Importance of Grain Refinement and Modification of Aluminium Alloys: A Review

Suresh Raj Jain[1], Dr. Y.Vijayakumar[2], Dr. S. Vidya Shankar[3]

[1]Research Scholar, Mechanical Engineering, Jain University, Bangalore, India
[2]Principal, Shirdi Sai Engineering College, Anekal, Bangalore, India
[3]Professor, P G Coordinator, Dept of Mechanical Engineering, B I T, Bangalore, India

Abstract: ***In view of the wide application of the heat treated LM25 (A356) Aluminium alloy in the area of automotive, military, marine, electrical and aerospace industry due to its microstructure and mechanical properties. It's imperative to control the grain refinement and modification of such alloys. The present paper investigates the application of the aluminium base master alloy containing Sr, Ti and B in simultaneous grain refining and modification of A356 aluminium alloy. It is also imperative that the element Ti has a high growth restriction factor (GRF) which correspondingly decreases the grain size without undergoing fading phenomena. There is close agreement between the results obtained which use master alloy separately and in combination. From the economic point of view it is better to investigate its combined role in achieving fine equiaxed dendrites and plate like eutectic silicon to round particles leading to further improvement of mechanical properties and to generate valuable data on comparative performance.***

Keywords: Grain Refinement, Growth Restriction Factor, Grain Size, Micro Structure, Mechanical Properties.

1. Introduction

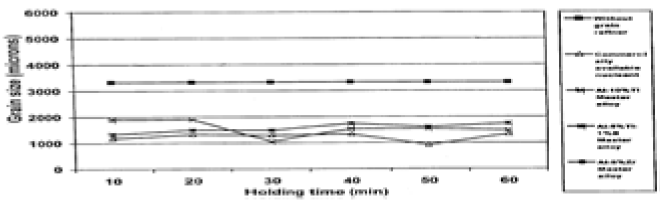
The microstructure and mechanical properties of A356 alloy strongly depends on the grain refinement and modification. The change in the microstructure from coarse columnar *a* -aluminium dendrites to fine equiaxed dendrites and plate like eutectic silicon to rounded particles leads to improved mechanical properties. They are light weight, low cost production easy to machine and have good recycling possibilities (up to 95%) A356 alloy is widely used in automotive, aerospace and marine engineering sectors, because of high fluidity, low shrinkage in casting, good weldability, easy brazing, excellent castability, high corrosion resistance and good mechanical properties. The mechanical properties are influenced by secondary dendrite arm spacing inter dendrite porosities, silicon particle size and the size of other inter metallic inclusions. The grain refinement achieved by heterogeneous nucleation through the use of inoculants methods has become quite popular. When the refiner added to melt, it takes some time for nucleation. The time required to reach the ultimate grain size is referred as optimum contact time. A ideal grain refiner is one which is not only fast acting but doesn't fade with time. There are number of methods of preparation of grain refiner, among which the reaction of halides with molten aluminium is quite popular. The reaction of the molten metal and salt is highly exothermic in nature, which has been proved by many researchers. In this paper an attempt has been made to review the available literature on grain refinement with respect to various methods (ways).

1.1 Effects and Mechanisms of Grain Refinement in Aluminium Alloys

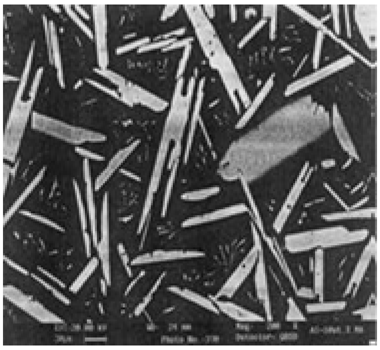
It is well known fact that the grain refiner plays an important role in improving the, mechanical characteristic of cast and wrought aluminium alloys. Usually the master alloy like AL-Ti and AL-Ti-B are mixed with aluminium alloy during the process of refining. Grain refinement can be understood to be directly related to the nucleation and growth process of aluminium grains. The theory involves homogeneous and heterogeneous nucleation. In industry both wrought and cast aluminium alloys are grain refined prior to casting. Commercially available nucleants or master alloys are commonly used.

Macrostructure of Al–Si (356) alloy without any grain refiner

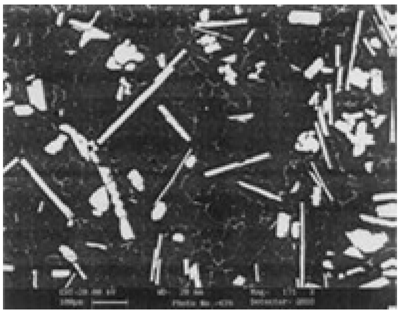
Macrostructure of Al–Si (356) alloy after adding Al–10Ti master alloy



Graph showing grain size vs holding time

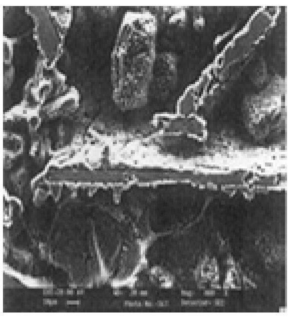


Scanning electron micrograph showing needle morphology of Al–10Ti and Master Alloy TiAl3



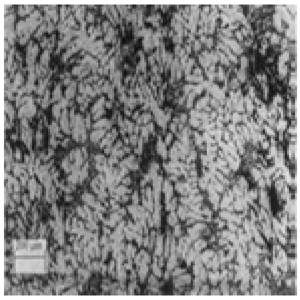
Scanning electron micrograph of Al–5Ti-1B Master alloy showing the combination of both flakey and blocky morphology of TiAl3

Macrostructure of Al–Si (356) alloy after adding Al-5Ti-1B master alloy



Scanning electron micrograph showing the nucleation of *a* - aluminium on the $TiAl_3$ needle

Macrostructure of Al-Si (356) alloy after adding the commercially available nucleants

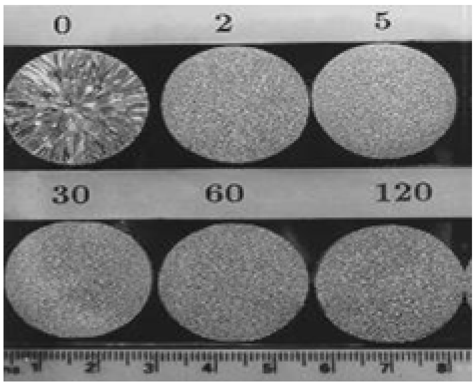


Microstructure of Al-Si (356) alloy after grain refining with Al-5Ti-1B master alloy (x 50)

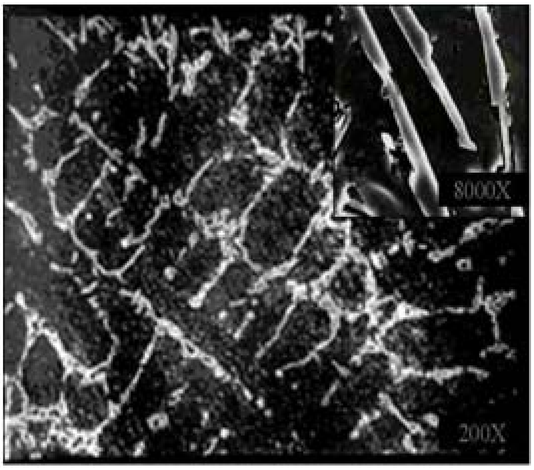
It is also shown through the photography that there exist a difference between macrostructure of aluminium alloy with or without addition of grain refiner Al-10Ti and further enumerated through graphics that there is drastic reduction in grain size, after the addition of grain refiner thereby increasing its efficiency. It is also shown through SEM that one of the grain refining constitutes Al-10Ti master alloy added to the melt changes the morphology taking from needle state to the blocky and flaky state of Ti-AL3 and also confirming the mechanism of nucleation of *a* -aluminium Ti-AL3 needle.

1.2 Grain Refinement and Modification of Al Alloy

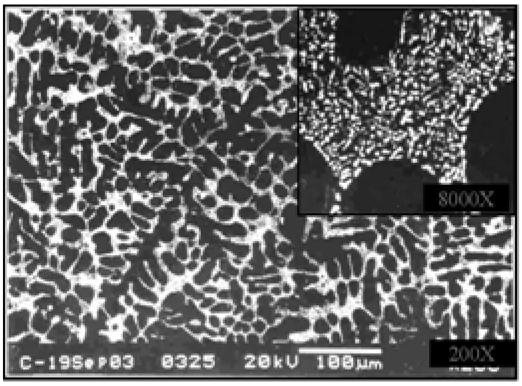
This work led to the understanding of the poisoning and the fading phenomena observed during grain refinement. This proved to be very useful in designing requirement of Al-Si alloy for effective grain refinement and how the excess of Si(>2%) in Al-Si alloy counteract the Poisoning phenomena.



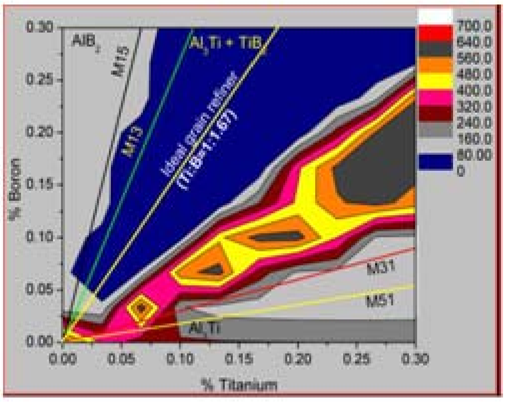
Shows the macrostructures of Aluminium after grain refinement of Al-5Ti-B master alloy



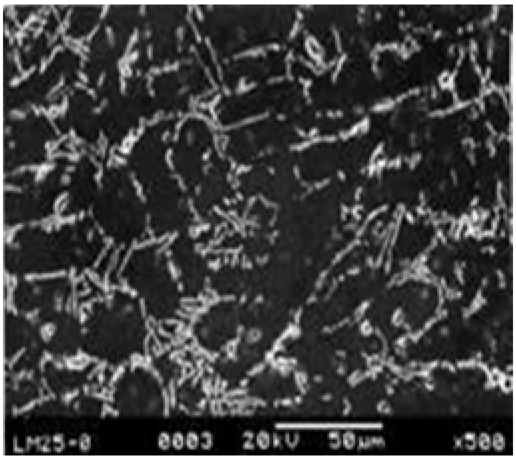
Shows the microstructure of Al-7Si alloy without grain refiner and modifier, Grain refinement and modification has been active research area to focus on fading phenomena



Shows the microstructure of Al-7Si alloy with grain refiner and modifier

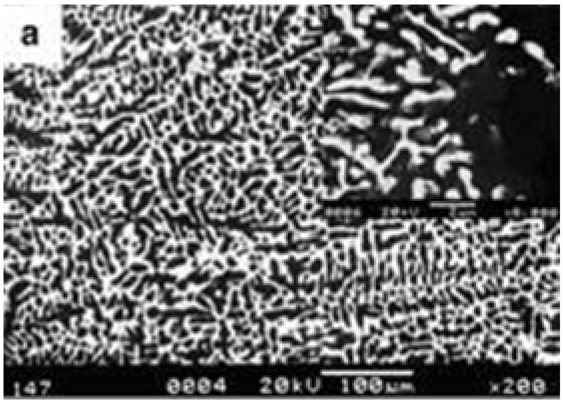


Shows Neural network modeling of grain refiner for Al-7Si alloy

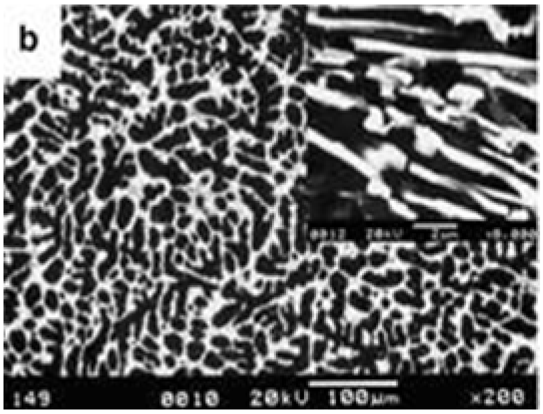


Shows the microstructure of Al-7Si alloy Without inoculation (500X)

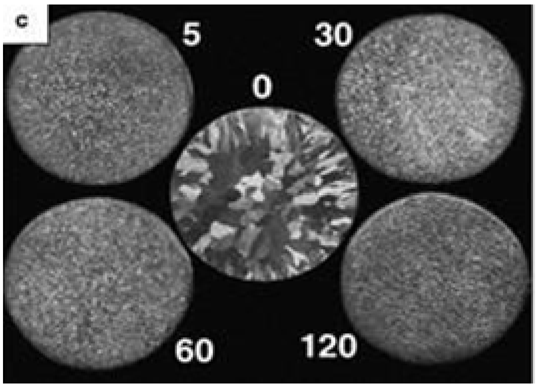
Grain refinement by inoculation of the melt is an established industrial practice while casting the Aluminium and aluminium alloys. Over the years, lot of work has been done in preventing or enhancing good grain refinement in the preparation of grain refiners and during the inoculation of the melts. Researchers also proposed theoretical Models for evaluating grain refiners by predicting the behavior with inoculation or without inoculation.

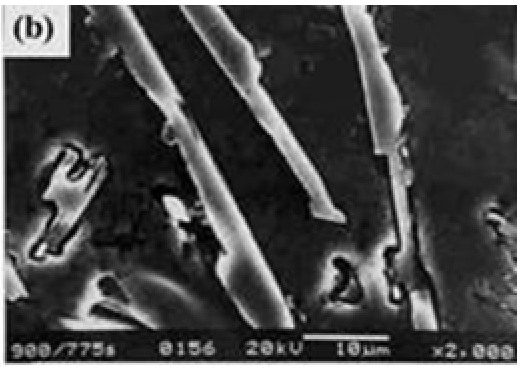


After inoculation (5min)

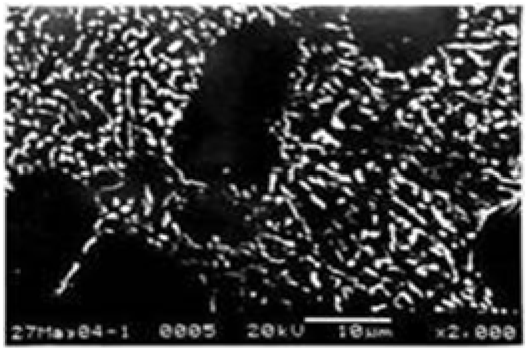


After inoculation (120min)





Without Incolulation



After inoculation (5 min)

Further it is also shown through the figure that the macro and microstructures of aluminium alloys with and without grain refiner using artificial neural network modeling the best combination Ti and B in Al-Ti-B master alloy for achieving effective grain refinement for Al and Al-Si alloys is identified. Following the modification effect a new Al-Ti-C-Sr inoculants master alloy is developed resulting in simultaneous grain refinement and modification of A356 alloy. The figure shown through SEM photo micrograph reveals the extent of modification of eutectic silicon in un-inoculated and inoculated A356 alloy.

1.3 Grain Refinement of Light Alloys

This study involves the grain refinement of light alloys like magnesium and aluminium. The use of this alloy plays an important role in achieving the relative grain size. The resulting grain size varies from few μm on solidification to a fraction of μm on severe plastic deformation (SPD). In view of the increasing application of the above light alloys in the automobile sector many of these studies have been revoked to ensure that the process of grain refinement is efficient and ecofriendly. Inoculation is the most commonly employed method and is carried out using grain refinement like Al-Ti, Al-Ti-B, Al-Ti-C, Al-B and AL- Sr-B alloys. The performance of the grain refiner can be evaluated by withdrawing samples at different intervals of time following its addition and determining the grain size of solidified alloys.

Table 1 Commercially Available Grain Refining Alloys

Alloy type	*Composition*
Al-Ti	Al-10Ti, Al-6Ti
Al-Ti-B	Al-3Ti-1B, Al-5Ti-1B, Al-5Ti-0.6B, Al-3Ti-0.2B, Al-5Ti-1B, Al-5Ti-0.2B, Al-10Ti-0.4B, Al-1.6Ti- 1.4B (TiBloy for hypoeutectic Al-Si alloys), Al-1.2Ti-0.5B (Hydloy), Al-3Ti-3B, Al-1Ti-3B
Al-B	Al-10B, Al-5B, Al-3B, Al-10Sr-2B, Strobloyä, (Al-10Sr-1.6Ti-1.4B)
Al-Ti-C	Al-6Ti-0.02C, Al-3Ti-0.15C
Al-Sc	Al-1Sc, Al-2Sc
Mg-Zr	AM cast (Mg-25Zr), Zirmax (Mg-33.3Zr)

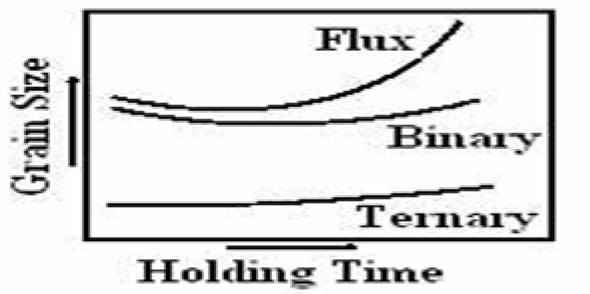


Figure 1a: Schematic of grain size variation with holding time for aluminium using flux, binary Al-Ti and ternary Al-Ti-B alloys

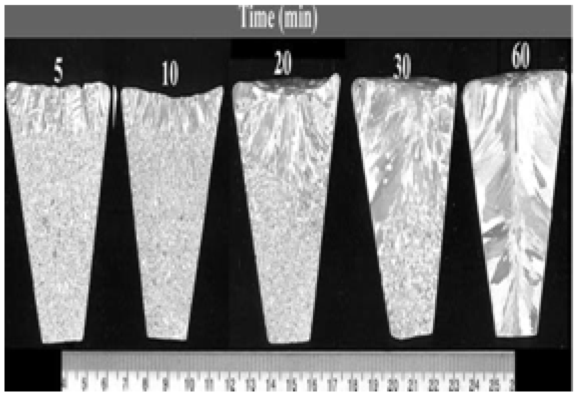


Figure 1b: Macrographs of commercial aluminum grain refined by Al-1.2Ti-0.5B, 50 ppm Ti addition

Accordingly, a set of grain refiner i.e. flux binary and ternary are schematically illustrated through a figure and following these it is shown that how macrostructure of aluminium samples grain refined with Al-1.2Ti-0.5B alloy addition using the above test and withdrawn at various intervals of holding time.

1.4 Simultaneous Grain Refining and Modification of A356 Aluminium Alloy Using Aluminium Base Master Alloys Containing Strontium, Titanium and Boron

This study is taken up to investigate the application of aluminium base master alloy containing Sr, T & B in simultaneous grain refining and modification of A356 alloy. During the study it is observed that there is a close harmony existing between results obtained conventionally using master alloy separately and results obtained using combined alloy.

The grain size and morphology of eutectic silicon particles have often been considered to have an important influence on the mechanical properties of cast alloys. It is known that most of the foundries employ Ti and B containing refiners (conventional Al-5Ti-B) to arrive at the grain structure and Al-Sr master alloy modify the eutectic silicon particles. An intensive literature study has been undertaken for grain refinement and modification of Al-Si-Mg and experiment programmed is conducted to determine the optimum process condition. It is also known that hypoeutectic cast Al-7Si-0.35Mg alloy with designation LM25 or A356 have wide spread application in automobile and aerospace industries as these exhibit good mechanical properties.

After modification due to addition of Sr in the form of Al-10Sr results in finer fibrous eutectic network. The geometric parameter of eutectic Si particles determined through image analysis, reveals interconnected Si needles act as stress risers and consequently the material fractures to brittle mode.

1.5 Influence of Grain Refiner and Modifier on the Microstructure and Mechanical Properties of A356 Alloy

In this study, investigations carried out to find out the effect of grain refinement (Al-Ti & Al-B) and modification (by Al-10Sr) of A356 alloy. A356 is widely used in automotive, aerospace and engineering sectors for their excellent mechanical properties like castability, corrosion resistance etc. A356 used in this study is a hypoeutectic aluminium alloy (Al, 6.96 wt % Si, 0.3 wt % Mg, 0.1 wt % C, 0.5 wt % Fe).

Specimens are prepared by melting A356 alloy in a resistance furnace and the melt held at 720 ^{o} C. After degassing, the melt is poured into graphite moulds. Similarly the grain refined and modified samples, the master alloy chips (Al-Ti-B & Al-Sr) is added to the hypoeutectic alloy after degassing. The melt is stirred for 30 seconds with zirconia coated steel rod after the addition of master alloy, there after no stirring is required and after 5 min of holding time the melt is poured into graphite moulds.

1.6 The Effect of Alloy Content on the Grain Refinement of Aluminium Alloys

In this study, it is observed that much importance has not been given in quantifying the role of solute elements in achieving fine grain size. The theory behind is that there are two parameters that have been used to quantify the role of solute on the grain size of castings.

(1) Growth Restriction Factor (G. R. F.) designated by $Q= m_l c_0 (k-1)$.
(2) The super cooling parameter Designated by $P= m_l c_0 (k-1)/k$.

The data required for calculating GRF (Q) and super cooling parameter (P), for binary aluminium alloy is shown in Table (I). In continuation, a model is developed that predicts the relative grain size due to change in solute contents and the potentiality of the nucleant particles present in the melt. This model connects the development of solid fraction (f_s) in an equation i.e. $d\Delta T_c / dfs = m_l c_0 (k-1)$ in which the GRF (Q) at $f_s = 6$. From this equation, it is arrived that Q is the measure of how rapidly the constitutionally under cooled zone is formed at the earliest stages of growth.

The fig (1) shows the development of constitutional under cooling zone (ΔT_c) with fraction solid (f_s) calculated using the above equation for two binary alloys Al – 0.02T_i and Al – 0.05T_i. Further in order to predict relative grain size it is assumed that grain must grow to a particular solid fraction (f_{sn}) to produce the constitutional under cooling equivalent to under cooling required for nucleation of another grain on an adjacent nucleant substrate (ΔT_c) and hence (f_{sn}) represents the distance between nucleation events for the purpose of determining the effect of solute content and nucleation on grain size.

Table I: Element Details

Element	k_i	m_i	max. conc. (wt%)	m(k-1)	m(k-1) /k
Ti	7-8	33.3	0.15	~220	~30
Ta	2.5	70	0.10	105	42
V	4.0	10.0	~0.1	30.0	7.5
Hf	2.4	8.0	~0.5	11.2	4.7
Mo	2.5	5.0	~0.1	7.5	3.0
Zr	2.5	4.5	0.11	6.8	2.7
Nb	1.5	13.3	~0.15	6.6	4.4
Si	0.11	-6.6	~12.6	5.9	53.7
Cr	2.0	3.5	~0.4	3.5	1.8
Ni	0.007	-3.3	~6	3.3	4714
Mg	0.51	-6.2	~3.4	3.0	5.9
Fe	0.02	-3.0	~1.8	2.9	145
Cu	0.17	-3.4	33.2	2.8	16.5
Mn	0.94	-1.6	1.9	0.1	0.1

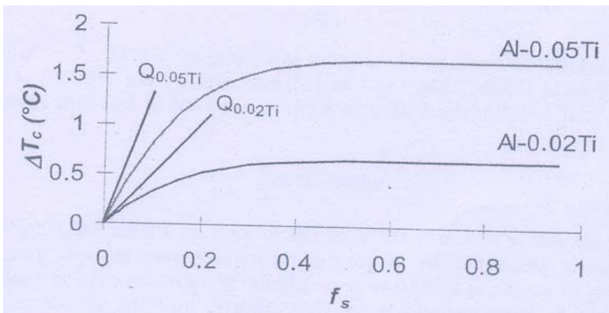


Figure 1: Development of two binary Alloys

2. Conclusions

1. Grain refinement of aluminium alloys is by heterogeneous nucleation and growth of grain.
2. Nucleating effects in grain refinement are important but solute effect plays a vital role in requirement.
3. Of all the nucleant effects, the Duplex nucleation theory i. e. $TiAl_3$ layer forming on boride particles may be inconsequential as solute Ti is required to activate nucleation.
4. Al-Ti-B alloys are efficient grain refiners for aluminium alloys but the work force Al-5Ti-1B alloy is slowly giving way to the more dilute alloys such as Al-1.2Ti-0.5B.
5. Injection of fine gas bubbles into the melt satisfies the requirements of both grain refinement and melt treatment, the method requires more elaborate study
6. Rapid studies are made in understanding the mechanism of grain refinement with the ultimate objective of predicting a suitable refiner for a given alloy but more information needs to be collected in this regard.
7. Combined master alloys (Al-0.5Sr-5Ti-1B and Al-4Sr-2B) are efficient materials in grain refining and modification of an A356 alloy.

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Authors Profile

Suresh Raj Jain is presently pursuing Ph.D at JAIN University, who has completed B E in Mechanical Engineering and M E in Metal Casting & Sciences. The author has 3 decades of Teaching Experience and attended several seminars and workshops.

Dr. Y. Vijayakumar currently working as Principal at Shirdi Sai Engineering College (SSEC), Sai Leo Nagar, Anekal, Bangalore, graduated in Mechanical Engineering in the year 1984 from Sri Venkateswara University College of Engineering, S.V. University – Tirupati, AP and subsequently acquired Masters Degree in Industrial Engineering from National Institute of Technology (NIT), Calicut (Kerala) and Ph. D degree in Industrial Engineering (OR & SQC) from Sri Krishna Devaraya University – Anantapur A.P. I also served various academic bodies in various capacities like Governing Council Member, BOE & BOS Member etc., recently I have been declared elected as **Member** of the **Section Managing Committee** of ISTE from Karnataka Section for the term 2012 - 2014.