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DESIGN OF GRAVITY DIE CASTING PROCESS PARAMETERS OF AL-SI-MG ALLOYS

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ABSTRACT:

In the gravity die casting process the metal enters the mould under gravity. Despite recent innovations and advances in die casting technology that have significantly expanded the products, the development of complementary new alloys. The documentation of reliable properties data for these new alloys has all categorically lagged behind. The pouring of molten metal into the mould and its subsequent filling are quite critical steps in metal casting, since the behavior of the liquid metal and its freezing determine whether the cast shape will be properly formed and free from defects. In the present work, the Al-Si-Mg alloys are considered to investigate the casting and mechanical characteristics with respect to gravity die casting process. The following areas have been identified and selected for the analysis of gravity die casting process from Al-Si-Mg alloys: The solidification time of these alloys in the die casting process mould increases with increase in the pouring temperature of melt, decreases with increase in the pre-heat temperature of mould. It has been found that the Si content in the alloy reduces the freezing range whereas the Mg content widens it. Sufficient degasification of the melt improves the solidification process.
Keywords: gravity diecasting, Al-Si-Mg alloys, solidification, Taguchi techniques

1. INTRODUCTION

The gravity die-casting process parameters influence the casting quality especially solidification and the mechanical properties. The increase in the appeal of the gravity die-

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casting process may also be attributed to the excellent die-casting characteristics of aluminium alloys, as well as to the increased demand for large quantities of identical parts. However, the development of complementary new alloys, the optimization of existing alloys, and the documentation of reliable data on solidification phenomena and mechanical properties for these alloys have all categorically lagged behind. The following observations are made from the available literature:

1. Mondolfo (1976) has found that the alloys with dissolved Cu can result the largest increase in strength, and retain substantial ductility.
2. Gruzieeski (1990) has described in his work that Mg has the strong tendency to react with other elements to form inclusions and intermetallic particles. These inclusions and intermetallics can reduce the fluidity of alloys and adversely affect the overall mechanical properties.
3. Backerud (1990) has expressed that the presence of Fe is detrimental, and efforts are made to keep its levels as low as economically possible.
4. Amita Iyer and Sadhu (2000) have detailed in their work that the presence of Mn in Al-Si alloys may increase slightly the alloy's high temperature properties, enhances its fatigue resistance, and reduces its solidification shrinkage; Ni in Al-Si alloys raises slightly the alloy's strength and ductility at both room and elevated temperatures; When present in Al-Si alloys Zn decreases the high temperature strength, inclines to increase the tendency for hot tearing, but improves the alloy's machinability; and Lead in Al-Mg alloys improves the machinability without loss of strength or loss of corrosion resistance.
5. Tiwari (1998) has presented that the alloy composition, degasification, pouring temperature can influence the fluidity characteristics of Al-Si-Mg alloys.
6. When present in Al-Si alloys, Cr can increase the alloy's strength at room and also at elevated temperatures and slightly reduces ductility.
7. Babington (1951) has studied the effect of die casting process variables on the mechanical properties. He has depicted that modulus of elasticity, hardness, ultimate tensile strength, 0.2% yield strength, elongation, bending strength, flexibility, compressive strength, shear strength, impact strength, and fatigue strength are all dependent on the wall thickness of the castings.
8. Mazumdar et al (1990) have expressed that the nature of solidification in Al-alloys depends upon the specific gravity, thermal conductivity of liquid melt.
9. Venik (1961) has established that the metal flow in the die castings is influenced by the pouring temperature, die temperature, and the thermal conductivity of alloy.

This paper is to analyze and interpret the experimental results obtained from the design of experiments process (according to Taguchi Technique) to improve the performance of the gravity die-casting process relative to the solidification and mechanical behavior of the castings. The decisions were made concerning which parameters affect the performance of the gravity die-casting process. The various analytical techniques used for decision making are i) Column affects method; ii) Plotting method and iii) Analysis of variance. The analysis of variance (ANOVA) is a predominant statistical method used to interpret experimental data and make necessary decisions since this method is the most objective. The other methods are supporting and reinforcing techniques. The determination of influential factors and their relative strengths is based on the levels chosen for those factors. The statistical confirmation tests were also conducted to validate the conclusions drawn during the analysis phase.

2. DESIGN OF EXPERIMENTS

The following raw materials were used to develop and characterize Al-Si-Mg alloy die-castings:

- Al-Si-Mg alloys
- Cast iron mould (die)
- Degasifier

The alloys were prepared and chemical analysis of their ingredients was done. The chemical composition alloys is given in Table-1. The cast iron mould was employed to investigate the solidification phenomena of the alloys. The melts were degasified with tetrachlorethane tablets.

Table-1. Chemical composition of alloys

Alloy	Composition determined spectrographically, %				
	Al	Si	Mg	Fe	Cu
1	93.99	2.0	4.0	---	0.01
2	91.99	5.0	3.0	---	0.01
3	88.49	9.0	2.0	0.5	0.01

The quality characters, which were selected to influence the gravity die-casting process from Al-Si-Mg alloys, are as follows:

- Solidification time of alloys
- Tensile strength of castings
- %Elongation of castings
- Hardness of castings

The parameters, which influence the performance of the gravity die casting process, are:
Alloy composition ---- Al
--- Si
--- Mg
--- Fe
Gravity die-casting--- Pouring temperature of the metal
--- Degasification
--- Preheating temperature of the mould

The selected levels for the chosen control parameters are summarized in Table-2. The orthogonal array (O.A), L9 was selected for the present work. The parameters were assigned to the various columns of O.A. The assignment of parameters along with the OA matrix is given in Table–3.

Table-2. Control Factors and Levels

FACTOR	Symbol	Level – 1	Level – 2	Level-3
ALLOY COMPOSITION	A	1	2	3
POURING TEMPERATURE OF MELT, ^{0}C	T	675	700	725
MOULD PRE-HEAT TEMPERATURE, ^{0}C	P	200	300	400
Degasification with Tetrachlorethane, %	D	0.75	1.00	1.25

Table-3. Orthogonal Array (L_9) and control parameters

Treat No.	A	T	P	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

The casting design shown in figure1 is employed to study the solidification phenomena in gravity poured diecasting alloys. The calculations of riser dimensions were carried as mentioned in Appendix-A. The dimensions of riser are given Table-4. The location of riser on the casting is shown in figure 2. The Al-Si-Mg alloys were melted in an oil-fired furnace. The melting losses of aluminum and magnesium were taken into account while preparing the charge. During melting the charge was fluxed with coveral-11 (a Foseco company product) to prevent dressing. The molten metal was then degasified by tetrachlorethane (in solid form) using a plunger ending in a small inverted crucible. The melt was also modified with sodium in the crucible before pouring. The modification promotes the fine particles of silicon instead of coarse polyhedral and platelet of silicon in the melt. The crucibles were made of graphite.

Table 4. Riser size

Risher height Riser Diameter	Riser diameter, mm	Neck diameter, mm	Neck height, mm
1.25	96.82	24.20	67.77

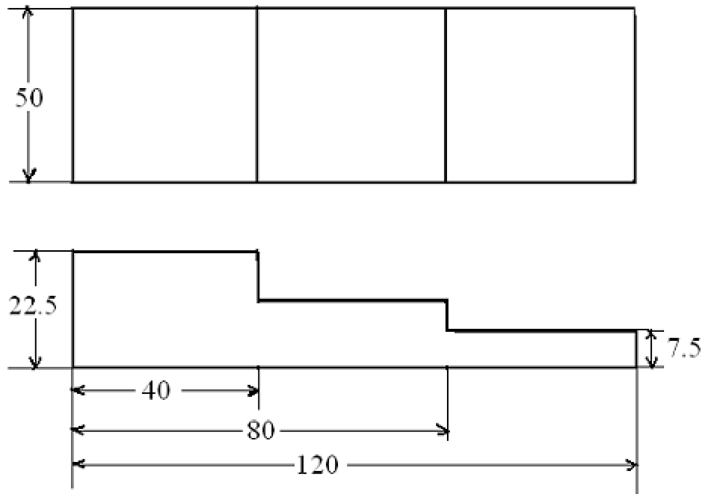

Figure 1. Casting design

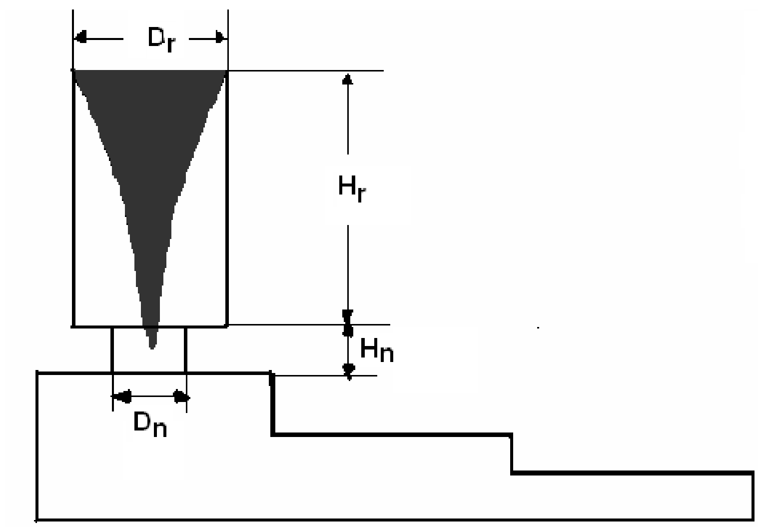

Figure 2. Location of riser on the casting

The charge was reheated to the required pouring temperature in a muffle furnace. The temperature of the melt was measured using a dip type thermocouple. The dross removed melt was finally gravity poured into the preheated mould. The setup for the measurement of solidification is shown in figure 3. With each casting poured, the temperature decreases due to solidification of liquid alloy. The time taken (i.e solidification time) to reach solidus temperature was noted down using stopwatch. Four thermocouples were placed in the casting to record solidification time and one thermocouple was placed in the mould to record the temperature of the mould.

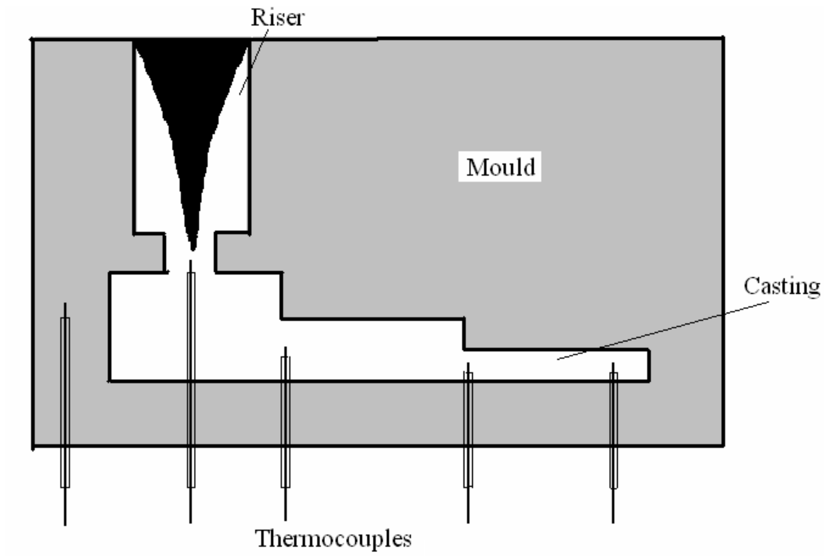

Figure 3. Setup for the measurement of solidification time

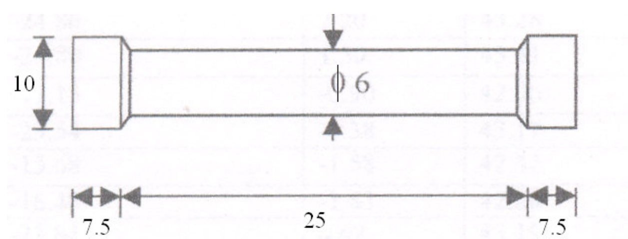

Figure 4. Tensile specimen, all dimensions are in mm

The gravity poured die-castings were machined on the lathe to get specimens for microstructure, tensile, and hardness tests. The dimensions of the tensile specimen are shown in figure 4. The computer-interfaced UTM (Universal testing machine) was used for the tensile test. The specimens were loaded hydraulically. The load at which the specimen was broken was noted down. The extensometer was used to measure the elongation. The load v/s deflection graph was also obtained for each specimen from the computer attached to the machine. Two specimens were used for each trial. The Brinell hardness tester was employed to measure the hardness of the castings. Standard procedure required that the test be made with a ball of 1/8'' (3.175 mm) diameter under a load 100 Kg. The diameter of the impression produced was measured by means of a microscope containing an ocular scale graduated in tenths of a millimeter. The Brinell hardness number (BHN) is the ratio of the load in kilograms to the impressed area in square millimeters. Metallography consists of the microscopic study of the structural characteristics of the die-castings. It was used to determine the grain size and shape and distribution of various phases and inclusions, which have a great effect on the mechanical properties of the castings.

3. RESULTS OF TAGUCHI'S EXPERIMENTAL PLANNING

The experiments were scheduled throughout the year to accommodate the environmental impacts. The liquidus and solidus temperatures are given Table - 5. The cut sections of gravity die-castings are shown in figures 5-13 as per the design of experiments by Taguchi's techniques. The optimization is with respect to solidification, and mechanical behavior of the die-castings. The experimental results are given in Table -6.

Table-5. Liquidus and solidus temperatures

Alloy	Liquidus temperature, ^{0}C	Solidus temperature, ^{0}C	Freezing range, ^{0}C
1	634	586	48
2	621	535	86
3	647	572	75

Table-6. Experimental results of Taguchi's design matrix

Treat No.	Solidification time, min	
	Trial-1	Trial-2
1	9.6	9.8
2	9.8	9.6
3	9.6	9.7
4	9.5	9.4
5	9.6	9.5
6	9.7	9.9
7	9.5	9.5
8	10	9.8
9	9.8	10.1

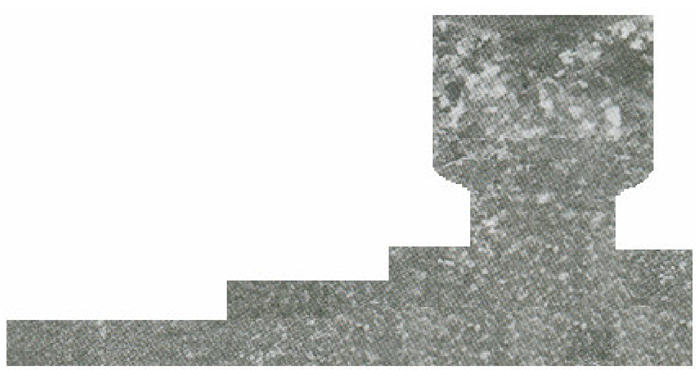

Figure 5. Gravity diecasting section having the process parameters: alloy-1, pouring temperature = 675^0 C, mould pre-heat temperature = 200^0 C, and degasified with 0.75% tetrachlorethane.

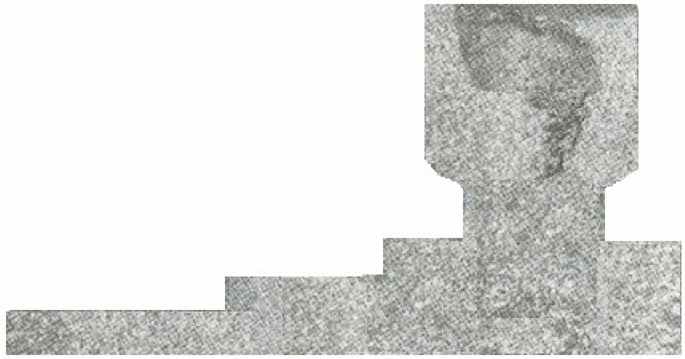

Figure 6. Gravity diecasting section having the process parameters: alloy-1, pouring temperature = 700^0 C, mould pre-heat temperature = 300^0 C, and degasified with 1.00% tetrachlorethane.

Figure 7. Gravity diecasting section having the process parameters: alloy-1, pouring temperature = 725^0 C, mould pre-heat temperature = 400^0 C, and degasified with 1.25% tetrachlorethane.

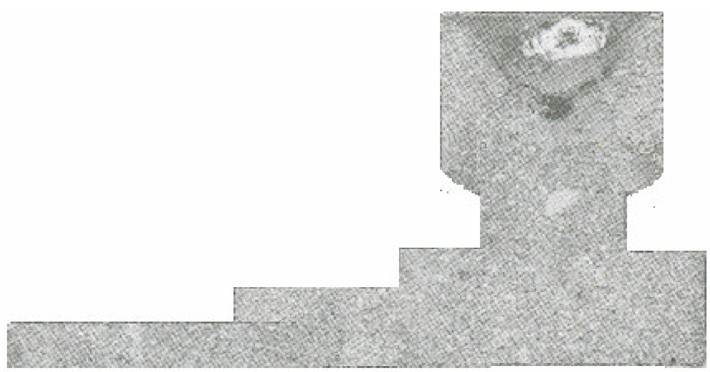

Figure 8. Gravity diecasting section having the process parameters: alloy-2, pouring temperature = 675^0 C, mould pre-heat temperature = 300^0 C, and degasified with 1.25% tetrachlorethane

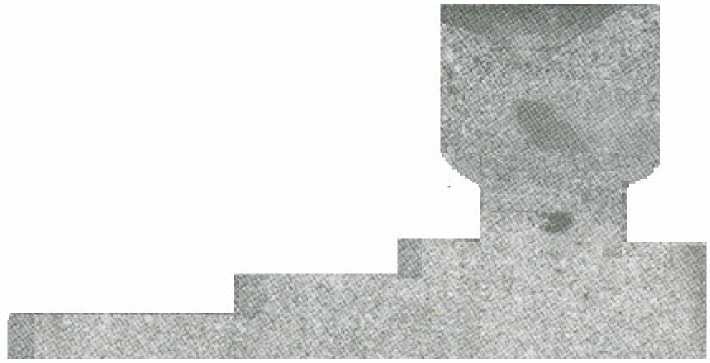

Figure 9. Gravity diecasting section having the process parameters: alloy-2, pouring temperature = 700^0 C, mould pre-heat temperature = 400^0 C, and degasified with 0.75% tetrachlorethane

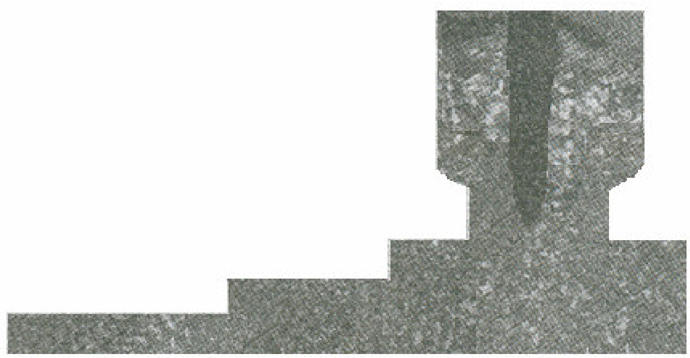

Figure 10. Gravity diecasting section having the process parameters: alloy-2, pouring temperature = 725^0 C, mould pre-heat temperature = 200^0 C, and degasified with 1.00% tetrachlorethane

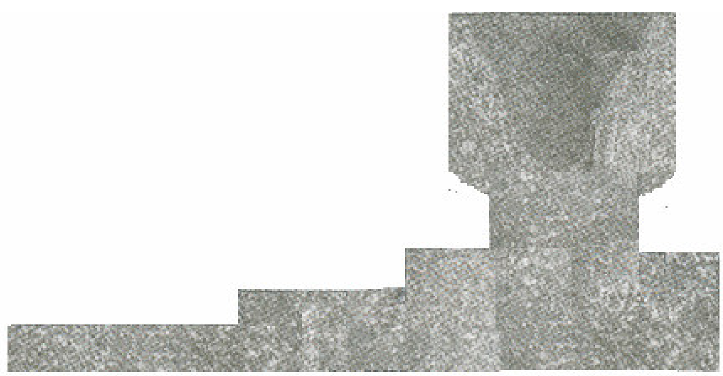

Figure 11. Gravity diecasting section having the process parameters: alloy-3, pouring temperature = 675^0 C, mould pre-heat temperature = 400^0 C, and degasified with 1.00% tetrachlorethane

Figure 12. Gravity diecasting section having the process parameters: alloy-3, pouring temperature = 700^0 C, mould pre-heat temperature = 200^0 C, and degasified with 1.25% tetrachlorethane

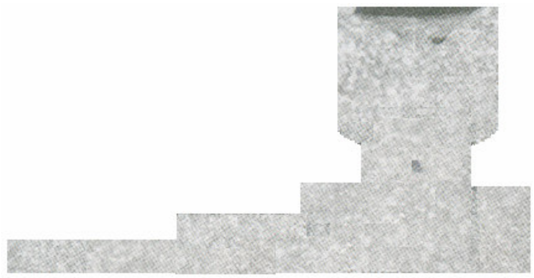

Figure 13. Gravity diecasting section having the process parameters: alloy-3, pouring temperature = 725^0 C, mould pre-heat temperature = 300^0 C, and degasified with 0.75% tetrachlorethane

4. EFFECT OF PROCESS PARAMETERS ON THE SOLIDIFICATION

Table–7 gives the pooled ANOVA summary of raw data. The percent contribution indicates that the parameter T (pouring temperature of melt) contributes 37.95% of variation, parameter P (mould pre-heat temperature) aids 33.09% of variation, parameter A (alloy composition) influences 22.84% of variation, and parameter D (degasification with tetrachlorethane) contributes 15.83%.

Table-7. ANOVA summary of solidification time

Column No	Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
1	A	58.1	57.6	58.7	0.101111	2	0.050556	2.527778	22.84
2	T	57.3	58.3	58.8	0.194444	2	0.097222	4.861111	37.95
3	P	58.8	58.2	57.4	0.164444	2	0.082222	4.111111	33.09
4	D	58.4	58.0	58.0	0.017778	4	0.004444	0.222222	15.83
5	e	----	----	---	0.14	7	0.02	---------	13.13
6	T	----	----	----	0.617778	17	--------	---------	100.00

*95% confidence

A low temperature level of solidification (difference between pouring temperature and mould pre-heat temperature), which reduces temperature gradients between the mould and casting, decreases the temperature gradient within the casting. Figure 14 shows the influence of pouring temperature of melt on the solidification time of the die-casting. It can be seen that the solidification time increases with increase in the pouring temperature of melt.

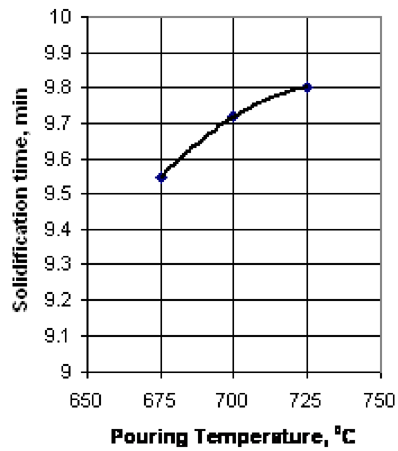

Figure14. Influence of pouring temperature of melt on the solidification time of casting

Yamamoto (1991) studied the solidification behavior of Al-Mg binary alloys. In their experiments the molten metal was poured into the die-casting sleeve at 640^0C. It was found that the temperature of the melt decreased and reached the solidifying temperature rapidly. They did not obtain the mathematical relation between pouring temperature and solidification time of binary Al-Mg alloys. In the present work on the solidification behavior of Al-Si-Mg trinary alloys, it is also proved that the solidification is faster at low pouring temperature than at high pouring temperature. It is also observed that the relation between pouring temperature and solidification time is quadratic in nature. The mathematical relation between pouring temperature and solidification time is given by

$$S = -7x10^{-5}T^2 + 0.0983T - 26.45 \qquad (1)$$

where,

S is the solidification time, Min

T is the pouring temperature, ^{0}C

Figure 15 illustrates the influence of mould pre-heat temperature on the solidification time of the die-casting. The graph indicates that the solidification time decreases with increase in mould pre-heat temperature. The temperature level of solidification (difference between pouring temperature and mould pre-heat temperature) decreases with increase in mould pre-heat temperature for the specified pouring temperature of melt. The mould pre-heat temperature decreases the temperature gradient within the casting. Hence, there is a reduction in the solidification time of the casting. The mathematical relation between pouring temperature and solidification time is given by

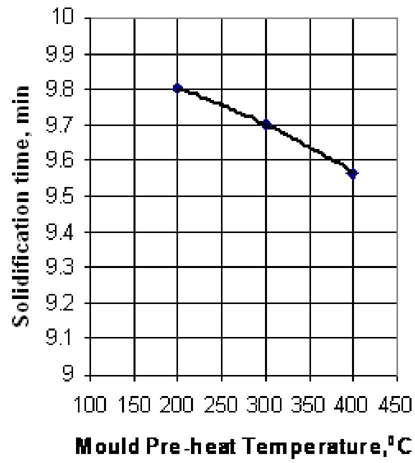

Figure15. Influence of mould pre-heat temperature on the solidification time of casting

$$S = -0.2x10^{-6}P^2 - 0.0002P + 9.9 \quad (2)$$

where,

S is the solidification time, Min

P is the mould pre-heat temperature, 0C

The influence of alloy composition on the solidification time of die-casting is presented in the figures 16 and 17. Figure-16 illustrates the effect of Si content in the alloy on the solidification time. The freezing range of the alloy decreases with increase in the Si content. The decrease in the cooling rate is accompanied by a contraction in the solidification range that resulted from an increase in the end temperature. From the Figure.16, it can be seen that as the Si content increases from 2% to 4% the solidification time decreases. It can also be observed that as the Si content increases from 4% to 9% the solidification time increases. It is contradictory to the above-said statement. The reason could be the presence of Fe in the alloy-3. Fe results the precipitation of AlSiFe type phase during the solidification of melt. This results in the decrease of Si content in the remaining liquid. Hence, the solidification time is increased. Spear and Gardner (1960) proved that in alloys containing elements that form intermetallic constituents with high solidification temperatures, the constituents could grow to such that they would impede feeding. The mathematical relation between Si content in the alloy and solidification time is given by

$$S = 0.0105A_{Si}^2 - 0.1014A_{Si} + 9.844 \quad (3)$$

where,

S is the solidification time, Min

ASi is the Si content in the melt, %

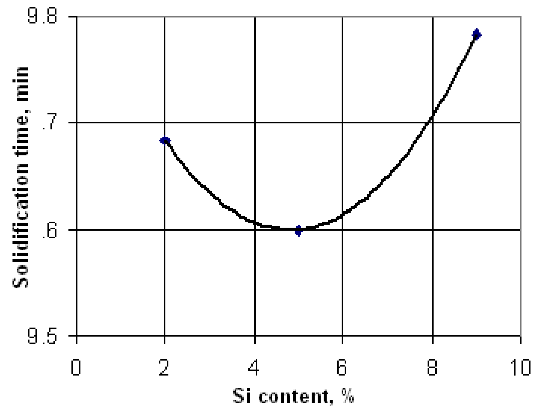

Figure16. Influence of Si content in the alloy on the solidification time of casting

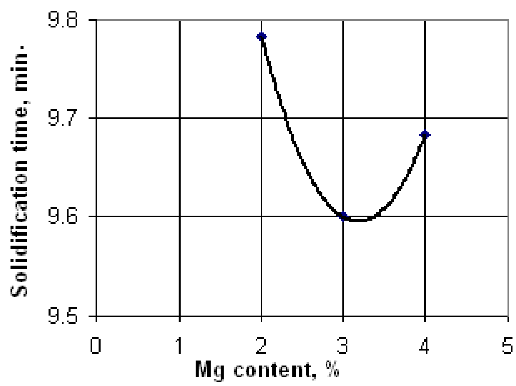

Figure17. Influence of Mg content in the alloy on the solidification time of casting

Figure17 represents the effect of Mg content in the alloy on the solidification time. The influence of Mg content is just opposite to that of Si content. The influence of Mg addition is not well documented, but could be attributed to the tendency of Mg to react with other elements. Mg results in wide freezing range of die casting alloys. Mg has a strong tendency to react with refractories and oxides, and introduces finely dispersed particles into the melt. These finely dispersed particles may reduce melt fluidity. In alloys containing Mg (2-4%) the eutectic phase Mg_5Al_8 may appear. When these alloys contain considerable amount of Fe, the following ternary eutectic reaction results

$$L \rightarrow Al + FeAl_3 + Mg_5Al_8 \tag{4}$$

where,

L is the liquid melt

Mg also reacts with Si to form Mg_2Si phase. A complex eutectic reaction completes the solidification process as follows:

$$L \rightarrow Al + FeAl_3 + Mg_2Si + Mg_5Al_8 \tag{5}$$

The mathematical relation between Si content in the alloy and solidification time is given by

$$S = 0.1333A_{Mg}^2 - 0.85A_{Mg} + 10.95 \tag{6}$$

where,

S is the solidification time, Min

A_{Mg} is the Mg content in the melt, %

The influence of degasification of melt with tetrachlorethane on the solidification time is shown in figure18. At low content of tetrachlorethane, the solidification time is high. This is owing to the presence of dissolved gases present in the melt. The dissolved gases hinder the heat transfer from melt to the mould. The gases are poor at heat transfer by conduction or convection from melt to mould. Once the dissolved gases are removed from the melt, there is no effect of degasification on the solidification. 1% of tetrachlorethane is sufficient to remove the dissolved gases from the melt. Because of combustible nature of tetrachlorethane, there is a possibility of fluxing and purging of the melt.

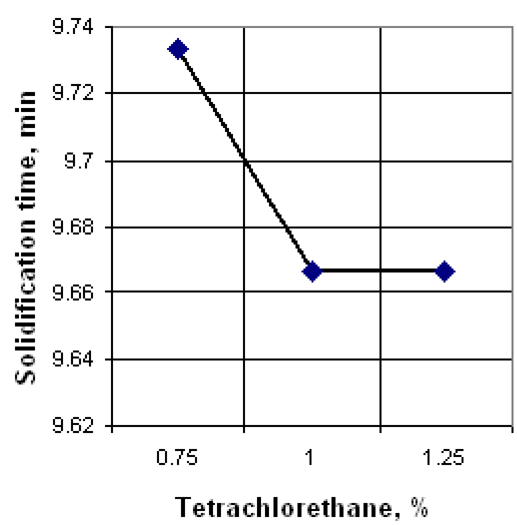

Figure18. Influence of degasification on the solidification time of casting

5. EFFECT OF PROCESS PARMETERS ON THE MECHANICAL PROPERTIES

The ANOVA summary of tensile strength is given in Table-8. The parameter A (alloy composition) all by itself contributes the variation of 92.85 % on the tensile strength of Al-Si-Mg alloy die-castings.

Table-8. ANOVA summary of tensile strength

Column No	Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
1	A	1663	1518	1602	1766.778	2	883.3889	407.7179*	92.85
2	T	1596	1605	1582	44.77778	2	22.38889	10.33333*	2.58
3	P	1587	1596	1600	14.77778	2	7.388889	3.410256	--------
4	D	1599	1605	1579	61.77778	2	30.88889	14.25641*	3.47
5	e	----	----	---	19.5	9	2.166667	---------	--------
6	T	----	----	----	1907.611	17	--------	---------	--------

*95% confidence

The influence of Si and Mg contents are shown in figure19 and 20 respectively. The reactions during the solidification of alloy-1 (93.99% Al – 2% Si – 4% Mg – 0.01% Cu) and alloy-2 (93.99% Al – 5% Si – 3% Mg – 0.01% Cu) may be as follows:

$$L \rightarrow Al + Si + Mg_2Si + Al_2Cu + Al_5Mg_8Cu_2Si_6$$

where, L is the liquid melt.

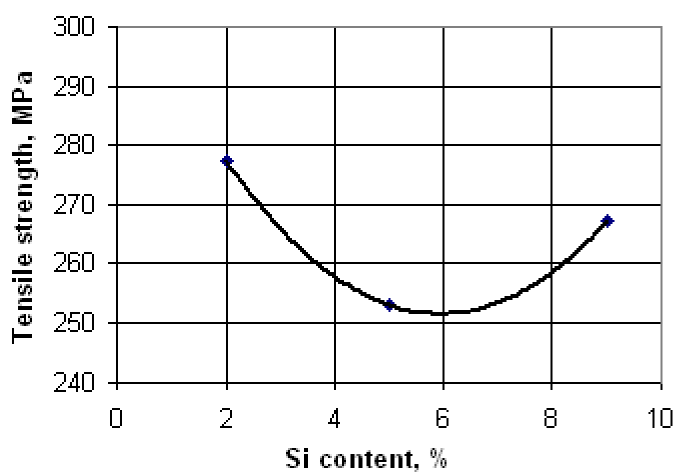

Figure19. Influence of Si content on the tensile strength of Al-Si-Mg alloy die-castings

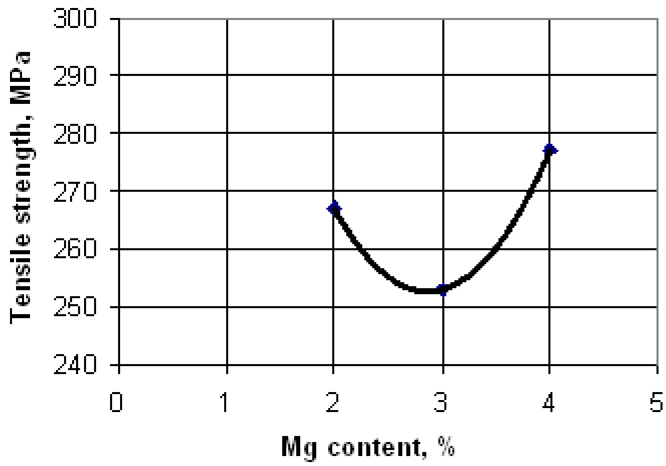

Figure 20. Influence of Mg content on the tensile strength of Al-Si-Mg alloy die-castings

The amount of precipitation of phases Mg_2Si , Al_2Cu , and $Al_5Mg_8Cu_2Si_6$ depend on the concentrations of Si and Mg in the melt. The tensile strength depends on the distribution of the silicon particles than on the silicon content. Magnesium content (>3%) in the alloy increases the tensile strength of die-castings. The tensile strength depends on the dispersion of Mg_2Si , and $Al_5Mg_8Cu_2Si_6$ in the final die-casting.

The effect of solidification time on the tensile strength is shown in figure 21. During the solidification, once a stable nucleus is formed, it grows by acquiring atoms from the liquid. If the first skin of solid metal is formed, the latent heat of fusion is released. Growth continues on some of the grains already formed. The rate of growth is governed by the amount of super heat, the preheat temperature of the mould, and the composition of the liquid. The complete solidification of the melt depends upon the thermal gradients prevailed from the center of the casting towards the raiser. If the thermal gradients are too steep, the solidification is fast which result in more amount of metal trapped between the dendrite arms (fine crystals with core-like structure at the grain boundaries). If the thermal gradients are flat, the solidification is slow which results in dendrite structure with primary and secondary arms (large crystals). In these two conditions, the tensile strength of the casting is low. From figure 21, it can be seen that the tensile strength is low for shorter and longer solidification times. The tensile strength is found to be high for the solidification time in the range of 9.55 to 9.65 min

The microstructure of alloy-1 and alloy-2 are revealed in figure 22a and 22b respectively. For alloy-1 and alloy-2 the micrometer size particles Mg_2Si , and $Al_5Mg_8Cu_2Si_6$ form in the matrix. The tensile strength of alloy-2 is lower than alloy-1 due to the presence of primary Si or eutectic Si in the matrix. In alloy-2 the primary Si is less faceted and acicular. The reaction during the solidification of alloy-3 (88.49% Al – 9% Si – 2% Mg – 0.5% Fe - 0.01% Cu) may be as follows:

$$L \rightarrow Al + Si + Mg_2Si + Al_2Cu + Al_3Fe + Al_3FeSi + Al_5Mg_8Cu_2Si_6$$

where, L is the liquid melt.

In the alloy-3, Fe concentration increases in the interdendritic areas and Al3Fe needles precipitate. The dendrites of alloy-3 are bigger than those of alloy-1 and alloy-2. The tensile strength is affected by the coarse structure of alloy-3. The microstructure of alloy-3 is shown in figure 22c.

The ANOVA summary of %elongation is given in Table-9. According to the analysis of variance, the strongest parameter is A (alloy composition). The other parameters (P: mould pre-heat temperature, D: degasification and T: pouring temperature of melt) are weak. The parameter A has the largest effect (53.77%). The influence of alloy composition (figures 23 and 24) is same as that of tensile strength.

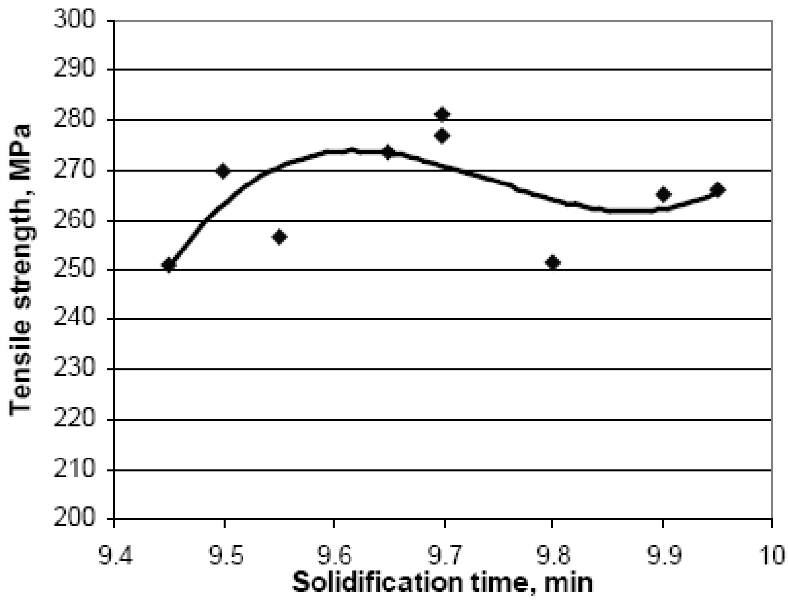

Figure 21. Effect of solidification time on the tensile strength

Table-9. ANOVA summary of %elongation

Column No	Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
1	A	51	58	51	5.444444	2	2.722222	6.125*	53.77
2	T	54	53	54	0.111111	2	0.055556	0.125	-------
3	P	52	56	52	1.777778	2	0.888889	2.0	-------
4	D	54	54	52	0.444444	2	0.222222	0.5	-------
5	e	----	----	---	4.00000	9	0.444444	---------	-------
6	T	----	----	----	11.77778	17	--------	---------	-------

*95% confidence

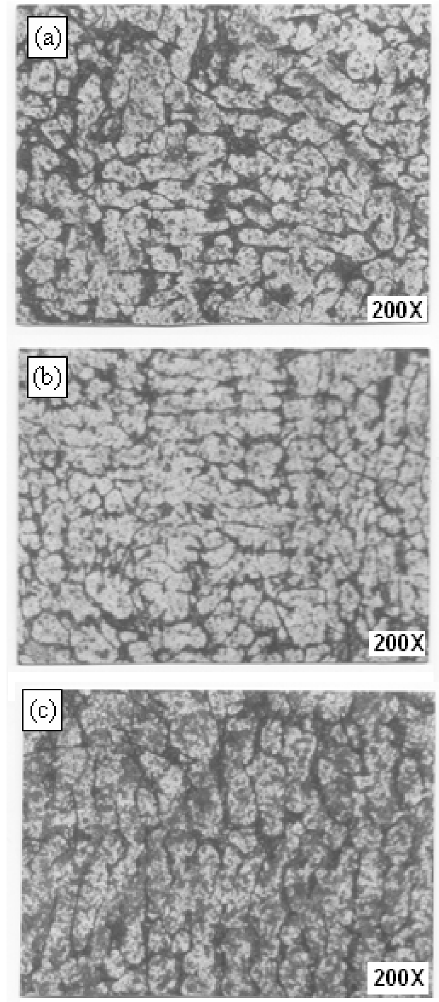

Figure 22. Microstructure of Al-Si-Mg alloy diecastings (a) alloy-1, (b) alloy-2 and (c) alloy-3

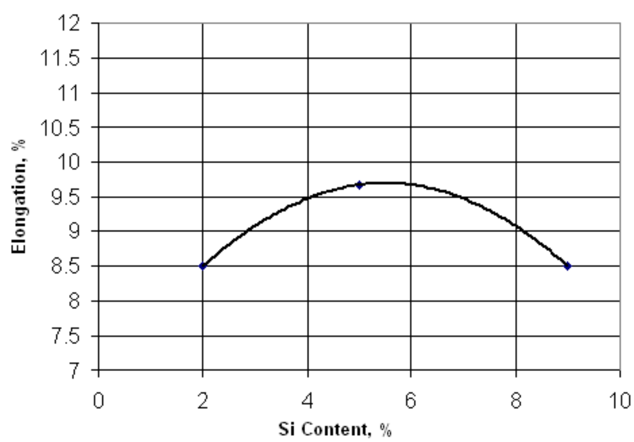

Figure 23. Influence of Si content on the %elongation of Al-Si-Mg alloy die-castings

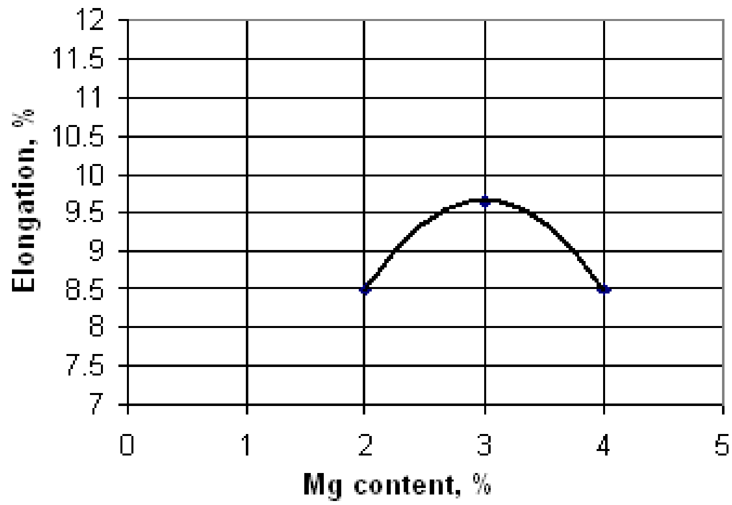

Figure 24. Influence of Mg content on the %elongation of Al-Si-Mg alloy die-castings

The ANOVA summary of hardness is given in Table-10. Looking at the analysis of variance, parameter A (alloy composition) has the largest effect, parameter P (pre-heat temperature of mould) the second largest effect and the parameter D (degasification) the third largest effect. Pouring temperature has the weakest effect on hardness.

Table-10. ANOVA summary of hardness

Column No	Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
1	A	481	455	466	56.77778	2	28.38889	36.5*	66.4557
2	T	465	465	472	5.444444	2	2.722222	3.5	-------
3	P	474	464	464	11.11111	2	5.555556	7.14*	14.43
4	D	462	469	471	7.444444	2	3.722222	4.79*	10.25
5	e	----	----	---	7	9	0.777778	---------	-------
6	T	----	----	----	87.77778	17	--------	---------	-------

*95% confidence

The influence of alloy composition on the hardness is illustrated in figures 25 and 26. It is observed that the increase in Si content decreases the hardness of Al-Si-Mg alloy die-castings (figure 25). It is also observed that the increase in Mg content increases the hardness (figure 26). The influence of mould pre-heat temperature on the hardness is illustrated in figure 27. Pre-heated moulds retard the chilling effect during the solidification of liquid metal. If the pre-heat temperature is high, the chilling effect is low. The chilling results fine grain structure in the castings.

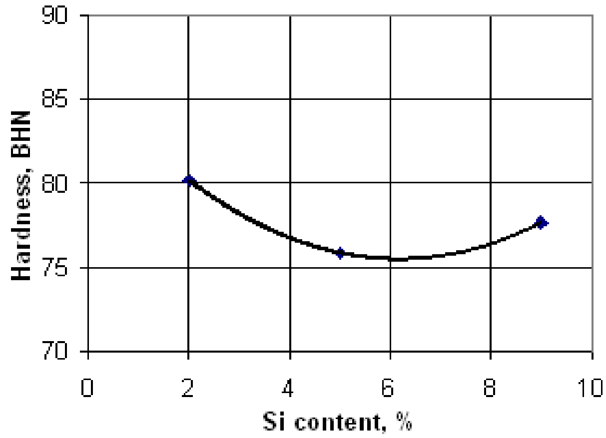

Figure 25. Influence of Si content on the hardness of Al-Si-Mg alloy die-castings

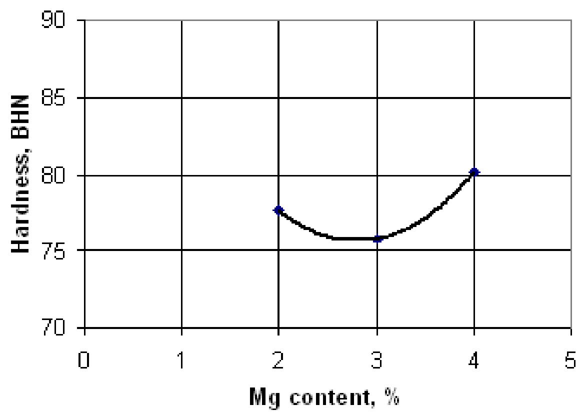

Figure 26. Influence of Mg content on the hardness of Al-Si-Mg alloy die-castings

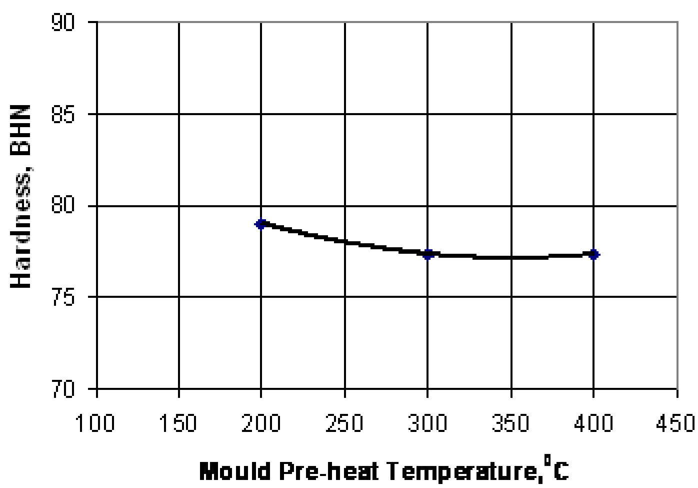

Figure 27. Influence of mould pre-heat temperature on the hardness of Al-Si-Mg alloy diecastings

The influence of degasification of melt with tetrachlorethane is shown in figure 28. If the melt contains dissolved gases due to improper degasification the castings results with porosity. If the melt is treated with excess tetrachlorethane, the flux is formed over the melt. The flux if trapped into the mould cavity during pouring, the final casting has the inclusions, which reduce the tensile properties and increase hardness. The degasifying compound also acts as grain refining agent.

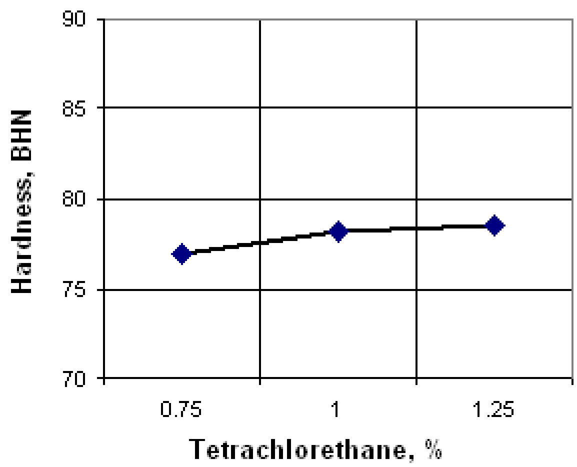

Figure 28. Influence of degasification on the hardness of Al-Si-Mg alloy die-castings

6. Optimization of Process Parameters

The solidification process of die-castings depends upon the removal of heat from the castings through the mould. The modes of heat removal are by conduction, convection and radiation. The role of radiation is very much limited in the foundry environment, but conduction and convection play vital role in the removal of heat from the castings. The phenomena of conduction and convection depends on the following characteristics

1. Thermal conductivity of alloy and mould
2. Specific heat of alloy
3. Enthalpy of alloy
4. Thermal expansion of alloy and mould
5. Fluidity of alloy
6. Dissolved gases (porosity) in the castings

The above-characteristics depend on the alloy composition, pouring temperature of melt, mould pre-heat temperature and degasification of the melt for gravity die- casting process.

Fe is often added unintentionally through the use of steel or cast iron tools during melting and metal die used for casting, and the reuse of remelting materials containing rust. In aluminium die casting alloys it is added purposely to minimize die soldering. Looking into the importance of die-casting characteristics, the statistical confirmation test was carried out to optimize process parameters as follows:

The significant process parameters which effect the solidification time of castings are alloy composition (alloy-3), pouring temperature of melt (T1), mould pre-heat temperature (P3) and degasification of the melt (D2).

The estimated mean of solidification time, min = A3 + T1 + P3 + D2 –3T

= 9.78 + 9.55 + 9.57 + 9.67 –3 x 9.69 = 9.5

where , T = grand mean

= 9.69 min

The confidence interval, CI = $\sqrt{\dfrac{F_{\alpha;2;v_e} V_e}{n_{eff}}}$ (7)

where,

$F_{\alpha;2;v_e}$ = Fisher's ratio

α = risk

ve = degrees of freedom for error

Ve = error variance

$$n_{eff} = \frac{N}{1 + \text{total degrees of freedom associated with items in the estimate of mean}}$$

$$n_{eff} = \frac{18}{1+4} = 3.6$$

For 95% confidence level, the Fisher's ratio is

$F_{5;\,2;9}$ = 4.26

$$CI = \sqrt{\frac{4.26 \text{ x}0.015556}{3.6}} = 0.14$$

The predicted range of solidification time is

$$9.36 < \text{solidification time} < 9.64$$

The predicted value of solidification time for the die-casting alloy is 9.5 min, which is equal to the average value of treatment No. 7 (9.5). Hence, all the process parameters with the levels of treatment No. 7 are chosen for the manufacturing of Al-Si-Mg alloy castings. The process parameters with their optimum levels are given in Table-11.

Table-11. Process parameters with optimum levels

Parameter	Level
Alloy composition	Alloy-3
Pouring temperature, ^{0}C	675
Mould pre-heat temperature, ^{0}C	400
Tetrachlorethane, %	1.0

APPENDIX-A: RISER CALCULATIONS

The governing equation for parabola is

$$Y = \frac{D_r}{2}\sqrt{\frac{X}{H_a}} \tag{A.1}$$

$$\text{Volume of the parabolic pipe,} V_p = \frac{\pi}{24} D_r^2 H_a \tag{A.2}$$

$$\text{Volume of the riser,} Vr = \frac{\pi}{4} D^2{}_r H_a \tag{A.3}$$

The volume of the pipe is equal to the volume of shrinkage in the casting.

Volume of the shrinkage $= \frac{S}{100} X \text{ volume of the casting}$

$$= \frac{SV_c}{100} \tag{A.4}$$

$$\frac{\pi}{24} D_r^{\,2} H_a = \frac{SV_c}{100} \tag{A.5}$$

$$D_r = \sqrt{\frac{24}{100} \frac{SV_c}{\pi H_a}} \tag{A.6}$$

Neck height, Hn $= \frac{D_r}{4}$ (A.7)

Neck diameter, Dn = 2Hn + 0.2 Dr (A.8)

where,

Vc = Volume of the casting

Ac = Area of the casting

Vr = Volume of the riser

Ar = Area of the riser

Ha = Active height of the riser

Dr = Diameter of the riser

Hr = Height of the total riser

Hn = Height of the neck

Dn = Diameter of the neck

S = Percentage of volume contraction

NOMENCLATURE:

SS	Sum of squares
V	degrees of freedom
V	Variance
F	Fisher's ratio
P	Percent contribution
E	error

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