## 2.2 FUNCTIONALLY GRADED MATERIALS

In materials science **functionally graded material (FGM)** may be characterized by the variation in composition and structure gradually over volume, resulting in corresponding changes in the properties of the material. Functionally graded materials can also be defined as materials having graded transition in mechanical properties, either continuous or in fine, discrete steps, across the interface [7-9]. This type of materials can be designed for specific function and applications. Various approaches based on the bulk (particulate processing), preform processing, layer processing and melt processing are used to fabricate the functionally graded materials.

The FGM concept originated in Japan in 1984 during the space plane project, in the form of a proposed thermal barrier material capable of withstanding a surface temperature of 1726°C and a temperature gradient of 727°C across a cross section <10 mm. Since 1984, FGM thin films have been comprehensively researched, and are almost a commercial reality.

A functionally graded material (FGM) is a two-component composite characterized by a compositional gradient from one component to the other. In contrast, traditional composites are homogeneous mixtures, and they therefore involve a compromise between the desirable properties of the component materials. Since significant proportions of an FGM contain the pure form of each component, the need for compromise is eliminated. The properties of both components can be fully utilized. For example, the toughness of a metal can be mated with the refractoriness of a ceramic, without any compromise in the toughness of the metal side or the refractoriness of the ceramic side.

However, in functionally graded materials (FGMs), the property of one side differs from that of the other side. Thus, it arise different functions within a material. For example, one side may have high mechanical strength and the other side may have high thermal resistant property; thus, there are "two aspects" in one material.

FGM's are materials that can be purposefully processed to obtain higher superficial hardness and adequate internal toughness. Special processing is required to produce these materials in order to exhibit characteristics that are not attainable by monolithic or homogeneous materials [10].

It is now well known that abrupt transitions in materials composition and properties within a component often result in sharp local concentrations of stress, whether the stress can be internal or applied externally. It is also known that these stress concentrations are greatly reduced if the transition from one material to the other is made gradual.

These considerations form the essential elements of the logic underlying the majority of functionally graded materials. By definition, functionally graded materials are used to produce components featuring engineered gradual transitions in microstructure and/or composition, the presence of which is motivated by functional performance requirements that vary with location within the part. With functionally graded materials, these requirements are met in a manner that optimizes the overall performance of the component.

This new concept of materials engineering hinges on materials science and mechanics due to the integration of the material and structural considerations into the final design of structural components. Because of the many variables that control the design of functionally graded microstructures, full utilization of the FGMs potential requires the development of appropriate modelling strategies for their response to combined thermo-mechanical loads.

The processing of graded materials is revealing a very wide spectrum of methods available. As a consequence of this diversity, much work to date is largely developmental or exploratory in nature, and aimed most often at providing proof of the viability of a given processing route toward FGM production.

Some common threads can, however, be found in this wide variety of processes. According with Surresh and Mortensen [8] can be distinguish two principal classes of methods for the production for FGMs containing a metallic phase: (i) processes where the graded material is constructed spatially, layer by layer and according to essentially any pre-chosen distribution, and (ii) processes wherein natural transport phenomena, such as fluid flow, atomic diffusion, or heat conduction, are exploited towards the creation of macroscopic gradients in composition and microstructure (Figure 2.1). For each process class, different subclasses exist.

In the first class of processes, the FGM is constructed layer by layer, in a manner that starts with an appropriate distribution of constituents of the FGM, often in a precursor of the component. These techniques are named constructive processes because the gradients are literally constructed in space. Constructive processes are, thus, ones which are amenable to computer-control of the gradients produced, and represent largely an outgrowth of the tremendous advances that have been made over the past decades in automation of materials processing: such meticulous distribution of phases would otherwise be absurdly expensive.

Constructive processes are distinguished from a second class of FGM processes, which rely on natural transport phenomena to create gradients within a component. These transport-based processes use the flow of fluid, the diffusion of atomic species, or the conduction of heat, to create gradients in local microstructures and/or compositions that are useful. Both heat and mass diffusion have been used for centuries to create functional, microstructural, and/or compositional gradients in steel. Fluid flow, interfacial segregation, and solid state diffusion during solidification are responsible for macrosegregation in single crystals and alloy castings. Although generally viewed as a problem in the processing of homogeneous materials, these are naturally segregative phenomena which can be used to create tailored gradients within a component. If these processes are quantitatively understood and harnessed, gradients produced can still be optimized, albeit within a narrower window of possible structures.

Transport phenomena, of fundamental importance in the latter class of FGM processes, must also be considered in the context of constructive processes because these tend to erase gradients incorporated early in the FGM process cycle. It is therefore generally instructive, in the processing of FGMs, to consider approximate time or velocity scales for each of heat, solute, and liquid transport.

The centrifugal casting method is one of advantageous transport-based techniques to fabricate functionally graded materials such a cylindrical composite parts as its main functions like strength and thermal expansion coefficient vary along the wall thickness of a cylinder in some conveniently gradient fashion.

The previous studies on the functionally graded materials obtained by centrifugal casting method have mainly treated the case where dispersion-hardening particles in the composite have a higher density than that of the matrix substance, so that they segregate on the outer side of the cylinder wall [11-13]. The Al-Si base functionally graded materials obtained by centrifugal casting method studied in the present research are however different from the previous ones in the respect that Si particle as the dispersion-hardening phase has a lower density than that of the Al enriched matrix.

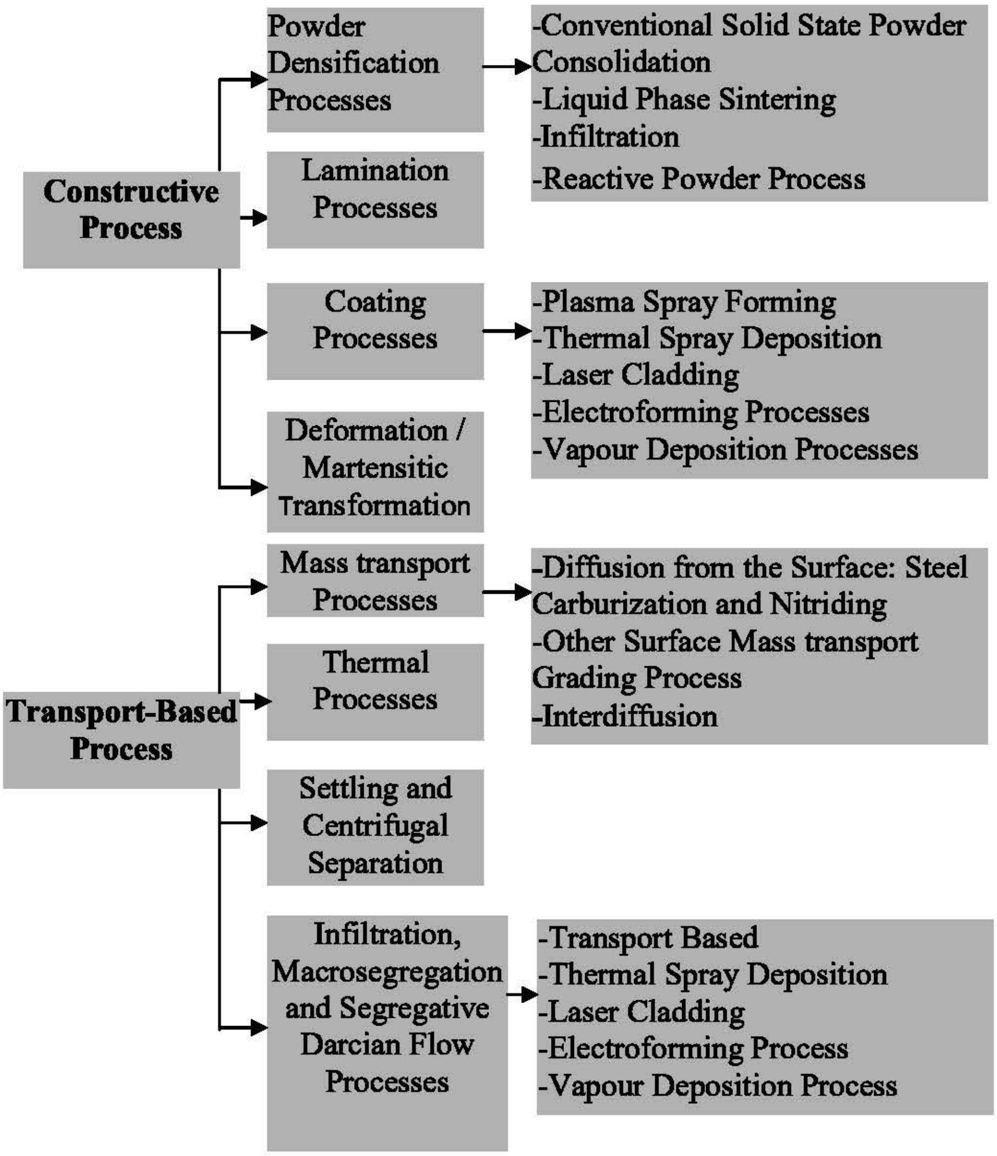


Figure 2.1 - FGM processing methods, and their classification [8].

Many processing methods have been proposed to fabricate FGMs, such as chemical vapour deposition, the plasma spray technique and various powder metallurgy techniques. The centrifugal method was introduced recently and has attracted a lot of attention due to its unique merits [14]. In particular, Al based FGMs fabricated by the centrifugal method showed interesting properties that are not obtained in conventional monolithic materials, such as gradual changes in hardness, wear resistance, Young's modulus, etc [15].

FGMs offer great promise in applications where the operating conditions are severe. For example, wear-resistant linings for handling large heavy abrasive ore particles, rocket heat shields, heat exchanger tubes, thermoelectric generators, heat-engine components, plasma facings for fusion reactors, and electrically insulating metal/ceramic joints. They are also ideal for minimizing thermo-mechanical mismatch in metal-ceramic bonding.

Most of studies in the domain of functionally graded materials (FGMs), obtained by centrifugal casting deal with functionally graded composites where an alloy is reinforced with a solid phase as for example silicon particles [17-20]. In these cases the gradation as well as the improvement of mechanical properties is attributed to the reinforcement. Moreover in some cases it is possible to obtain FGMs with metallic materials where there is a high difference of density and low solubility of different phases or different materials of the same alloy. In this last case the phases with higher density move in the radial direction to the outer surface of the casting due to the centrifugal force [16, 21].

However, in this study, an aluminium alloy, without reinforcement, and with very close densities between phases, is used. It will be shown that the casting may be very influenced by the centrifugal effect and functionally graded castings may be obtained. In order to understand why a homogeneous alloy, with similar densities between phases, may give rise to an FGM, by using the centrifugal effect, an analysis of the most important effects of the centrifugal casting process on metallurgical features is necessary.

In this research the mechanical and also the fatigue properties were obtained the same way as for the homogenous materials with the particularity shown in chapter 3 that the samples were obtained by cutting the ingots by layers to be able to characterise the functionally graded material along the gradient of properties.