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Full Length Research Paper

Statistical evaluation of hardness behavior in a thermally aged A356.0-type Al-Si-Mg alloy

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A statistical study has been made on the isothermal treatments of A356.0-type Al-Si-Mg alloy. The reprocessed alloy was subjected to hardness evaluation. The values obtained were processed using statistical package for social scientists (SPSS) software to compare all tempers and multiple-step thermal ageing treatment (MSTAT) values by analysis of variance (ANOVA) and Pearson Correlation Index. Equally, a non-parametric and parametric statistics consisting of sign test and t- test respectively were employed for further evaluation of results. This indicate that up to 47% (obtained from the adjusted R square) of the variation in hardness is explained by ageing time. From the statistical analysis of the reprocessed alloy, it was evidenced using one-way ANOVA that all the temper conditions and MSTAT showed six hardness values that have been computed with their corresponding mean and standard error bars. Most of the treatments conducted indicate a significant improvement in the hardness value of the alloy. The Post Hoc Test using the Pearson Correlation Index for all the ageing temperatures and time has been compared. A regression line analysis was also used to compare tempers. The results obtained from these statistical evaluations indicate positive correlations between all the groups of treatments considered in this work.

Key words: Significant level, ANOVA, statistical evaluation, reprocessed alloy.

INTRODUCTION

The use of Al-Si-Mg alloys for automotive industry is attractive due to light weight and reasonable strength after ageing treatment (Seyedrezai et al., 2009; Thompson et al., 2004). For the purpose of improving its hardness, precipitation heat treatment is usually adopted (Seyedrezai et al., 2009; Thompson et al., 2004; Cavazos and Colas, 2001; Leo and Cerri, 2003; Khomamizah and Ghasemi, 2004). Although, other methods such as alloying, nanocomposite e.t.c have been demonstrated as a means of enhancing the thermo-mechanical properties of this group of alloy (Ali and Mohsen, 2012; Sajjadi et al., 2012). However, the effects of these methods can effectively and significantly be seen by means of statistical method, since it has been reported (Popescu et al., 2010; Devore, 1999) that statistical analysis helps to explain the results of a given treatment. In the present study, the experimental results from the hardness measurement using statistical package for social scientists (SPSS) software to generate data and compare all the temper and multiple-step thermal ageing treatment (MSTAT) values by analysis of variance (ANOVA) and Pearson Correlation Index were presented. Equally, from the statistical analysis of the reprocessed alloy, the regression coefficients of the tempers were graphically outlined.

EXPERIMENTAL METHOD

All samples for hardness were solution heat treated at temperature of 540°C for 1 h in an electrical furnace and then rapidly quenched in

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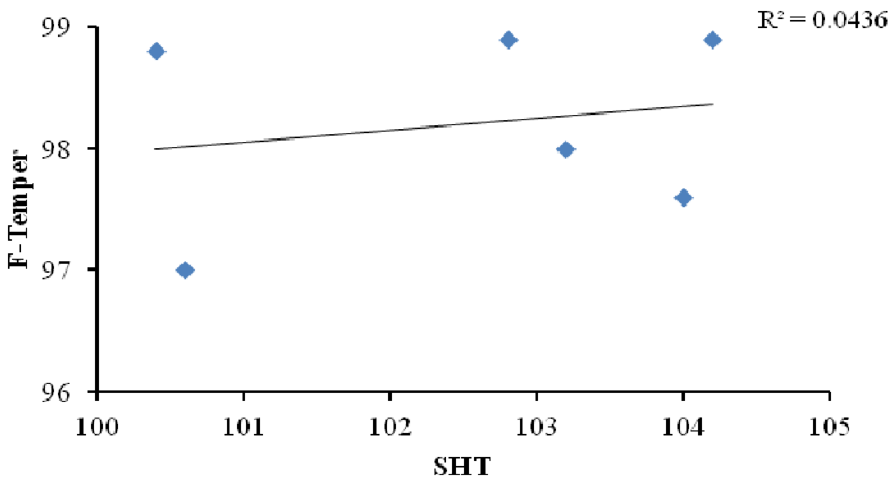

Figure 1. Variations in linear regression line with respect to F-temper and SHT temper for A356.0-type alloy.

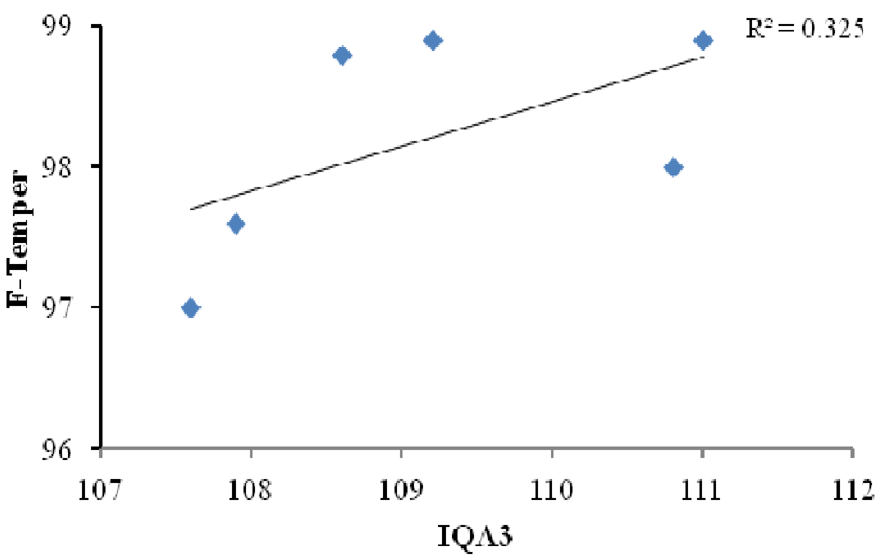

Figure 2. Variations in linear regression line with respect to F-temper and IQA3 temper for A356.0-type alloy.

warm water. The quenched samples were given series of multiple-step thermal ageing treatments ranging from double thermal ageing treatment (DTAT), single thermal ageing treatment (STAT), interrupted-quenching-ageing (IQA) and step-quenching-ageing (SQA). Some of the samples undergo temper conditions such as; ageing without solution heat treatment (SHT), T5, at temperature of 150°C for 1 to 5 h, incomplete DTAT/STAT (DTAT1/DTAT 2 and STAT1/STAT 2, respectively). Equally, the result of the hardness from these different tempers and treatments were processed by using SPSS software and compare all the temper and multiple-step-thermal ageing treatment (MSTAT) values by analysis of variance (ANOVA) and Pearson Correlation Index. From the statistical analysis of the reprocessed alloy, it was evidenced using one-way ANOVA that all the temper conditions and MSTAT showed six hardness values that have been computed with their corresponding mean and standard error bars. The linear regression lines were also drawn for the temper conditions. To further ascertain significance between treatments, parametric and no-parametric statistics consisting of sign test and t- test / ANOVA; sign factor were used.

RESULTS

The linear regression lines for various tempers with respect to F-tempers (control) were presented in Figures 1 to 7. Tables 1 to 6, 9 to 10 represent the multiple-comparism chart from post hoc test at various ageing temperatures and time in double thermal ageing

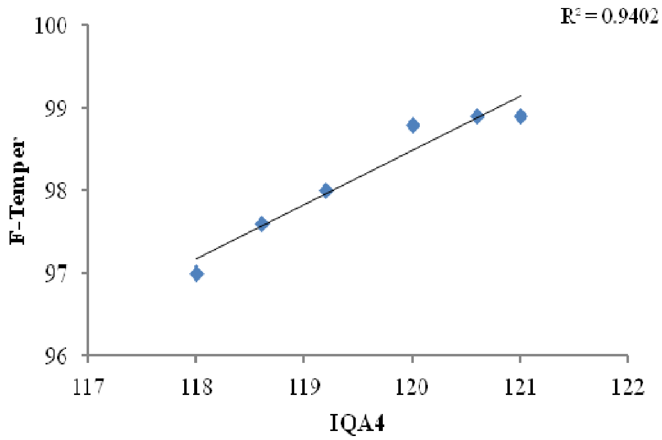

Figure 3. Variations in linear regression line with respect to F-temper and IQA4 temper for A356.0-type alloy.

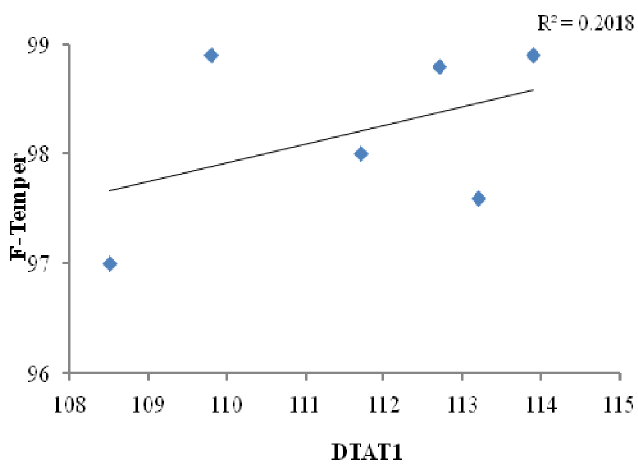

Figure 4. Variations in linear regression line with respect to F-temper and DTAT1 treatment for A356.0-type alloy.

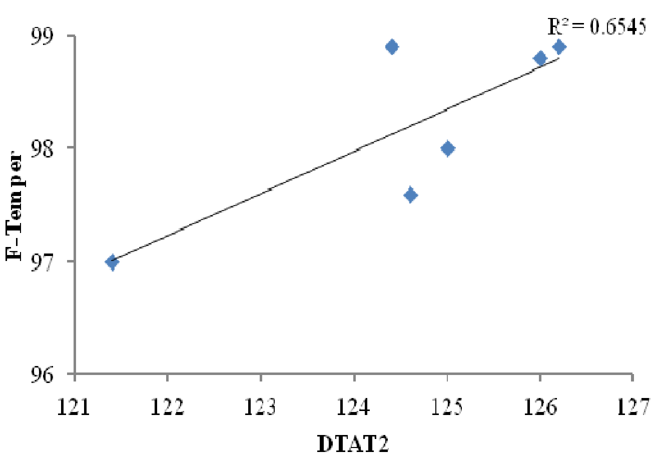

Figure 5. Variations in linear regression line with respect to F-temper and DTAT2 treatment for A356.0-type alloy.

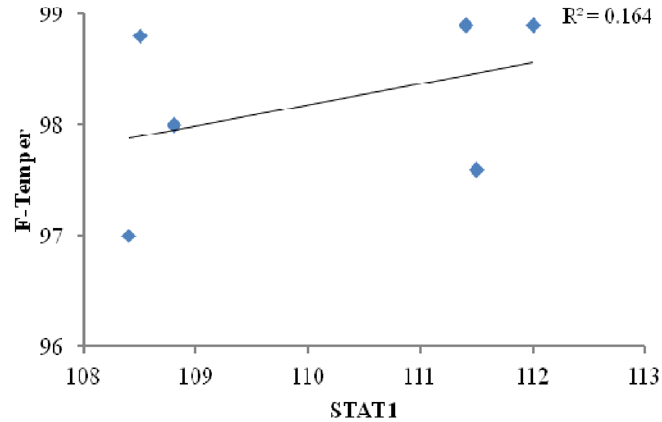

Figure 6. Variations in linear regression line with respect to F-temper and STAT1 treatment for A356.0-type alloy.

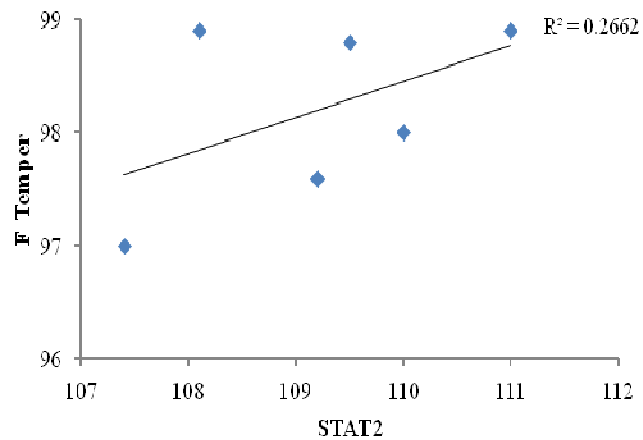

Figure 7. Variations in linear regression line with respect to F-temper and STAT2 treatment for A356.0-type alloy.

treatment (DTAT) and single thermal ageing treatment (STAT), DTAT- step-quenching –ageing and STAT-step-quenching –ageing treatments. While Tables 7 to 8 are the mean hardness derived from DTAT and STAT at different ageing temperatures and time. Table 11 represents DTAT- step-quenching –ageing and STAT-step-quenching –ageing treatments at 180°C for 2 and 4 h with their step-quenching time.

DISCUSSION

Interaction between the treatment and tempers using statistical tools

From the regression line analysis (Figures 1 to 7), the F-temper (control) is compared with the various temper conditions. Such that all the temper conditions indicate a

Table 1. Post Hoc Tests at 150°C for different ageing time in the DTAT treatment condition.

(I) MSTAT (h)	(J) MSTAT (h)	Mean difference (I-J)	Std. error	Sig.	95% confidence interval	95% confidence interval
					Lower bound	Upper bound
1	2	-4.0333*	0.75569	0.000	-5.5767	-2.4900
	3	-4.0500*	0.75569	0.000	-5.5933	-2.5067
	4	-19.0000*	0.75569	0.000	-20.5433	-17.4567
	5	-10.9667*	0.75569	0.000	-12.5100	-9.4233
	18	3.9167*	0.75569	0.000	2.3733	5.4600
2	1	4.0333*	0.75569	0.000	2.4900	5.5767
	3	-0.0167	0.75569	0.983	-1.5600	1.5267
	4	-14.9667*	0.75569	0.000	-16.5100	-13.4233
	5	-6.9333*	0.75569	0.000	-8.4767	-5.3900
	18	7.9500*	0.75569	0.000	6.4067	9.4933
3	1	4.0500*	0.75569	0.000	2.5067	5.5933
	2	0.0167	0.75569	0.983	-1.5267	1.5600
	4	-14.9500*	0.75569	0.000	-16.4933	-13.4067
	5	-6.9167*	0.75569	0.000	-8.4600	-5.3733
	18	7.9667*	0.75569	0.000	6.4233	9.5100
4	1	19.0000*	0.75569	0.000	17.4567	20.5433
	2	14.9667*	0.75569	0.000	13.4233	16.5100
	3	14.9500*	0.75569	0.000	13.4067	16.4933
	5	8.0333*	0.75569	0.000	6.4900	9.5767
	18	22.9167*	0.75569	0.000	21.3733	24.4600
5	1	10.9667*	0.75569	0.000	9.4233	12.5100
	2	6.9333*	0.75569	0.000	5.3900	8.4767
	3	6.9167*	0.75569	0.000	5.3733	8.4600
	4	-8.0333*	0.75569	0.000	-9.5767	-6.4900
	18	14.8833*	0.75569	0.000	13.3400	16.4267
18	1	-3.9167*	0.75569	0.000	-5.4600	-2.3733
	2	-7.9500*	0.75569	0.000	-9.4933	-6.4067
	3	-7.9667*	0.75569	0.000	-9.5100	-6.4233
	4	-22.9167*	0.75569	0.000	-24.4600	-21.3733
	5	-14.8833*	0.75569	0.000	-16.4267	-13.3400

*. The mean difference is significant at the .05 level.

significant improvement in the A356.0-type Al-Si-Mg alloy studied. Comparatively, the solution heat treatment (SHT) differs distinctively from the interrupted-quenching-ageing (IQA4) and DTAT2. Equally, IQA4 and DTAT2 with regression value; R^2 = 0.9402 and 0.6545 (Figures 3 and 5) have higher values of R, close to unity. The results of the post hoc test in a multiple-comparison chart (Tables 1 to 3) for DTAT treatment at 150°C ageing temperature (Table 1) indicates that the mean difference is significant within the ageing time with standard error bars ranging from ± 0.33 to ± 0.72 (Table 7). Coincidentally, at the highest standard error bars: 180°C at 20 h, the highest hardness value of the alloy was achieved. Though similar to this, hardness was obtained at 2 h ageing time. Particularly, from this comparism at 150°C DTAT, the post hoc test result indicates that ageing at 2 h compare to 3 h ageing time and vise versa are not significant to each other, since the 0.983 level outreached the significant level (0.05 levels). Notably, at these points, 95% confidence level: lower bound values are the smallest compared to others within the group of analysis. From the results (Tables 2 to 3) for 180 and

Table 2. Post Hoc Tests at 180℃ for different ageing time in the DTAT treatment condition (Multiple comparisons).

(I) MSTAT (h)	(J) MSTAT (h)	Mean difference (I-J)	Std. error	Sig.	95% confidence interval	95% confidence interval
					Lower bound	Upper bound
1	2	-13.9833*	0.82354	0.000	-15.6795	-12.2872
	3	5.6167*	0.82354	0.000	3.9205	7.3128
	4	10.3500*	0.82354	0.000	8.6539	12.0461
20		-15.8833*	0.82354	0.000	-17.5795	-14.1872
2	1	13.9833*	0.82354	0.000	12.2872	15.6795
	3	19.6000*	0.82354	0.000	17.9039	21.2961
	4	24.3333*	0.82354	0.000	22.6372	26.0295
20		-1.9000*	0.82354	0.030	-3.5961	-.2039
3	1	-5.6167*	0.82354	0.000	-7.3128	-3.9205
2		-19.6000*	0.82354	0.000	-21.2961	-17.9039
	4	4.7333*	0.82354	0.000	3.0372	6.4295
20		-21.5000*	0.82354	0.000	-23.1961	-19.8039
4	1	-10.3500*	0.82354	0.000	-12.0461	-8.6539
2		-24.3333*	0.82354	0.000	-26.0295	-22.6372
3		-4.7333*	0.82354	0.000	-6.4295	-3.0372
20		-26.2333*	0.82354	0.000	-27.9295	-24.5372
20	1	15.8833*	0.82354	0.000	14.1872	17.5795
2		1.9000*	0.82354	0.030	.2039	3.5961
3		21.5000*	0.82354	0.000	19.8039	23.1961
4		26.2333*	0.82354	0.000	24.5372	27.9295

*. The mean difference is significant at the .05 level.

210℃ ageing temperatures, all the ageing time considered remained significant to each other with values of significant level far less than 0.05. At this point (Table 7) it is worthy to note that ageing at 150℃ for 4 h (126.73 HVN ± 0.34); 180℃ for 20 h (134.92 HVN ± 0.72) and 210℃ for 4 h (125.03 HVN) remained the peak ageing conditions for this reprocessed alloy. The alloy is improved in hardness as a result of the isothermal treatment. This has been reported by Estey et al. (2004) and Sha et al. (2012). The multiple-comparism chart (Table 4) for the STAT treatment at 150℃, ageing at 18 h compare to other ageing time at the same temperature is all significant. In every dependency at 150℃ STAT, there is at least one combination of ageing time which is not significant, except at 18 h ageing which shows a dependent-associate with other ageing time within the group. The post hoc test indicates that ageing at this temperature for 1 and 4 h, 2 and 3 h, 4 and 5 h are not significant, since their respective significant level are greater than 0.05. While at 180 and 210℃ (Tables 5 to 6) all the ageing times are significant except for 3 and 20 h at 210℃ ageing temperature. The post hoc test indicates a multiple-comparism at STAT 180℃ (Table 5) shows that there exist a good relationship between all the ageing times considered in this study. While at 210℃, multiple-comparism between 3 and 20 h (Table 6) are not significant. Considering the 95% confidence interval; lower and upper bound, these ageing time inter-link with their bound been the smallest. Equally, their mean difference remained the lowest within the comparing group. This may probably account for insignificant occurrence associated at this treatment condition. From Table 8, ageing at 150℃ for 3 h (110.37 HVN); 180℃ for 2 h (127.23 HVN) and 210℃ for 3 h (121.70 HVN) remained the peak aged value obtainable from the hardness measurement under the STAT treatment condition.

Equally, Tables 9 to 10 indicate a novel treatment of step-quenching-ageing (SQA) at 2 and 4 h (180°) for various SQA time. For DTAT-SQA, step-quenching (SQ)

Table 3. Post Hoc Tests at 210°C for different ageing time in the DTAT treatment condition (Multiple comparisons).

(I) MSTAT (h)	(J) MSTAT (h)	Mean difference (I-J)	Std. error	Sig.	95% confidence interval	95% confidence interval
					Lower bound	Upper bound
1	2	6.2000*	0.7205	0.000	4.7161	7.6839
	3	7.9667*	0.7205	0.000	6.4828	9.4506
	4	-10.43338	0.7205	0.000	-11.9172	-8.9494
20		12.1167*	0.7205	0.000	10.6328	13.6006
2	1	-6.2000*	0.7205	0.000	-7.6839	-4.7161
	3	1.7667*	0.7205	0.022	.2828	3.2506
	4	-16.6333*	0.7205	0.000	-18.1172	-15.1494
20		5.9167*	0.7205	0.000	4.4328	7.4006
3	1	-7.9667*	0.7205	0.000	-9.4506	-6.4828
2		-1.7667*	0.7205	0.022	-3.2506	-.2828
	4	-18.4000*	0.7205	0.000	-19.8839	-16.9161
20		4.1500*	0.7205	0.000	2.6661	5.6339
4	1	10.6333*	0.7205	0.000	8.9494	11.9172
2		16.6333*	0.7205	0.000	15.1494	18.1172
3		18.4000*	0.7205	0.000	16.9161	19.8839
20		22.5500*	0.7205	0.000	21.0661	24.0339
20	1	-12.1167*	0.7205	0.000	-13.6006	-10.6328
2		-5.9167*	0.7205	0.000	-7.4006	-4.4328
3		-4.1500*	0.7205	0.000	-5.6339	-2.6661
4		-22.5500*	0.7205	0.000	-24.0339	-21.0661

*. The mean difference is significant at the .05 level.

at 10 and 30 s, there is no significant different at this time in all the ageing condition considered. At 20 s of SQ time in all, with respect to SQA 180°C/2 h, 4 h DTAT, there exist a significant correlation indicating peak aged hardness at SQ time of 20 s treatment condition.

Generally, the analyses of variance between the groups remain significant for all the studied conditions. Equally, at peak ageing conditions, the standard deviation and standard error bars have the highest value as compared to other treatment within the same group of analysis.

Parametric and non-parametric statistical evaluation of the treatments

The processed data of various treatments are represented in Tables 12 to 15. Using a sign test as a non-parametric statistic to evaluate the probability of outcome to relate the treatment condition at 150°C;

Sum (+) = 0, Sum (-) = 6

$X \approx b_i$ (x, n, p), where n is the number of trial, x is the outcome and p is the probability of outcome = (0, 6, 0.5) = 0.015625.

That is the relationship between treatments DTAT and STAT, p Value = binomial distribution which equals 0.015625. At 95%, the result is significant and we can state that there is a significant difference in the treatment considered at 150°C. The null hypothesis was; H_o: There is no different between the treatment means at 150°C ageing temperature or

H_o: $\mu_{DTAT} = \mu_{STAT}$ or H_o: $\mu_{DTAT} - \mu_{STAT}$

This gives the relationship between ageing time at 150°C for DTAT treatment condition

From Table 12b output, 25% of the variation in hardness is explained by ageing time. The lower output is as a result of wide range of 5 to 18 h interval of ageing time.

Table 4. Post Hoc Tests at 150°C for different ageing time in the STAT treatment condition (Multiple comparisons).

(I) MSTAT (h)	(J) MSTAT (h)	Mean difference (I-J)	Std. error	Sig.	95% confidence interval	95% confidence interval
					Lower bound	Upper bound
1	2	-5.1333*	0.68718	0.000	-6.5368	-3.7299
	3	-5.9833*	0.68718	0.000	-7.3868	-4.5799
	4	-0.0333	0.68718	0.962	-1.4366	1.3701
	5	0.6167	0.68718	0.377	-0.7868	2.0201
	18	2.2667*	0.68718	0.003	0.8632	3.6701
2	1	5.1333*	0.68718	0.000	3.7299	6.5368
	3	-0.8500	0.68718	0.226	-2.2534	0.5534
	4	5.1000*	0.68718	0.000	3.6966	6.5034
	5	5.7500*	0.68718	0.000	4.3466	7.1534
	18	7.4000*	0.68718	0.000	5.9966	8.8034
3	1	5.9833*	0.68718	0.000	4.5799	7.3868
	2	0.8500*	0.68718	0.226	-0.5534	2.2534
	4	5.9500*	0.68718	0.000	4.5466	7.3534
	5	6.6000*	0.68718	0.000	5.1966	8.0034
	18	8.2500*	0.68718	0.000	6.8466	9.6534
4	1	0.0333	0.68718	0.962	-1.3701	1.4368
	2	-5.1000*	0.68718	0.000	-6.5034	-3.6966
	3	-5.9500*	0.68718	0.000	-7.3534	-4.5466
	5	.6500	0.68718	0.352	-0.7534	2.0534
	18	2.3000*	0.68718	0.002	.8966	3.7034
5	1	-0.6167	0.68718	0.377	-2.0201	0.7868
	2	-5.7500*	0.68718	0.000	-7.1534	-4.3466
	3	-6.6000*	0.68718	0.000	-8.0034	-5.1966
	4	-0.6500	0.68718	0.352	-2.0534	0.7534
	18	1.6500*	0.68718	0.023	0.2466	3.0534
18	1	-2.2667*	0.68718	0.003	-3.6701	-0.8632
	2	-7.4000*	0.68718	0.000	-8.8034	-5.9966
	3	-8.2500*	0.68718	0.000	-9.6534	-6.8466
	4	-2.3000*	0.68718	0.002	-3.7034	-0.8966
	5	-1.6500*	0. 68718	0.023	-3.0534	-0.2466

*. The mean difference is significant at the .05 level.

From Table 12c output, 26% (obtained from the adjusted R Square) of the variation in hardness is explained by ageing time. The lower output is as a result of wide range of 5 to 18 h interval of ageing time. It can be seen that sign test under non-parametric and t- test in parametric statistic, the results of the test agree with each other. That is if /t/ ≥ 2, reject the null hypothesis, else accept.

Using a sign test as a non-parametric statistic to evaluate the probability of outcome to relate the treatment condition at 180°C; Sum (+) = 2, Sum (-) = 3 $X \approx b_i$ (x, n, p), where n is the number of trial, x is the outcome and p is the probability of outcome n = 5, x = 2 P Value: binomial distribution (x, n, 1) = 0.5

From Table 13b output, 21% (obtained from the adjusted R square) of the variation in hardness is explained by ageing time. The lower output is as a result of wide range of 4 to 20 h interval of ageing time.

From Table 13c output, 47% (obtained from the adjusted R square) of the variation in hardness is explained by ageing time. The higher output is as a result of the close range of the ageing time.

Table 5. Post Hoc Tests at 180°C for different ageing time in the STAT treatment condition (Multiple comparisons).

(I) MSTAT (h)	(J) MSTAT (h)	Mean difference (I-J)	Std. error	Sig.	95% confidence interval	95% confidence interval
					Lower bound	Upper bound
	2	-8.2833*		0.000	-9.7005	-6.8662
1	3	4.7500*		0.000	3.3329	6.1671
	4	6.5167*		0.000	5.0995	7.9338
20		17.0333*		0.000	15.6162	18.4505
	1	8.2833*		0.000	6.8662	9.7005
2	3	13.0333*		0.000	11.6162	14.4505
	4	14.8000*		0.000	13.3829	16.2171
20		25.3167*		0.000	23.8995	26.7338
3	1	-4.7500*		0.000	-6.1671	-3.3329
2		-13.0333*		0.000	-14.4505	-11.6162
	4	1.7667*		0.017	.3495	3.1838
20		12.2833*		0.000	10.8662	13.7005
4	1	-6.5167*		0.000	-7.9338	-5.0995
2		-14.8000*		0.000	-16.2171	-13.3829
3		-1.7667*		0.017	-3.1838	-.3495
20		10.5167*		0.000	9.0995	11.9338
20	1	-17.0333*		0.000	-18.4505	-15.6162
2		-25.3167*		0.000	-26.7338	-23.8995
3		-12.2833*		0.000	-13.7005	-10.8662
4		-10.5167*		0.000	-11.9338	-9.0995

*. The mean difference is significant at the .05 level.

Table 6. Post Hoc Tests at 210°C for different ageing time in the STAT treatment condition.

(I) MSTAT (h)	(J) MSTAT (h)	Mean difference (I-J)	Std. error	Sig.	95% confidence interval	95% confidence interval
					Lower bound	Upper bound
	2	12.6167*	0.77993	0.000	11.0104	14.2230
1	3	-7.1000*	0.77993	0.000	-8.7063	-5.4937
	4	10.2000*	0.77993	0.000	8.5937	11.8063
20		-7.9333*	0.77993	0.000	-9.5396	-6.3270
2	1	-12.6167*	0.77993	0.000	-14.2230	-11.0104
	3	-19.7167*	0.77993	0.000	-21.3230	-18.1104
	4	-2.4167*	0.77993	0.005	-4.0230	-.8104
20		-20.5500*	0.77993	0.000	-22.1563	-18.9437
3	1	7.1000*	0.77993	0.000	5.4937	8.7063
2		19.7167*	0.77993	0.022	18.1104	21.3230
	4	17.3000*	0.77993	0.000	15.6937	18.9063

Table 6. Contd.

20		-0.8333	0.77993	0.296	-2.4396	0.7730
4	1	-10.2000*	0.77993	0.000	-11.8063	-8.5937
2		2.4167*	0.77993	0.005	.8104	4.0230
3		-17.3000*	0.77993	0.000	-18.9063	-15.6937
20		-18.1333*	0.77993	0.000	-19.7396	-16.5270
20	1	7.9333*	0.77993	0.000	6.3270	9.5396
2		20.5500*	0.77993	0.000	18.9437	22.1563
3		.8333	0.77993	0.296	-0.7730	2.4396
4		18.1333*	0.77993	0.000	16.5270	19.7396

*. The mean difference is significant at the .05 level

Table 7. Mean hardness from six averages of DTAT treatment at different ageing temperatures and time.

Ageing temperature (°C)	Ageing time (h)	Mean hardness (HVN) with STD error	Data range
150	1	107.73 ± (0.58)	106.00-109.10
	2	111.77 ± (0.66)	110.10-114.00
	3	111.78 ± (0.64)	110.20-113.80
	4	126.73 ± (0.34)	125.80-128.00
	5	118.70 ± (0.33)	117.90-120.00
	18	103.82 ± (0.54)	102.60-106.00
180	1	119.03 ± (0.37)	118.00-120.00
	2	133.02 ± (0.67)	130.00-134.70
	3	113.42 ± (0.47)	112.00-114.60
	4	108.68 ± (0.59)	107.10-110.60
	20	134.92 ± (0.72)	133.00-136.80
210	1	114.60 ± (0.51)	113.20-116.00
	2	108.40 ± (0.46)	107.00-110.00
	3	106.63 ± (0.51)	105.40-108.40
	4	125.03 ± (0.56)	123.70-127.00
	20	102.48 ± (0.50)	100.60-104.20

Table 8. Mean hardness from six averages of STAT treatment at different ageing temperatures and time.

Ageing temperature (°C)	Ageing time (h)	Mean hardness (HVN) with STD error	Data range
150	1	104.38 ± (0.33)	103.40-105.20
	2	109.52 ± (0.60)	108.00-111.60
	3	110.37 ± (0.65)	108.00-112.00
	4	104.42 ± (0.37)	103.30-105.60
	5	103.77 ± (0.47)	102.60-105.20
	18	102.12 ± (0.40)	100.90-103.00
180	1	118.95 ± (0.50)	117.00-120.20
	2	127.23 ± (0.45)	126.00-129.00
	3	114.20 ± (0.37)	112.80-115.10
	4	112.43 ± (0.53)	111.20-114.10
	20	101.92 ± (0.56)	100.00-103.80

Table 8. Contd.

210	1	114.60 ± (0.48)	113.20-116.10
	2	101.98 ± (0.53)	100.30-103.60
	3	121.70 ± (0.64)	119.90-123.50
	4	104.40 ± (0.54)	103.00-106.00
	20	122.53 ± (0.56)	121.00-124.00

Table 9. Post Hoc Tests at 180°C /2 and 4 h for different step-quenching time in the DTAT-SQA treatment condition (Multiple comparisons).

Dependent variable	(I) SQ time (S)	(J) SQ time (S)	Mean difference (I-J)	Std. error	Sig.	95% confidence interval	95% confidence interval
						Lower bound	Upper bound
SQA 180°C/2h DTAT	10	20	-25.3667*	0.75692	0.000	-26.9800	-23.7533
		30	-1.3833	0.75692	0.088	-2.9967	0.2300
	20	10	25.3667*	0.75692	0.000	23.7533	26.9800
		30	23.9833*	0.75692	0.000	22.3700	25.5967
	30	10	1.3833	0.75692	0.088	-0.2300	2.9967
		20	-23.9833*	0.75692	0.000	-25.5967	-22.3700
SQA 180°C/4h DTAT	10	20	-15.4000*	0.70836	0.000	-16.9098	-13.8902
		30	1.1333	0.70836	0.130	-0.3765	2.6432
	20	10	15.4000*	0.70836	0.000	13.8902	16.9098
		30	16.5333*	0.70836	0.000	15.0235	18.0432
	30	10	-1.1333	0.70836	0.130	-2.6432	0.3765
		20	-16.5333*	0.70836	0.000	-18.0432	-15.0235

*. The mean difference is significant at the .05 level.

Table 10. Post Hoc Tests at 180°C/2 and 4 h for different step-quenching time in the STAT-SQA treatment condition (Multiple comparisons).

Dependent variable	(I) SQ Time (S)	(J) SQ time (S)	Mean difference (I-J)	Std. error	Sig.	95% confidence interval	95% confidence interval
						Lower bound	Upper bound
SQA 180°C/2h STAT	10	20	-4.0333*	0.57054	0.000	-5.2494	-2.8173
		30	4.4167*	0.57054	0.000	3.2006	5.6327
	20	10	4.0333*	0.57054	0.000	2.8173	5.2494
		30	8.4500*	0.57054	0.000	7.2339	9.6661
	30	10	-4.4167*	0.57054	0.000	-5.6327	-3.2006
		20	-8.4500*	0.57054	0.000	-9.6661	-7.2339
SQA 180°C/4h STAT	10	20	-11.1333*	0.73457	0.000	-12.6990	-9.5676
		30	-6.1167*	0.73457	0.000	-7.6824	-4.5510
	20	10	11.1333*	0.73457	0.000	9.5676	12.6990
		30	5.0167*	0.73457	0.000	3.4510	6.5824
	30	10	6.1167*	0.73457	0.000	4.5510	7.6824
		20	-5.0167*	0.73457	0.000	-6.5824	-3.4510

*. The mean difference is significant at the 0.05 level.

Table 11. Mean hardness from six averages of DTAT and STAT treatments at different ageing temperatures and time.

Treatment and ageing temperature/time (°C/h)	Step-quenching-ageing time (s)	Mean hardness (HVN) with STD error	Data range
DTAT 180/ 2	10	100.53 ± (0.25)	99.90 - 101.00
	20	125.90 ± (0.72)	125.30 - 126.80
	30	101.92 ± (0.53)	100.00 - 103.80
DTAT 180/ 4	10	102.27 ± (0.55)	101.6 - 103.40
	20	117.67 ± (0.38)	116.30 - 118.40
	30	101.13 ± (0.55)	100.40 - 102.20
STAT 180/ 2	10	105.17 ± (0.43)	103.80 - 106.30
	20	109.20 ± (0.41)	107.90 - 110.50
	30	100.75 ± (0.36)	99.80 - 102.00
STAT 180/ 4	10	101.10 ± (0.54)	99.90 - 103.00
	20	112.23 ± (0.45)	111.00 - 114.00
	30	107.22 ± (0.56)	106.00 - 109.20

Table 12a. Non-parametric statistic for treatment at 150°C.

Ageing time	DTAT HVN	STAT HVN	Difference (+ number)	(- number)
1	107.73	104.38	-3.35	1
2	111.77	109.52	-2.25	1
3	111.78	110.37	-1.41	1
4	126.73	104.42	-22.31	1
5	118.70	103.77	-14.93	1
18	103.82	102.12	-1.7	1

At 95%, the result is not significant and we can state that there is no significant difference with the treatments at 180°C and that the parametric and non parametric statistics are in agreement.

At 95%, the result is not significant and we can state that there is no significant difference with the treatments at 210°C and that the parametric and non parametric statistics are in agreement.

Using a sign test as a non-parametric statistic to evaluate the probability of outcome to relate the treatment condition at 210°C;

Sum (+) = 2, Sum (-) = 2,

$x = 2$, $n = 4$ and p-Value = 0.6875

From Table 14b output, 52% (obtained from the Adjusted R Square) of the variation in hardness is explained by ageing time. The higher output is as a result of the close range of the ageing time.

Considering the averages obtained in treatment condition at SQA-DTAT and SQA-STAT180°C/2 h, 4 h. It can be seen that the result is not statistically significant as the computed $f = 0.11 < f$ critical $= 4.066$, we therefore fail to reject the null and state that, at 95% there is no difference between the groups or equivalently the observations come from the same populations.

Conclusions

i. From the statistical evaluation of this group of alloy under the studied isothermal conditions, the alloy showed response to these treatments and most of the treatment and tempers indicated a significant impact on the alloy.
ii. The results obtained from these statistical evaluations indicate positive correlations between all the groups of treatments considered in this work.
iii. It can be seen that sign test under non-parametric and t- test in parametric statistic, the results of the test agree with each other.
iv. Higher percentages of the variation in hardness is explained by ageing time in some of the treatment

Table 12b. Regression statistics 150℃ for DTAT treatment.

Regression statistics	
Multiple R	0.67076
R Square	0.449919
Adjusted R Square	0.249919
Standard error	92.35073
Observations	6

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	34878.55	34878.55	4.089570864	0.113205
Residual	5	42643.28	8528.657		
Total	6	77521.83			

	Coefficient	Standard error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
AGT	9.593113	4.743738	2.022269	0.099083152	-2.60105	21.78728	-2.60105	21.78728

Table 12c. Regression statistics and relationship between ageing time at 150℃ for stat treatment condition.

Regression statistics	
Multiple R	0.679646229
R Square	0.461918996
Adjusted R Square	0.261918996
Standard error	85.02206713
Observations	6

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	31027.84	31027.84	4.292281	0.107014
Residual	5	36143.76	7228.752		
Total	6	67171.6			

	Coefficient	Standard error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
AGT	9.048073879	4.36729	2.071782	0.093029	-2.1784	20.27455	-2.1784	20.27455

Table 12d. Parametric statistic for treatment at 150℃ (Using the parametric statistic, t-Test: Paired two sample for means at 150℃).

Parameter	DTAT	STAT
Mean	113.4216667	105.7633
Variance	66.99653667	11.25987
Observations	6	6
Pearson correlation	0.005018356	
Hypothesized mean difference	0	
df	5	
t Stat	2.124301833	
P(T<=t) one-tail	0.043514975	
t Critical one-tail	2.015048372	
P(T<=t) two-tail	0.087029949	
t Critical two-tail	2.570581835	

Table 13a. Non-parametric statistic for treatment at 180°C.

Ageing time	DTAT HVN	STAT HVN	Difference (+ number)	+ number	- number
1	119.03	118.95	-0.08		1
2	133.02	127.23	-5.79		1
3	113.42	114.20	0.78	1	
4	108.68	112.43	3.75	1	
20	134.92	101.92	-33		1

Table 13b. Regression Statistics 180°C for DTAT treatment.

Regression statistics	
Multiple R	0.68060997
R Square	0.463229931
Adjusted R square	0.213229931
Standard error	100.1485101
Observations	5

ANOVA

	df	SS	MS	F	Significance F
Regression	1	34622.41024	34622.41	3.451980335	0.160155
Residual	4	40118.89626	10029.72		
Total	5	74741.3065			

	Coefficient	Standard error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
AGT	8.973139535	4.829590012	1.857951	0.1367245	-4.43595	22.38223	-4.43595	22.38223

Table 13d. Parametric statistic for treatment at 180°C (Using the parametric statistic, t-Test: Paired two sample for means at 180°C).

	DTAT	STAT
Mean	121.814	114.946
Variance	137.01338	85.87303
Observations	5	5
Pearson correlation	-0.011303396	
Hypothesized mean difference	0	
df	4	
t Stat	1.023051559	
P(T<=t) one-tail	0.182059031	
t Critical one-tail	2.131846782	
P(T<=t) two-tail	0.364118062	
t Critical two-tail	2.776445105	

Table 14a. Non-parametric statistic for treatment at 210°C.

Ageing time	DTAT	STAT	Difference	+ number	- number
1	114.60	114.60	0		
2	108.40	101.98	-6.42		1
3	106.63	121.70	15.1	1	
4	125.03	104.40	-20.63		1
20	102.48	122.53	20.05	1	

Table 14b. Regression statistics 210°C for DTAT treatment. Relationship between ageing time at 210°C for STAT treatment condition

Summary output								
Regression statistics								
Multiple R						0.922861		
R Square						0.851673		
Adjusted R square						0.518339		
Standard error						50.64645		
Observations						4		
ANOVA								
	df	**SS**	**MS**	**F**	**Significance F**			
Regression	1	44184.59	44184.59	17.22554	0.053442			
Residual	3	7695.189	2565.063					
Total	4	51879.78						
	Coefficient	**Standard error**	**t Stat**	**P-value**	**Lower 95%**	**Upper 95%**	**Lower 95.0%**	**Upper 95.0%**
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
AGT	38.37733	9.246735	4.150366	0.025419	8.950096	67.80457	8.950096174	67.80457

Table 14c. Parametric statistic, t-Test: Paired two sample for means at 210°C.

	DTAT	STAT
Mean	111.422	113.042
Variance	76.90522	91.11562
Observations	5	5
Pearson correlation	-0.614656698	

Table 14c. Contd.

Hypothesized mean difference	0
df	4
t Stat	-0.220077029
P(T<=t) one-tail	0.418293411
t Critical one-tail	2.131846782
P(T<=t) two-tail	0.836586823
t Critical two-tail	2.776445105

Table 15. Using the ANOVA: sign factor for SQA-DTAT and SQA-STAT180°C/2 h, 4h.

Summary						
Groups	**Count**	**Sum**	**Average**	**Variance**		
DTAT-180/2 h	3	328.35	109.45	203.4349		
STAT-180/2 h	3	315.12	105.04	17.8633		
DTAT-180/4 h	3	321.07	107.0233333	85.33853333		
STAT-180/4 h	3	320.55	106.85	31.0719		
ANOVA						
Source of variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit.**
Between group	29.502425	3	9.834141667	0.116480785	0.947919	4.066181
Within group	675.4172667	8	84.42715833			
Total	704.9196917	11				

especially when there is no wide range of ageing time.

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REFERENCES

Ali M, Mohsen OS (2012). Mechanical Properties of Squeeze-Cast A356 Composites Reinforced With B4C Particulates. J. Mater. Eng. Perform. 21(2):247-252.

Cavazos JL, Colas R (2001). Precipitation in a heat-treated aluminium alloy cooled at different rates. Mater. Charact. 47:175-179.

Devore JL (1999). Probability and Statistics for Engineering and the Sciences, 5th ed., Duxbury Publishing Co., Pacific Grove, CA, pp. 379-388.

Estey CM, Cockcroft SL, Maijer DM, Hermesmann C (2004). Constitutive behaviour of A356 during the quenching operation. Mater. Sci. Eng. A 383:245-251.

Khomamizah F, Ghasemi A (2004). Evaluation of quality index of A-356 aluminium alloy by microstructural analysis. Scientia Iranica 11(4):336-391.

Leo P, Cerri E (2003). Silicon Particle Damage in a thioxocast A356 Alminium Alloy. Metallurgical Sci. Technol. Teksid Aluminiums J. 21(1):27-31.

Popescu IN, Bratu V, Enescu MC (2010). Experimental researches and statistical analysis of the corrosion behavior of rolled and heat treated 2xxx Al alloys. Proceedings of the 9th WSEAS International Conference on applications of electrical engineering, pp. 225-232.

Sajjadi SA, Torabi PM, Ezatpoura HR, Sedghic A (2012). Fabrication of A356 composite reinforced with micro and nano Al_2O_3 particles by a developed compocasting method and study of its properties. J. Alloys Compds. 511:226-231.

Seyedrezai H, Grebennikov D, Mascher P, Zurob HS (2009). Study of the early stages of clustering in Al-Mg-Si alloys using the electrical resistivity measurements. Mater. Sci. Eng. A 525:18-91.

Sha G, Moller H, Stumpf WE, Xia JH, Govender G, Ringer SP (2012). Solute nanostructures and their strengthening effects in Al–7Si–0.6Mg alloy F357. Acta Mater. 60:692-701.

Thompson S, Cockcroft SL, Wells MA (2004). Advanced light metals casting development: solidification of aluminium alloy A356. J. Mater. Sci. Technol. 20:194-200.