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DESIGN FOR QUALITY IN THE CONCEPT GENERATION PHASE OF THE PRODUCT DESIGN PROCESS

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ABSTRACT

The design process with the quality in mind especially the customer requirement is the focus of this research. This is demonstrated through the application of the design process in developing a squeeze casting attachment for a stir casting furnace used in the production of Metal Matrix Composites (MMCs). Quality may refer to many attributes of a product, predominantly originating from the customer requirements. Among the several techniques available for understanding and ranking the customer requirements, Quality Function Deployment (QFD) is perhaps the most popular.

Although several engineering design textbooks deal with the product design process, they do not clearly point out how to use the information developed in the QFD in developing the concepts for the design. The proposed methodology provides a clear link between QFD and concept generation, at the same time ensuring that most important customer requirements are addressed and a quality product is developed.

Index Terms – Design Process, QFD, Metal Matrix Composites, Squeeze Casting

1. INTRODUCTION

Design for X is a terminology associated with product design process where X represents a performance measure of the design. In this paper, the issue being addressed is Design for Quality. Quality may refer to many attributes of a product, predominantly originating from the customer requirements. Among the several techniques available for understanding and ranking or prioritizing the customer requirements, Quality Function Deployment (QFD) is perhaps the most popular and the most commonly used by majority of the companies. In this paper, the QFD technique is applied systematically in achieving the goal of the design.

Several well written engineering design textbooks [1-5] deal with the product design process. QFD or House of Quality is the common methodology adopted for generating the design specifications for the product being developed [1,2,5]. Enormous amount of time and effort is spent in collecting information for the QFD. The QFD clearly shows the customer requirements and its associated engineering characteristics for which target values are set and later used in evaluating the performance of the product. Moreover, when used for redesign of existing products, the QFD clearly reveals the avenues for improving the existing design. It is essential to optimally use information from the QFD to properly initiate the concept generation process so as to meet the customer requirements consistently. This vital link between QFD and concept generation appears to be missing in published literature. Concept generation is based on functional decomposition, and the transition from QFD to this stage is not evident. The methodology proposed in this paper addresses the problem in the context of the traditional QFD, and this strategy has been applied in the redesign of a squeeze casting attachment for a stir casting furnace although the design process in general is the main focus of this paper.

The squeeze casting technology can simply be described as a combination of permanent mold casting and forging in a single operation. Figure 1 below illustrates the squeeze casting process schematically [6]. Molten metal is poured into the bottom die and the upper die is lowered and pressure is applied. The pressure is continuously applied to the molten metal until it has solidified and forms the required component shape. The upper die is then withdrawn and the component is ejected. The squeeze casting technology has several advantages such as low shrinkage, low gas porosity, enhanced mechanical properties because of fine grain structure caused by the rapid solidification and good surface quality. However, it also suffers from disadvantages such as high cost due to complex tooling and the process needs to be accurately controlled thus slowing the production time resulting in increased process costs [7]. Considering the disadvantages, the proposed design aims at developing a simple design that could be easily controlled.

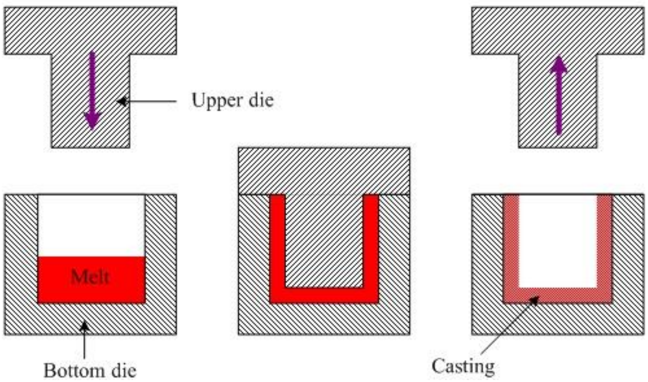


Figure 1. Schematic of the squeeze casting process

Ghomashchi and Vikhrov [8] have reviewed the squeeze casting process in all its aspects: its origins and developments; the processes and equipment involved, microstructure and mechanical properties of the products; the mechanics of the different squeeze casting processes and finally the advantages and disadvantages of squeeze casting process. They concluded that a large number of publications on the squeeze casting process indicate that it is still being developed.

Vijian and Arunachalam [9] have developed a simple setup using a hydraulic press. In their work, they attempted to analyze the process parameters of squeeze casting, while preparing solid and hollow components and investigated the mechanical properties and microstructure. The investigation clearly revealed that squeeze casting is very effective method and the component exhibited remarkable grain refinement and substantial improvement in mechanical properties.

Bo Lin et al., [10] compared the microstructures and mechanical properties of heat-treated Al–5.0Cu–0.6Mn–xFe alloys prepared by gravity die casting and squeeze casting. The major conclusion from their study was that squeeze cast alloys with different Fe contents have superior mechanical properties compared to the gravity die cast alloys and this is mainly attributed to the reduction of porosity and the refinement the microstructure.

From the above literatures, it is quite obvious that not much has been reported on the design of the squeeze casting setup itself and most literatures focus on the process parameters and their effect on the properties. Hence in this paper, the design aspect of the squeeze casting setup is discussed specifically the development of the concept since the objective of this paper is the design process.

Figure 2 shows the QFD developed for the redesign of a squeeze casting attachment. Prior to developing this QFD, physical and functional decomposition of setups described in available literature was carried out, followed by identifying the customer requirements. A customer survey form was prepared and used to collect information from customers, design team members, and marketing team members. Values obtained through these surveys are shown as customer importance, customer satisfaction, design team, and marketing team in the QFD. The last column of the QFD shows the relative weight (incorporating response from all the four surveys) that can be used to identify the most important customer requirements. This information provides the missing link to the concept generation phase. Redesign can of course not be attempted for improvement of all customer requirements listed in the QFD. The highest 4 relative weight values (highlighted in yellow colour) translate into the most important functions for which redesign should be attempted. Thus the proposed methodology provides a clear link between QFD and concept generation, at the same time ensuring that most important customer requirements are addressed and a quality product is developed.

2. CONCEPT GENERATION AND EVALUATION

It is very important to find as many concepts as possible in order to fulfill the most important customer requirement identified in the QFD. The four most important customer requirements identified from the QFD are:

- Easy to Clean.
- Casting Multi-shapes.
- Safe to use.
- Casting Variety of Materials.

The customer requirements could be considered as the major sub functions that need to be fulfilled in order to satisfy those selected customer requirements. These major sub functions would be further decomposed if possible. As mentioned earlier, it would be time consuming if all the customer requirements are considered in the concept generation and so some of the design to fulfill other sub functions would be retained in the proposed concepts. The flow diagram shown in Figure 3 illustrates the functional decomposition for the selected customer requirements.

	Casing temperature	Die Melting Point	Pressure	Geometry - Complicated Shapes	Material Strength	No. of cleaning steps	No. of Die Shapes	No. of Steps to Operate/Assemble	Surface Roughness	Temperature	Die Tolerance Limit	Volume	Weight of die	Customer importance	Customer Satisfaction(Competition)	Planned (Design Team)	Improvement Ratio	Sales / Marketing Team	Improvement Weight	Relative Weight
Functional & Physical Performance:																				
Easy to operate								5						4.33	4	4.67	1.17	4	20.22	0.09
Setup accuracy											5			4	3.667	4.67	1.27	3.67	18.67	0.08
Accurate & precise applied force			5											4	3	3.67	1.22	3	14.67	0.06
Good casting surface finish									5					3.67	2	2.67	1.33	3.67	17.93	0.08
Easy to clean						5								4	3.333	4.67	1.4	4.67	26.13	0.11
Reliability, Ergonomics & Manufacturing:																				
Safe to use	5													4.33	4.333	5	1.15	4	20	0.09
Easy to attach/remove die								5					4	3.33	3.333	4.33	1.3	4.33	18.78	0.08
Easy to manufacture				5	4								3	3.33	2.667	4	1.5	2.67	13.33	0.06
New Features:																				
Casting variety of materials		5												4.33	3	4.33	1.44	4	25.04	0.11
Casting multi-shapes							5							4.67	4.333	5	1.15	4.33	23.33	0.1
Sensing the casting & die temp.										5				3.67	2.667	4.33	1.62	2.67	15.89	0.07
Sensing the amount of molten metal												5		3.67	3.333	4.33	1.3	3.33	15.89	0.07
Absolute importance	0.435	0.544	0.3188	0.28986	0.23188	0.568	0.507	0.848	0.39	0.34541	0.406	0.345	0.5005	5.73					230	1
Relative importance	0.076	0.095	0.0556	0.05059	0.04047	0.099	0.089	0.148	0.068	0.06028	0.071	0.06	0.0873	1						
Current Product	40-50	1500	30-300	-	140-300	5	1	3	2.0-5.0	150-300	0.35	30.4	60-70		1 : Low Importance					
Target Value	30°	1700	400	No	350	4	3	3	4.0-6.0	145-250	0.35	30.4	60-50		3: Med-Importance					
Improvement direction (↑, ↓)	↓	↑	↑	-	↑	↓	↑	↓	↑	↓	↓	↑	↓		5: High Importance					
Units	°C	°C	N/m^2	Yes/No	MPa	#	#	#	µm	°C	mm	cm^3	Kg							

Figure 2. QFD for squeeze casting attachment

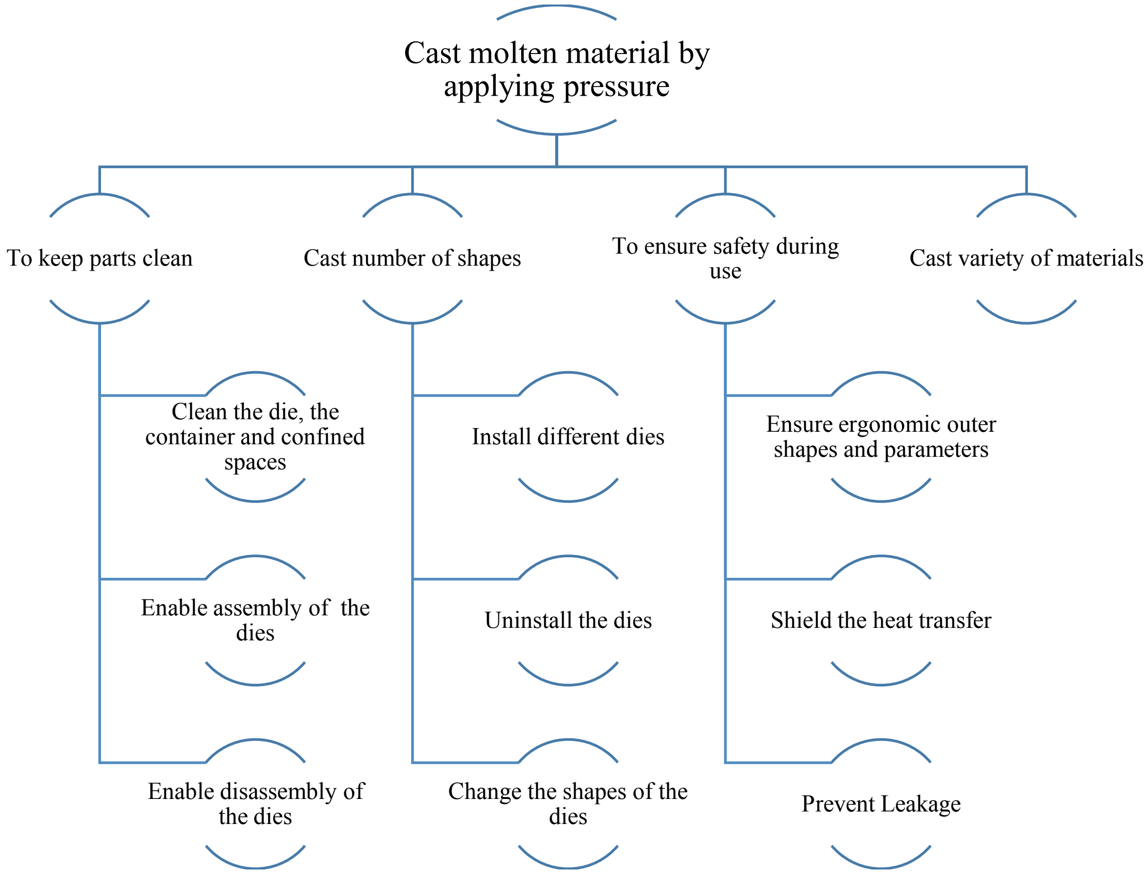
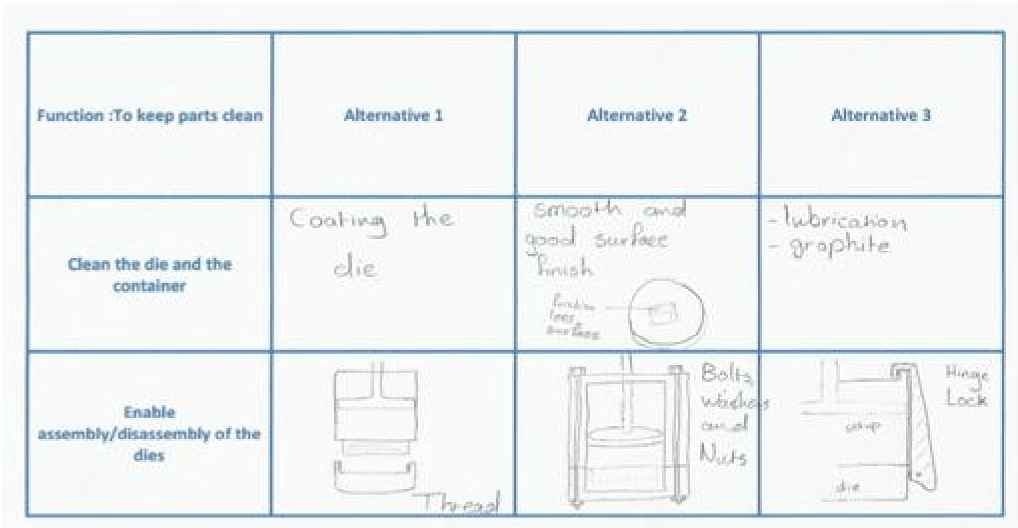


Figure 3. Functional decomposition for the selected customer requirements

Using the morphological method, three concepts would be generated. Each concept will have its own advantages and disadvantages. In the first step, many concepts would be generated that can fulfill each sub-function identified in the decomposition. The second step is to combine these individual concepts into overall concepts that meet all the functional requirements. The morphological chart for the first major sub-functions is shown in figure 4 as an illustrative sample and the same procedure is applied for the rest of the major sub-functions.



Function :To keep parts clean	Alternative 1	Alternative 2	Alternative 3
Clean the die and the container	Coating the die	Smooth and good surface finish	- lubrication - graphite
Enable assembly/disassembly of the dies	Thread	Bolts washers and Nuts	Hinge Lock

Figure 4. Morphological Chart for the sub-function: Easy to Clean

In the second step, the generated ideas for all the major sub-functions are combined. Although this may end up in almost infinite number of concepts, by applying the go, no go screening and technology readiness measures as discussed by Ullman [1], the possible concepts have been reduced to three. Figures 5, 6 & 7 illustrate the free hand sketches of those three concepts.

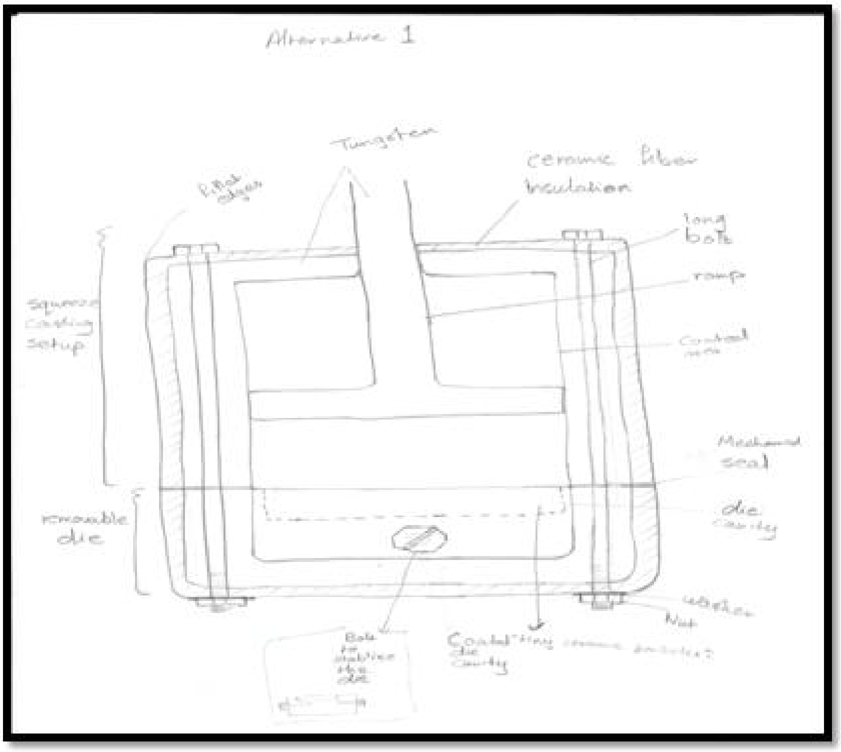


Figure 25. Free hand sketch of Concept 1

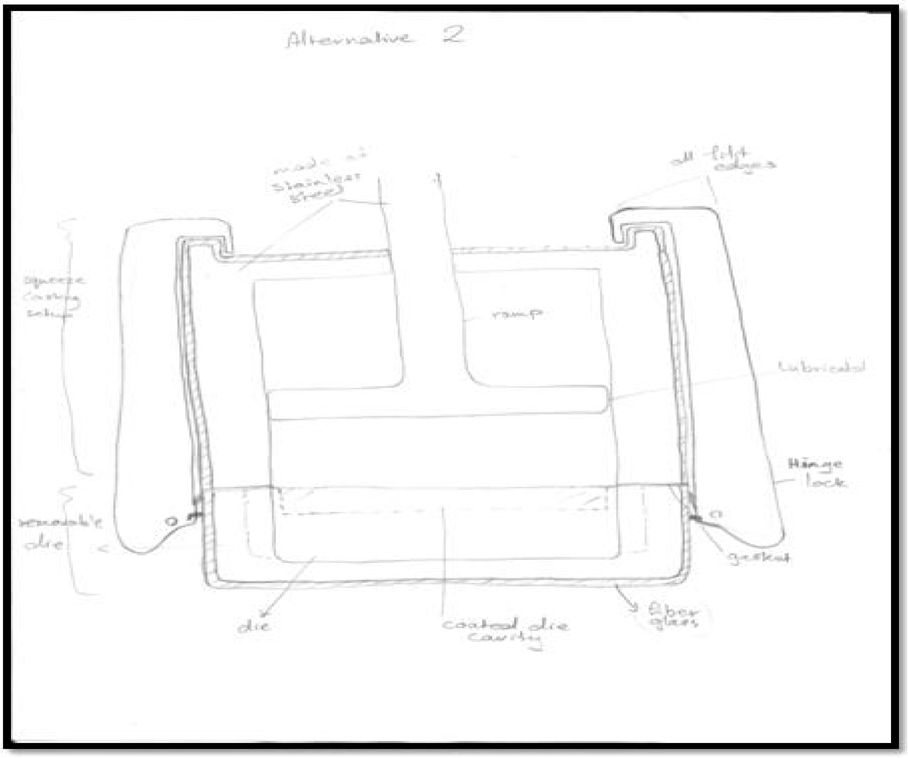


Figure 26. Free hand sketch of Concept 2

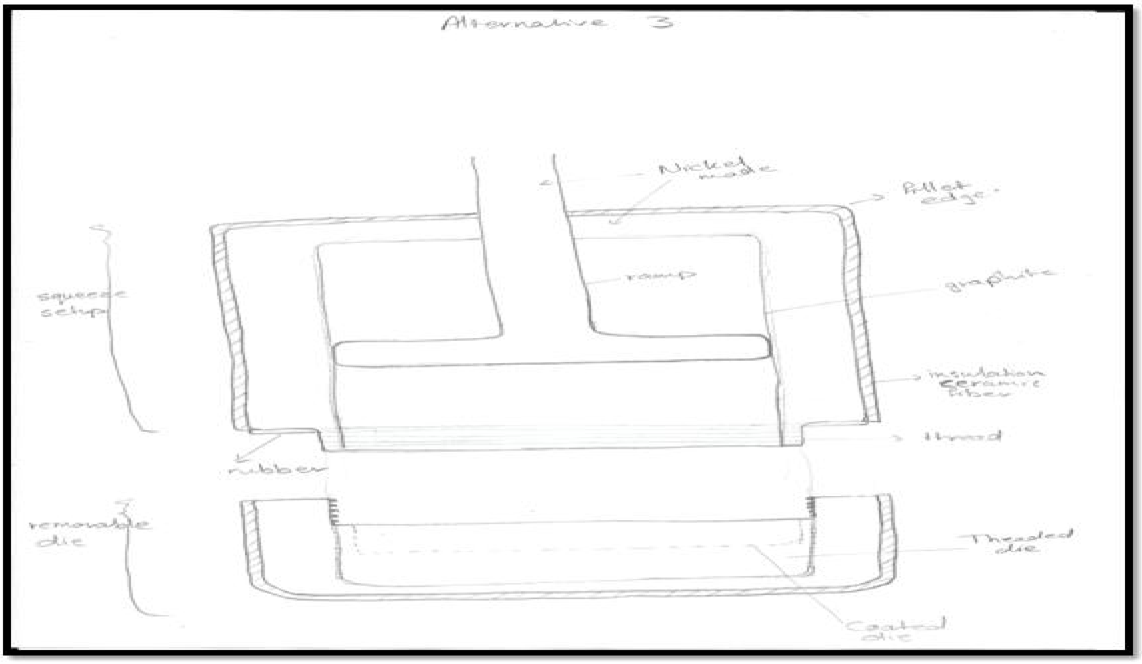


Figure 27. Free hand sketch of Concept 3

A basic decision matrix has been utilized to select the best concept from the three generated and is illustrated in Table 1 below. The setup reported by Vijian and Arunachalam [9] is used as the datum. Based on this method, concept 2 is chosen to be the best concept among the three since it has a weighted total of 0.86.

Table 1. Basic decision matrix used for selection of the concept

			Alternatives			
Criteria		**Importance**	**Concept 1**	**Concept 2**	**Concept 3**	
1	**Easy to operate**	0.1	+	+	**S**	Datu
2	**Setup accuracy**	0.08	**S**	+	**S**	
3	**Accurate & precise applied force**	0.07	+	+	+	
4	**Good casting surface finish**	0.08	+	**S**	+	
5	**Easy to clean**	0.11	-	+	+	
6	**Safe to use**	0.1	**S**	+	-	
7	**Easy to attach/remove die**	0.08	-	+	+	
8	**Easy to manufacture**	0.05	+	+	+	
9	**Casting variety of materials**	0.1	**S**	+	+	
10	**Casting multi-shapes**	0.11	+	+	+	
11	**Sensing the casting & die temp.**	0.06	**S**	+	**S**	
12	**Sensing the amount of molten metal**	0.07	+	**S**	**S**	
Total +			**5**	**10**	**7**	
Total -			**2**	**0**	**1**	
Over All Total			**3**	**10**	**6**	
Weighted Total			**0.74**	**0.86**	**0.39**	

3. PRODUCT DESIGN

The selected concept was developed into a detail product and the product design is illustrated by the exploded view shown in Figure 8. Since the focus of this paper is on developing the concept, the detail design is not discussed here.

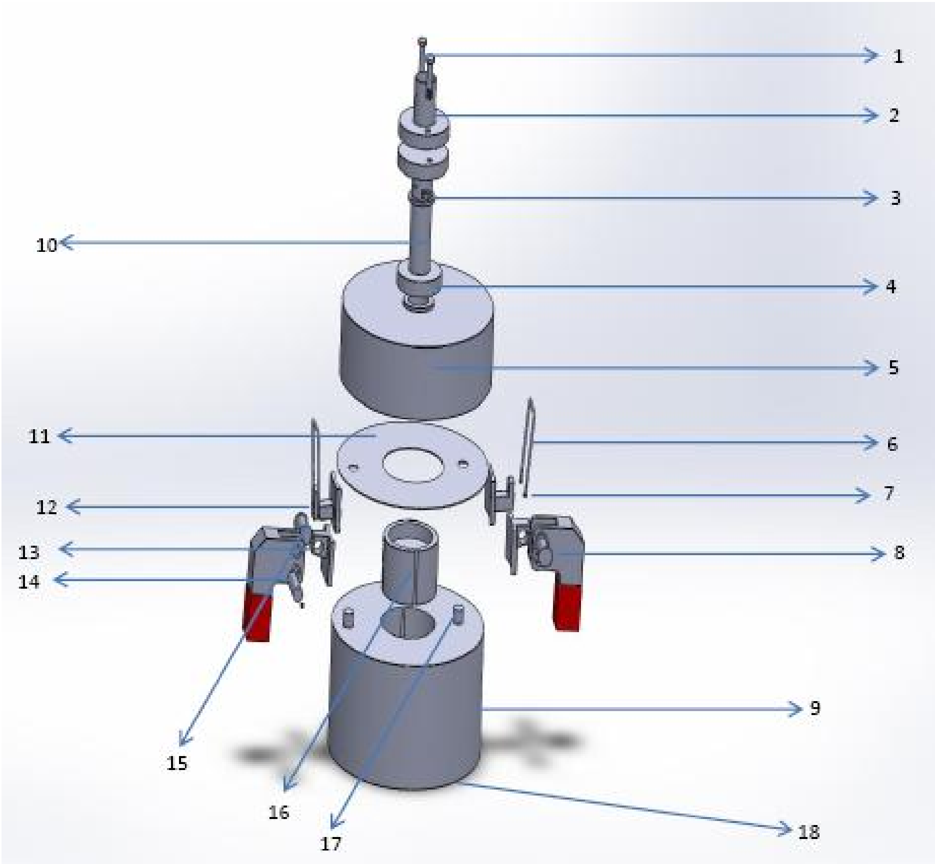


Figure 38. Exploded view of the developed design

Part #	Part Name	Part #	Part Name
1	Bolt	10	Ram
2	Tensile machine attachment	11	Gasket
3	Vents	12	Clamp lever hook
4	Ram Stopper	13	Handle base
5	Upper Die	14	Clamp lever shaft
6	U-Shape bolt	15	Clamp lever pin
7	Nut	16	Die
8	Clamp lever handle	17	Pins for alignment
9	Lower Casing	18	Ceramic Fiber Insulation

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4. CONCLUSIONS

With the present global competition it is vital that product design engineers adopt a scientific process while developing new and innovative products or even when improving an existing design. The design process has been applied to the redesign of a squeeze casting attachment used in a stir casting furnace that is used for the production of MMCs. This has resulted in a new concept that could be further refined to be developed into an innovative product. The design process focused on how to transfer the important customer requirements identified in the QFD and incorporate it when generating the concepts. This has been demonstrated through the example of developing a concept for a squeeze casting attachment through which the link between the QFD and concept generation has been clearly established.

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