Influence of Re-melting Aluminum Proportion Effect on Inclusions Defectives

Pahon Voradilokkul, and Somchai Puajindanetr

***Abstract*—This research is study on influence of re-melting aluminum material proportion including Re-melting aluminum scrap from external machining process (R_1) and Re-melting aluminum scrap from internal casting process (R_2) that effect on quality of molten aluminum and casting sample by study on mixture proportion of R_1 at 0, 100, 200 per hundred aluminum ingot (PHI) and R_2 at 100, 150 and 200 PHI. Experimental response determined in 2 types, Molten aluminum evaluation including K-mold value, Mg composition and H_2 gas. Gate inclusions defectives including Gate inclusions defect ratio, Amount of gate inclusions, Gate blowhole defect ratio and Amount of gate blowhole. Result of the study found that raise of re-melting material proportion would influent K-mold, H_2, Gate inclusions defectives, Gate blowhole defectives to be increased. Re-melting scrap from external process are more significant effected to defect occurrence than internal process scrap. K-mold value has significant relative to Gate inclusions defective and material proportion at R_1 = 0 PHI and R_2 = 100 PHI is the lowest defect result which has Gate inclusions defect ratio 0.59%, Amount of gate inclusions 96 points. Gate blowhole defect ratio is 0.07% and Amount of gate blowhole is 11 points.**

***Keywords*—Re-melting aluminum material, Aluminum inclusions, Aluminum high pressure die casting**

I. Introduction

Currently Automotive industries are widely produce automotive parts by aluminum high pressure die casting process. According to stability of process and could be support for new product’s production expansion. More over weight of aluminum is more lighter than steel, no rust and aluminum scrap are able to re-melt to be raw material for cost reduction [1] Therefore, quality of product must be concerned. This research is study an influence of aluminum material mixing proportion that would effect to aluminum inclusions defects. Base on study site data, Gate inclusions defect ratio is 2.2% and Gate blowhole defect ratio is 0.5% which are average from July to December. These 2 modes of defect are the first and second highest defect occurred in study site process and need to be study for quality improvement. After inclusion on gate of defect samples were analyzed by use Energy Dispersive X-ray spectrometer (EDX) then found that inclusions are composed of Mg, O, Al elements which are similar to Al dross in melting furnace.

By referring from prior studies theirs composite are $MgAl_2O_4$ or Spinel which happened from integration of Mg and Aluminum oxide and mostly found in dross of Al [2]. Dross formation was accelerate by oxidation of Mg content [3]. Therefore re-melting scrap those was processed would have bring contaminated component to the melting furnace and melting of re-melting aluminum with high temperature will caused to oxidation of the refractory material [4] in furnace wall surface and could contaminate in molten metal inside holding furnace[5]. In study site company raw material to be used are consist of new aluminum ingot and re-melting aluminum scrap from external machining process returning from customer as defect and another is in-house defect from high pressure die casting process. Evaluation of molten Al quality will made by the K-mold method [6] which known as inclusions inspection method. Mg composition is monitored to study changes when re-melting scrap proportions are increase. H_2 gas contaminated in aluminum, causing blowhole porosity [7] on sample. In this study would also find the relationship of molten Al quality and inclusions defectives, in case to prevention over production of inclusions defect by determine from molten Al quality

II. Materials and Methods

A. Sample Preparation

Aluminum material will be input by various designed proportions as shown in Table I which are combination of 3 sources. Aluminum ingot (I) is a new raw material from supplier. Re-melting aluminum scrap from external machining process (R_1) was a product sent to machined by customer process and was found as a customer defect, then returned scrap to study site company for cleaning and to be re-melting as a raw material. Re-melting aluminum scrap from internal casting process (R_2) which was a casting product and was found as in-process defect then to be re-melting as a raw material. In this research proportion of Aluminum ingot (I) would fix at 100, Thus R_1 and R_2 proportion are designed in unit called Per hundred ingot (PHI)

TABLE I: Input Proportion

	Level of experiment proportion								
No.	1	2	3	4	5	6	7	8	9
I	100	100	100	100	100	100	100	100	100
R1	0	0	0	100	100	100	200	200	200
R2	100	150	200	100	150	200	100	150	200

Master Student, Department of Industrial Engineering, Faculty of Engineering, Chulalongkorn University (Pahon.v@hotmail.com)

https://doi.org/10.17758/EAP.AE0517128

Each aluminum material mixture proportion is fill into melting furnace and holding the molten aluminum at temperature of 680°c. Molten aluminum sample will be taken from holding furnace. After be melted each aluminum material mixture proportion will cast to be sample part by high pressure die casting. Gate defectives sample will be taken after casting process with runner gate and overflow trimmed. Repeat each material batch 3 times. Steps of the experiment shown in Fig.1

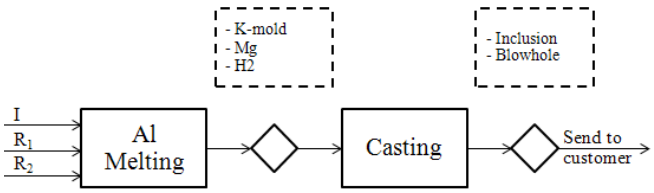

Fig. 1. Steps of experiment

B. Molten Aluminum Evaluation

Molten aluminum are evaluate by specify method with sample taken at fixed period for each experiment

K-mold value response made by casting sample in the sample mold and check at breakage section. If contaminated inclusions is found then each position will count as 0.1 point.

Mg composition response evaluated by analyze with spectrometer. Data would record as Mg percentage from all composition elements of molten metal.

H_2 gas response sample made by Aluvac that is an equipment for made vacuum to sample's environment then contaminated H_2 gas volume inside molten metal will be visualized and can be judge by inspector's visually with reference on study site judgment standard.

C. Gate Defect Evaluation

Gate inclusions defect ratio and Gate blowhole defect ratio are evaluate by operator's visual check after gate runner was trimmed out. Defectives judgment is refer on study site's sample appearance judgment standard that there will be no contaminated inclusions and deep hole that caused from contaminated inclusions and blowhole on sample's gate

Amount of inclusions and blowhole will be count each point on gate and record in case of inclusions and blowhole defect is found.

TABLE II: RESULT OF EXPERIMENT

Input material proportion		Molten aluminum evaluation			Gate defect evaluation			
R_1 (PHI)	R_2 (PHI)	K-mold (Point)	Mg (%)	H_2 (g/Al 100g)	Gate Inclusions defect ratio (%)	Amount of gate Inclusions (Point)	Gate blowhole defect ratio (%)	Amount of gate blowhole defect (Point)
0	100	0.45	0.163	0.10	0.53	29	0.06	3
		0.44	0.156	0.12	0.63	35	0.12	6
		0.46	0.161	0.12	0.61	32	0.04	2
	150	0.47	0.177	0.16	0.77	42	0.02	1
		0.46	0.167	0.14	0.75	43	0.02	1
		0.49	0.175	0.16	0.69	39	0.10	6
	200	0.50	0.165	0.14	0.84	44	0.04	2
		0.49	0.156	0.16	0.95	50	0.06	4
		0.48	0.158	0.13	0.88	47	0.02	1
100	100	0.53	0.198	0.26	0.96	53	0.15	9
		0.52	0.174	0.23	0.94	53	0.10	6
		0.54	0.181	0.24	0.87	47	0.19	10
	150	0.54	0.175	0.26	1.19	65	0.13	8
		0.53	0.159	0.24	1.09	58	0.04	2
		0.55	0.165	0.28	1.07	59	0.10	7
	200	0.57	0.181	0.24	1.31	75	0.08	4
		0.54	0.162	0.26	1.25	70	0.10	6
		0.56	0.155	0.28	1.21	64	0.08	5
200	100	0.59	0.158	0.34	1.35	70	0.25	17
		0.57	0.156	0.30	1.37	73	0.31	19
		0.59	0.172	0.32	1.46	80	0.33	19
	150	0.63	0.172	0.32	1.54	80	0.19	13
		0.58	0.159	0.30	1.50	78	0.17	11
		0.56	0.169	0.30	1.61	81	0.23	13
	200	0.64	0.184	0.28	1.98	92	0.17	9
		0.60	0.166	0.26	1.75	89	0.17	12
		0.60	0.161	0.32	1.71	90	0.19	11

https://doi.org/10.17758/EAP.AE0517128

D. Statistical Analysis

Result of the experiment will be analysis by MINITAB statistical program for Linear regression analysis to find relation between predictor sources and response variable result. Predictor sources are related to change in the response variable when P-value < 0.05.

III. RESULT AND DISCUSSION

Result of molten aluminum evaluation shown K-mold value are increasingly while proportion of R1 and R2 has been added up that would meant to be the formation of dross inclusions. Mg composition is not obviously seen in trend after re-melting proportion increased. H_2 gas volume result is gradually raised up along the proportion of re-melting material that has been added, especially with R_1 that would have composition affected by cleaning process by hot water after returning from customer site. On defectives result Gate inclusion defect ratio is obviously increased along with re-melting aluminum material from both R_1 and R_2 incremental. Also the Amount of gate inclusions that increased together with its defect ratio. In Gate blowhole defect ratio are resulted in trend to increasing while R_1 proportion has been input but they have some variation between each replication, also the similar way of Amount of gate blowhole result.

A. Relationship Analysis of Re-melting Aluminum Mixture Proportion and Variable Response

Experiment result of each aluminum material mixture proportion was analyzed by Linear Regression model method and the analysis result are shown that change of Re-melting aluminum material scrap from external process (R_1) are significantly related to change of K-mold, H_2, Gate inclusions and blowhole defect ratio, Amount of gate inclusions and gate blowhole. Re-melting aluminum material from in-process scrap (R_2) are significantly related (P<0.05) to change of K-mold, H_2, Gate inclusions and Amount of gate inclusions. Results are shown in Table III and simulated regression equation has been analyze from Regression model analysis.

TABLE III: P-VALUE AND R-SQUARE OF REGRESSION

	Molten aluminum evaluation			Gate defect evaluation			
Source	K-mold	Mg	H_2	Gate inclusions defect ratio	Amount of gate Inclusions	Gate blowhole defect ratio	Amount of gate blowhole
Constant	0.000	0.000	0.002	0.003	0.000	0.000	0.161
R_1	0.000	0.585	0.000	0.000	0.000	0.000	0.000
R_2	0.006	0.350	0.109	0.000	0.000	0.317	0.565
R_1 x R_2	0.608	0.500	0.302	0.165	0.796	0.069	0.019
R-Sq	92.10%	4.50%	91.30%	96.90%	97.30%	83.10%	85.80%
R-Sq (adj.)	91.10%	0.00%	90.20%	96.50%	96.90%	80.80%	83.60%

From relation analysis, Simulated regression equation can be written as follows :

$$\textit{K-mold} = 0.418 + 0.000697\,R_1 + 0.000372\,R_2 - 0.000001\,R_1{*}\,R_2 \quad (1)$$

$$Mg = 0.178 - 0.000054\,R_1 - 0.000078\,R_2 + 0.000000\,R_1{*}\,R_2 \quad (2)$$

$$H_2 = 0.100 + 0.00112\,R_1 + 0.000306\,R_2 - 0.000002\,R_1{*}\,R_2 \quad (3)$$

$$\textit{Gate inclusions defect ratio} = 0.281 + 0.00333\,R_1 + 0.00291\,R_2 + 0.000006\,R_1{*}\,R_2 \quad (4)$$

$$\textit{Amount of gate inclusions} = 15.9 + 0.199\,R_1 + 0.161\,R_2 + 0.000050\,R_1{*}\,R_2 \quad (5)$$

$$\textit{Gate blow hole defect ratio} = 0.0842 + 0.00149\,R_1 - 0.000288\,R_2 - 0.000004\,R_1{*}\,R_2 \quad (6)$$

$$\textit{Amount of gate blowhole} = 3.64 + 0.102\,R_1 - 0.0094\,R_2 - 0.000317\,R_1{*}\,R_2 \quad (7)$$

B. Relationship Analysis of Molten Aluminum Evaluation result and Defectives Response

Result of the experiment was taken to analyzed by Linear Regression model method for find relationship between molten Al response and defectives response for defect occurrence prediction in case to prevent of inclusions defect producing in production. The analysis result are shown that K-mold is the only source that has significantly related (P<0.05) to change of Gate inclusions and Amount of gate inclusions. H_2 is the only source significantly related to change of Amount of gate blowhole. Results are shown in Table IV and simulated regression equation has been analyze from Regression model analysis.

TABLE IV : P-VALUE AND R-SQUARE OF REGRESSION

	Gate defect evaluation			
Result source	Gate inclusions defect ratio	Amount of gate Inclusions	Gate blowhole defect ratio	Amount of gate blowhole
Constants	0.007	0.027	0.773	0.901
K-mold	0.000	0.000	0.921	0.751
Mg	0.179	0.231	0.883	0.787
H_2	0.979	0.341	0.039	0.013
R-Sq	88.2%	89.10%	56.70%	63.00%
R-Sq (adj.)	86.7%	87.80%	51.10%	58.20%

https://doi.org/10.17758/EAP.AE0517128

From relation analysis, Simulated regression equation can be written as follows :

$$\textit{Gate inclusions defect ratio} = -1.79 + 6.66\,\textit{K-mold} - 3.76\,Mg - 0.025\,H_2 \quad (8)$$

$$\textit{Amount of gate inclusions} = 66.1 + 267\,\textit{K-mold} - 156\,Mg - 41.9\,H_2 \quad (9)$$

$$\textit{Gate blow hole defect ratio} = -0.075 - 0.057\,\textit{K-mold} + 0.17\,Mg + 0.868\,H_2 \quad (10)$$

$$\textit{Amount of gate blowhole} = 1.8 - 10.4\,\textit{K-mold} - 18.2\,Mg + 61.2\,H_2 \quad (11)$$

C. Predictor's Result Confirmation

Find relative error between calculated results from regression equation with experimental results to confirm accuracy of prediction model. By choose material mixture proportion no.4, which has the value R_1 = 100 PHI and R_2 = 100 PHI. Take into equation (1) – (7) as the Table V. Found relative error of K-mold, Gate inclusions defect ratio and Amount of gate inclusions defect are less than 5%. From confirmation result proportion input of re-melting aluminum could likely to predict result of K-mold value and Gate inclusions defect that occurrence study site by referring from the model equation.

TABLE V: COMPARISON OF EXPERIMENT RESULT AND REGRESSION EQUATION RESULT

Result source	Experiment result	Calculate result	%Error
K-mold	0.51	0.53	2.85%
Mg	0.16	0.18	10.60%
H_2	0.22	0.24	8.52%
Gate inclusions defect ratio	0.97	0.92	4.51%
Amount of gate inclusions	52.40	51.00	2.75%
Gate blowhole defect ratio	0.16	0.15	11.51%
Amount of gate blowhole	17.95	8.33	115.40%

Find relative error between calculated results from regression equation with experimental results to confirm accuracy of prediction model. By choose material mixture proportion no.4, which has the value K-mold = 0.54, Mg = 0.162%, H_2 = 0.26 g/100g-Al. Take into equation (8) – (11). Results are shown in Table VI. Found relative error of Gate inclusions defect ratio and is less than 5% . From confirmation result K-mold is likely to predict result of the Gate inclusions defect occurrence in study site by referring from the model equation.

TABLE VI : COMPARISON OF EXPERIMENT RESULT AND REGRESSION EQUATION RESULT

	Experiment result	Calculate result	%Error
Gate inclusions defect ratio	1.19	1.25	4.74%
Amount of gate inclusions	41.91	70.00	40.12%
Gate blowhole defect ratio	0.15	0.10	53.34%
Amount of gate blowhole	9.15	6.00	52.46%

IV. CONCLUSION

Re-melting aluminum material could be use for purpose of material cost reduction but they would effect to the quality issue, especially scraped material that has been machined. Although they got cleaned in the right way that also could bring gas from the cleaning agent to melting process and caused to contaminate blowhole defectives. However from this study result was shown that inclusions defectives could be control by standardizing re-melting material proportion. Moreover K-mold evaluation has significantly result that can predict inclusions defectives output with less relative error, this will be useful to be realized defect output from molten metal evaluation before get to the next process. This research result is limit only in study site's melting furnace. Thus, further study research for causes of the inclusions occurrence in melting furnace and also to confirm outcome from other site of the study.

REFERENCES

[1] C. Sawangwong, "A Study of Effect of Die casting Control Factor on Workpiece defects" M.Eng. thesis, Dept. Ind. Eng., Chulalongkorn Univ., Bangkok, Thailand, 2011.

[2] S. Impey, D.J. Stephenson, and J.R. Nicholls, "A Study of the Effect of Mg Additions on the Oxide Growth Morphologies on Liquid Al Alloys," in Microscopy of Oxidation, ed., G.Tatlock and S. Neucomb, Science Reviews, 1991, pp. 238-244.

[3] R.D. Peterson and A. Revet, "Dross Analysis Methods and Their Application for Evaluating Secondary Furnace Operations," in Recycling of Metals and Engineered Materials, ed., D.L.Stewart, Jr., J.C. Daley, and R.L. Stephens, TMS, 2000, pp.1035-1044.

[4] D.V. Neff. "Corundum Formation in an Alloy Melting Furnace," Die Casting Engineer, NADCA, 1989. pp.123-124.

[5] F.L. Beichner, "Efficiency Evaluation of Melting Aluminum Furnaces," Light Metals, 2002, pp. 725 – 730

[6] J. Law, C. Tian, M. Murray, "Experiences in the Measurement of Molten Metal Quality in a High Pressure Diecasting Foundry", Transacations, NADCA, 1999, pp.235.

[7] D. L. Stewart, Jr., "Aluminum Melting Technology – Current Trends and Future Technology," Light Metals, 2002, pp. 719 – 724.