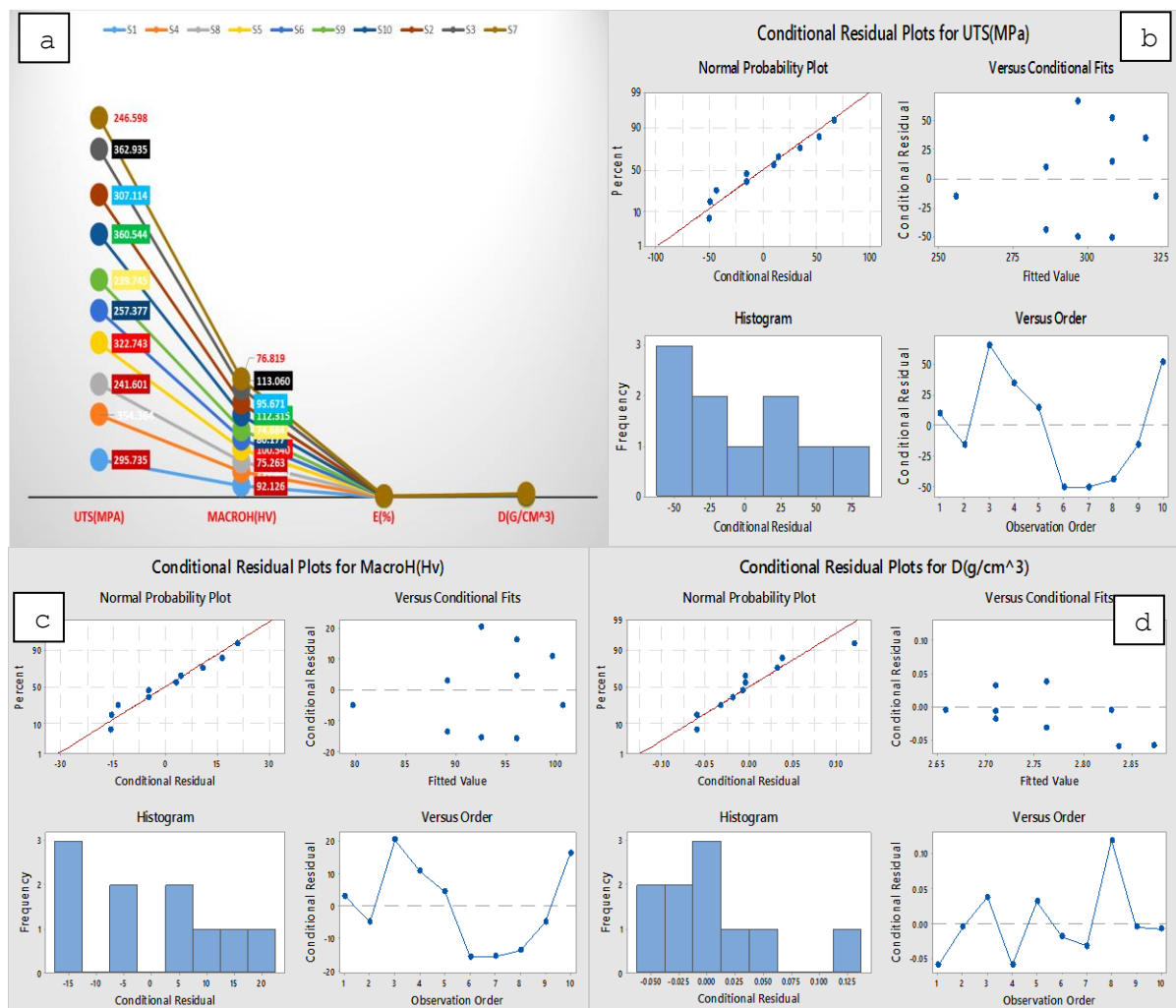
Zn and MnO were recovered through physical dissection of spent batteries. Recycled aluminium alloy and Zn ingots were cast from beverage cans and Zn bits respectively using gas fired furnace. Cu was recovered from windings of standing fan while Mg was as supplied. The wt. % of Mg, MnO, and Cu were fixed at 1.75, 1.00 and 0.35 with Zn varied from 5.0 - 4.0 wt. %. The disparity in Zn produced nine (9) samples. Casting was done using graphite crucible in an induction furnace of JT0332 model. Samples were aged for 24 hours before preparation for tensile and hardness following ASTM E8/E8M-11 and ASTM E384-17. Nexus 100-II universal CNC Lathe machine was used. After machining, precipitation hardening and artificial aging (T6) were delivered at 475 oC and 100-140 oC. T6 time (T6-Ti) alternated at 6, 10 and 15 hours. Testing followed ASTM B 557M – 02a on the Gotech AI-7000 LA5 Servo controlled machine. Load resolution was 1/200,000 and a test speed of 0.5 mm/minute was utilized. Buehler Macrohardness machine (model 1900-2005-250) based used based on ASTM E18. Load, time and testing speed were 5 kgf, 10 sec and 50  $\mu\text{m/sec}$  respectively. An average of 5-point investigation was taken to determine the hardness (Hv). Density was determined per ASTM-D-792 on Mettler Toledo machine.

## 3. Results and Discussions

To develop a model for the physical and mechanical properties using the Fit Mix Effect on the Minitab 18.0, Zn was fixed (4, 4.5, and 5.0), T6-Time was randomized while T6-temperatures (T6) were made covariate factors. Interaction and terms through order were 2 each. Model output were Microhardness, UTS and density.

The basis of the model developed was the result of experimental process obtained as presented in figure 1a. The ordering followed a variation in wt. % Zn where S1, S4 and S8 represent 4 wt. % Zn. Another classification are the S5, S6, S9 and S10 signifying the 4.5 wt. % Zn. the third set are 5 wt. % Zn. Overall, S3 artificially aged at 100 oC delivered the peak UTS of 362.935 MPa, hardness of 113.06 Hv, 1.38 mm elongation and density of 2.8001  $\text{g/cm}^3$ .

On the other hand, S9 was a 4.5 wt. % Zn alloy with T6-Ti of 10 hrs, sharing the same T6-Temp with S3. However, the least UTS of 239.745 MPa was observed in this alloy with corresponding hardness of 74.684 Hv, 0.338 mm elongation and 2.6527  $\text{g/cm}^3$  density respectively. The scattered nature of the conditional residual plot shown in figure 1(b-d) connote that the experimental and the condition-based predicted properties obtained are in harmony. A similar trend was observed in UTS and hardness. This is an evidence that the models are sufficient in representing the properties of this alloy after fitting.



**Figure 1:** Experimental physio-mechanical properties of X7475 aluminium alloy arranged in order of wt. % Zn (a) conditional residual plots for UTS (b) Macrohardness (c) and density (d).

### 3.1. Predicting UTS, hardness and density of the experimental alloy

The three linear models predicting the UTS, hardness and density of the novel alloy is presented partly in table 1. When T6-Ti was 6 hrs, an alloy 4 wt. % Zn might deliver an UTS of  $136 + 1.31 \cdot T6$  temperature after performing the Conditional Fitting. A linear increase in constant (k) was reported with increase in wt. % of Zn. This was due to the increase in wt. % Zn that supported the formation of hardening precipitates [11]. Parallel tendency holds with increase in T6-Ti to a point of tie between 6 hrs and 15 hrs (T6-Ti) albeit discrepancies in wt. % of Zn. The reason is because the dispersal of precipitates is time dependent [17-19]. A similar trend was maintained in the MacroHardness fitted models, correlating the duo. The model supported the findings of Li and Starink [19].

Additionally, a least constant of 40 and peak of 51.5 were predicted for an alloy of 4 wt. % Zn (T6-Ti =15 hrs) and 5 wt. % Zn (T6-Ti =6 hrs). The configuration differ with density, as was the case mentioned above. The implication is that each alloy sample has a unique model to be used in predicting the mechanical and physical properties and it is a function of T6 temperature. A summary of the models show the peculiarity of the samples. In the instance of variance (S), R<sup>2</sup> and adjusted R<sup>2</sup> for UTS and MH retained similar pattern.

**Table 1.** Conditional Fitted Equations (CFE) and Model Summary where T6 represent treatment Temperature

T6-Ti	Zn	UTS-CFE	MH-CFE	D(-CFE)	Model Summary
6	4	136 + 1.31 T6	42 + 0.41 T6	2.367 + 0.00335 T6	54.4563 (S for UTS)
6	4.5	158 + 1.31 T6	49 + 0.41 T6	2.286 + 0.00335 T6	29.12% (R <sup>2</sup> for UTS)
6	5	165 + 1.31 T6	51.5 + 0.41 T6	2.427 + 0.00335 T6	0.00% (R <sup>2</sup> adj for UTS)
10	4	102 + 1.31 T6	32 + 0.41 T6	2.404 + 0.00335 T6	16.964 (S for MH)
10	4.5	124 + 1.31 T6	39 + 0.41 T6	2.323 + 0.00335 T6	29.12% (R <sup>2</sup> for MH)
10	5	132 + 1.31 T6	41.0 + 0.41 T6	2.463 + 0.00335 T6	0.00% R <sup>2</sup> (adj for MH)
15	4	128 + 1.31 T6	40 + 0.41 T6	2.388 + 0.00335 T6	0.06811(S for D)
15	4.5	151 + 1.31 T6	47 + 0.41 T6	2.307 + 0.00335 T6	68.97%(R <sup>2</sup> for D)
15	5	158 + 1.31 T6	49.2 + 0.41 T6	2.448 + 0.00335 T6	53.46% R <sup>2</sup> (adj for D)

Table 2 depicts there that are nonzero parameters influencing the UTS and MH. This is represented by the -2 Log likelihood = 77.766. This means that the model left no any relevant parameter unconsidered. On the other hand, chances are that the density of this cast ally is not only influenced by the variables considered herein, with -2 Log likelihood = -2.556044. However, T6-time (T6-Ti) has more influence on UTS and density with a variation of 28.29%. There exist a correlation between the randomized parameters (wt. % Zn, T6-Ti, T6-Temp) and the empirical physio-mechanical properties modelled. The test of fixed effects (TFE) showed that the factors modeled are significant (P=0.991 for UTS and MH) as against a random effect model.

**Table 2.** Variance Components (VC) and Tests of Fixed Effects (TFE)

Source	Var	% of Total	SE Var	Z-Value	P-Value	TFE	Term	Zn	T6-Temp
T6-Ti	1170.134	28.29	3486.3050	0.335	0.369	UTS and MH	DF	2	1
	817	%					Num		
Error	2965.486	71.71	1910.9340	1.551	0.060		DF	2.52	5.57
	129	%					Den		
Total	4135.620	-2 Log likelihood = 77.766035 for UTS				Density	F-Value	0.01	0.16
	946						P-Value	0.991	0.703
T6-Ti	113.5521	28.29	338.31806	0.335	0.369		DF	2	1
	63	%					Num		
Error	287.7770	71.71	185.44110	1.551	0.060	Density	DF	1.43	5.34
	34	%					Den		
Total	401.3291	-2 Log likelihood = 63.770373 for MH					F-Value	0.82	0.62
	97						P-Value	0.58	0.464
T6-Ti	0.001456	23.89	0.005552	0.262	0.397	Density	DF		
		%					Num		
Error	0.004638	76.11	0.003039	1.526	0.063		DF		
		%					Den		
Total	0.006095	-2 Log likelihood = -2.556044 for Density							

#### 4. Conclusion

The need to derive optimum engineering benefit from recycled BCs by converting it to a new 7xxx alloy was achieved. Homogenization supported the formation of hardening phases and improved the mechanical properties of the new alloy. Zn addition reinforced UTS and hardness. Resource management was the justification for the development of FEM to predict the physical and mechanical properties of this alloy. The model presented is suitable for predicting the properties of this alloy. In

the same token, it fully represent the expected properties with marginal differences in T6-Ti and T6-Temp. Further studies may adopt this model to predict the properties of similar alloy and validate with experimental outcomes. Increase in sample size and implementation of design of experiment may offer more accurate data and reduce the chances of error.

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