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Experimental analysis on Generic principles for developing Robust Designs against Casting Defects

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Abstract: ***The world is running around invention and advancements in the existing products or components, and this wasn't be easy without design concepts and its principles. This paper is conferring on this facet, how the design can be made robust against manufacturing flaws by varying the parameters such as material properties, dimensions, shapes etc. If a design engineer compels a mistake while designing a product, results in the following aspects: confidence, business, customers, sales, servicers, repute etc. If we modify the design, and make it robust, some or all of these losses will be recouped., It is not an easy task to discuss all manufacturing capabilities in one go , to have a lucidity in the concept the flaws of manufacturing during casting were focused in this paper. Based on the theoretical study and experiment analysis conducted on a casting "+" model the results are outlined. Based on the output, a list of generic design principles was defined, which can be considered by a design engineer during casting design process. The paper starts with a brief introduction to robust design, followed by a literature review, then design solutions, computer simulation analysis of a casting component (using Solid Works) and finally the conclusions made from the results.***

Keywords: ***casting defects, Design considerations, Generic Principles, improper design, Manufacturing defects, reliability, Robust design***.

I. INTRODUCTION

Defects during manufacturing are common in day to day life. They are categorized into two types: 1. Defects due to improper manufacturing 2. Defects due to improper design (which includes material properties, environmental conditions, limitations etc). ". Before discussion about the basic concepts of robust design and casting defects, let me brief the evolution of robust design.

[1] During the late 50's, Ina Tile Company was struggling to produce high quality tiles, i.e. the company was facing problems of large variations in the dimension of tiles. The company decided to screen the output, which was an expensive solution, therefore they assigned some designers to work out the cause of the problem. The team showed that the outer tiles change temperature more when compared to the centre tiles. The team concluded that the problem occurs due to non-uniformity of temperature distribution and that it would cost approximately half a million dollars to redesign the kiln, which was too expensive. In searching for a lower cost solution, engineers came up with an idea of robust design and they followed the basic principles of Taguchi and concluded that, if the lime content of the clay was increased from 1 to 5 percent, they would greatly decrease the variation of tile dimensions by increasing the content of a cheap ingredient.[2,18]The basic principle of robust design is to increase the quality of a product by minimizing the consequence of the cause variation without removing the cause. This can be done by optimizing the product and process to make the performance minimally sensitive to the various causes of variation. [3].

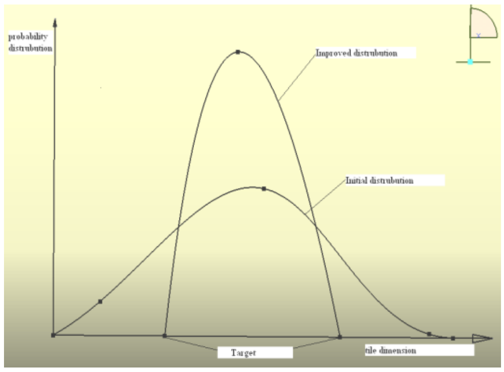

Figure 1.comparison of tile dimension distribution between robust design and non-robust design

The above figure: 1 illustrates the distribution of tile dimension vs. probability distribution, the initial distribution without robust design is not sufficiently reliable, whereas in the case of the improved distribution the probability distribution of tiles is within target.

[4,19] In the 1980s, many U.S manufacturing companies lost their market shares and regained them later, which caused the business to fluctuate. The companies realised that they were losing most shares to international competitors and that the best way to regain market shares was product quality.

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Many experts pointed out that the this focus on quality would enable them to remain competitive in the future, as would increasing the usage of statistical methods such as control charts, histograms and pareto diagrams. Similarly, the off-line quality controls that have been used by Japan recently have been recognized by American Industries to develop quality, which led to U.S Industries beginning to follow the concepts of Genichi Taguchi.

[5] The window photolithography application was the first application in the United States to demonstrate the power of Taguchi's approach to quality and cost improvement through robust process design. Photolithography is a wafer fabrication process. It can be divided into six steps: cleaning, photolithography, etching, implantation, diffusion and metrology. The benefits of the application were:

- 4-fold reduction in process variance
- 3-fold reduction in fatal defects
- 2-fold reduction in processing time
- Easy transition of design from research to manufacturing

Easy adaptation of the process to finer-line technology. Some examples of robust design are as follows:

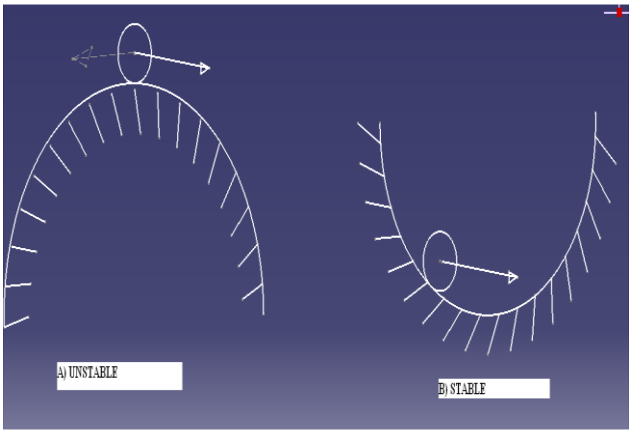

Figure 2 .Comparison between a non-robust design and robust design

The above figure 2 is an example for robust design. The semi-circle arc with the ball on the curve is not stable, moment in the ball leads to failure of the system (i.e.., the ball will not be on the curve), to make it robust the semi-circle is rotated to 90^0 by doing so the ball will remain within the region and is stable.

1.1. Example of robust design (Heat exchanger) comparison

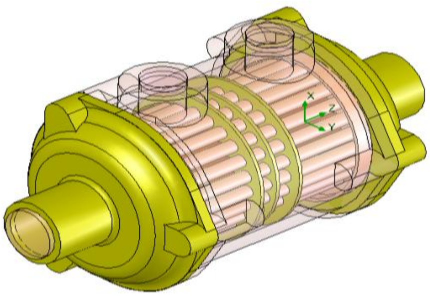

Figure 3 Bowman Heat exchanger (straight tubes)

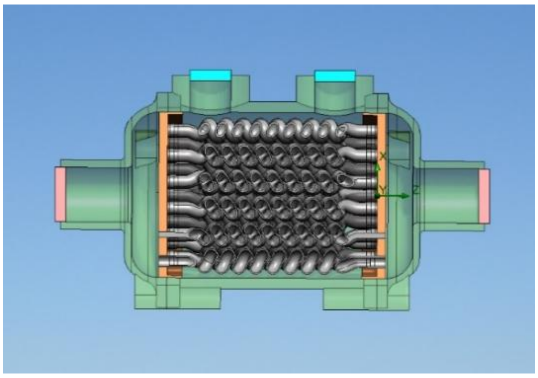

Figure.4 sectional view of helical heat exchanger

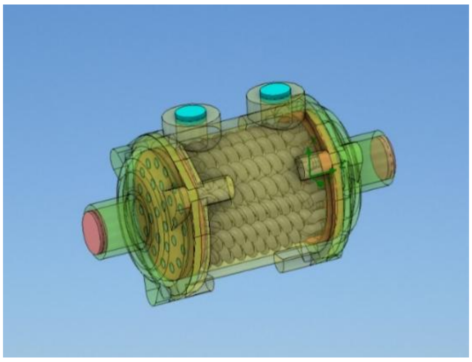

Figure 5 Helical Heat exchanger

The above diagrams figure 3,4 and figure 5 are the heat exchangers with different shapes of pipes inside. The main aspect is to optimise these heat exchangers with efficiency (efficiency = output / input). The Bowman Heat exchanger is a common example, which has straight parallel tubes arranged in a circular manner as shown in the figure 3. Though the efficiency achieved by this is very low, the maintenance cost is low when compared with other heat exchangers. [6] In order to overcome the lower efficiency, the tubes are redesigned helically instead of straight. Which can be shown in the figures 4& 5, though this design does increase the operating cost but high in efficiency.

II. OBJECTIVES:

- ➢ Finding the defects during casting process (which can be modified by proper design) and their impact of the defect on the performance of the component.
- ➢ Develop a design solution avoiding or mitigating the negative effect.
- ➢ Linking the generous design principles and methods for making the product

III. LITERATURE REVIEW

A considerable amount of literature has been published on robust design against manufacturing defects. The first serious discussions and analyses of robust design emerged during the period of 1940. During the past 60 years, more information has become available on

Product design and how to achieve robust design [7,20]. In recent years there has been an increasing amount of literature on the design for manufacturing and quality control etc., which is quite related to robust design.[8]

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The key research question of this concept is how best to increase the reliability of a component even after its failure by proper design.

The Robustness is an important property of components and systems. Robust design means an insensitive design to variations of the manufacturing quality, drifts in the parameter values, operating and maintenance conditions, environmental loads and deterioration with age [9]. Due to design modification, the material or product increases its reliability.

After World War 2, Japan started recovering but unfortunately failed to produce good quality materials and highly skilled engineers. During that period, Dr.Genichi Taguchi, who was an in-charge of developing telecommunication products at ECL (Electrical communications Laboratories), laid the foundation stone for robust design and validated some basic principles that helped to increase the life of products. He gave the definition for robust product design as "Reducing variation in a product without eliminating the causes of variation (or) making the product or process insensitive to variation." He was awarded individual Deming Award in 1962 for his work on robust design.

[11,23] Robust design plays a major role in all fields like Electrical, Mechanical, Electronics, Automotive products etc. The causes for variations are classified into three types.

a) Internal variation
b) External variation
c) Unit to Unit variation

[12] An updated version of Taguchi Proposals and there are also many additional articles published after this. He updated his work by concentrating on statistical methods which helps to achieve robust design. [13,21] Park gave an overview to different methods that help to achieve robust design but until now there have been few authors who concentrated on the principles of robust design. Taguchi's methods came into the picture after publishing his ideas in 1979.

Taguchi's ideas are summarized and made more widely understood by Hunter and Kacker .[14] In the period of 1890-1990, there are some discussions related to statistical methods suggested by Taguchi. Taguchi states that "Quality engineering is not intended to reduce the source of variation in products directly". Instead one needs to make the systems of products or production processes less sensitive to sources of uncontrollable noise or outside influences through parameter design.

IV. CASTING

Casting is a manufacturing process in which metal is melted to high temperatures and poured into a mould cavity. In order to minimize cost of the operation in the designing of casting several principles were established. The guidelines for the operation during the life of casting should include finishing and economical serving. The product design in casting process can be categorised as follows:

- Design for economical moulding
- Design for elimination of defects
- Design for features to aid handling of casting

4.1. Design for Casting

The fundamentals for a good sand casting apply to the production of investment casting. For a good casting we must consider three most important elements. They are

1. Minimize nonfunctional mass.
2. Provide uniform wall sections.
3. Provide a suitable gating system to ensure complete filling of the mould cavity.

4.2. Robust Design For Casting Process:

Based on the severity some of the solutions to the flaws in manufacturing resulting from improper design will now be discussed in detail [15]. The following are the steps for robust design of casting:

1. Design the chunk so that shape is cast easily 2. Select appropriate casting process 3.locate the parting line4. Allow uniform feeding with molten metal by arranging proper gate system 5. Appropriate geometry i.e., runners

4.3. Hot tears:

These are internal or external cracks with ragged edges occurring immediately after the metal has solidified. Hot tears may be produced if the casting is poorly designed and abrupt sectional changes take place, no proper fillets and corner radii are provided, and/or chills are wrongly placed [16,22]. Incorrect pouring temperatures, improper placement of gates and risers and hard ramming can also create hot tears.

Due to poor design there was a tear formation at the top which was shown in the figure 6. A hot tear forms because of excessive residual stress, which can be minimized by proper design shown in figure 6. Instead of having straight alignment, if we align it in a wave the chances are less for a hot tear

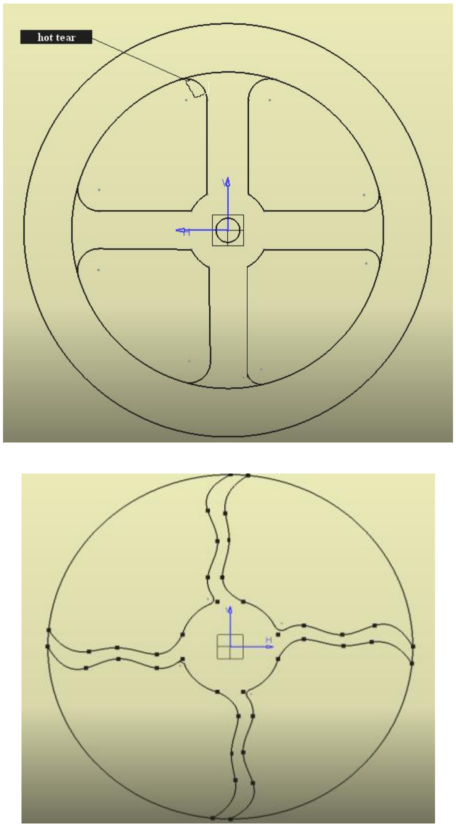

Figure.6. Centripetal casting (Robust design and non-robust design)

[17,23] Based on the principles discussed in the literature review, the concept has been applied for above and below models.

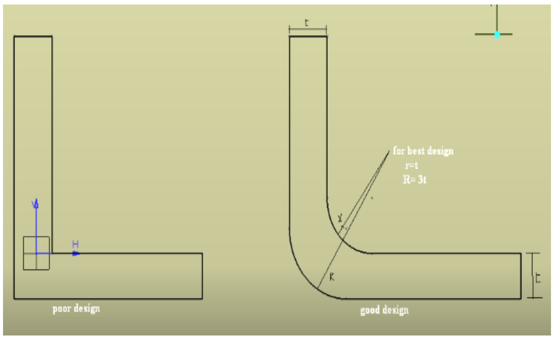

Figure 7 L-shape design

The above figure 7 shows how a non-robust design which can be modified to robust design, by removing sharp edges and by remaking them as fillets. The best design corresponds to r=t and R=3t where t is the width of the material.

Castings which are done in the form of "+" shapes often fail due to sharp corners near to the centre, the material may fail after loading, which leads to reduction in the lifespan of the product. This can be minimised in two ways:

[18] Two of the arms should be offset considerably as shown in the figure 8 below.

If the design doesn't permit offset arms, then the possibility is to place a hole at the centre and making the sharp corners into fillets. Making these changes in the design will increase the life span of the product

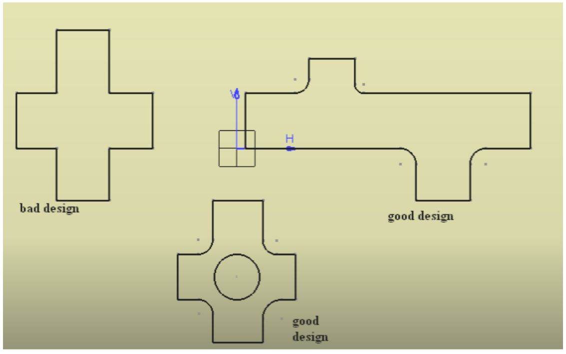

Figure 8"+ Design Modification "Analysing the "+" casting with robust design concept

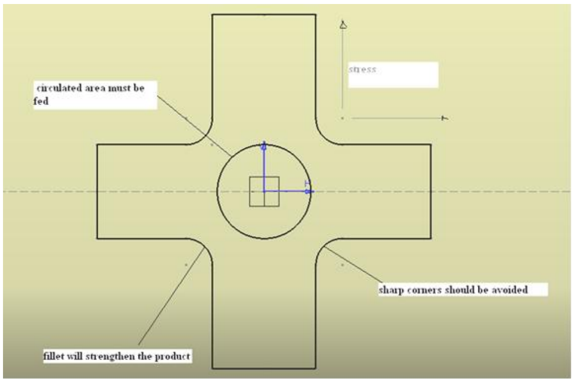

Figure 9"+ Design Modification (robust design) "

The above figure 9 depicts the design modification for '+' casting. The modifications are avoiding sharp corners and making them as fillets. Fillets help to strengthen the product. Also, providing a hole at the centre, helps to avoid stress concentration there. The analysis of this particular component was done in 'Solid Works' and discussed below.

V. METHODOLOGY

The software used in this project are Solid works and, Catia .Let's consider a casting component which was shaped in the form of '+' (consider material is grey cast iron). The dimensions of the product are shown in the figure 10

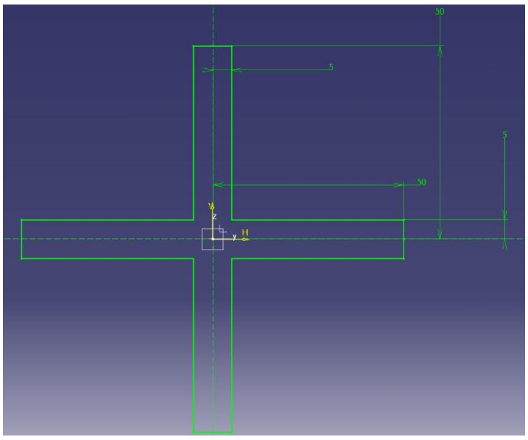

Figure 10 Dimensions of the '+' design (sharp edges)

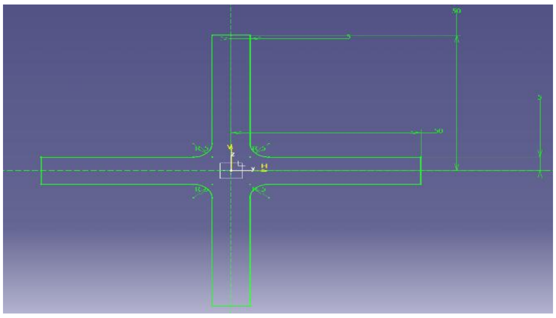

Figure 11'+' design with fillets

Figure 10, 11,12 gives complete idea of component in terms of dimensions and modification.

5.1. Boundary conditions:

- Fixed at one end (left side) of the bar
- Pulled in all the other directions by applying a load of 500 lb.
- The material used here is grey cast iron. All units are in mm.

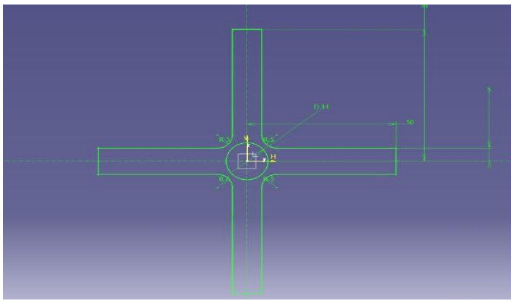

Figure 12 Achieving robust design by providing hole at the centre

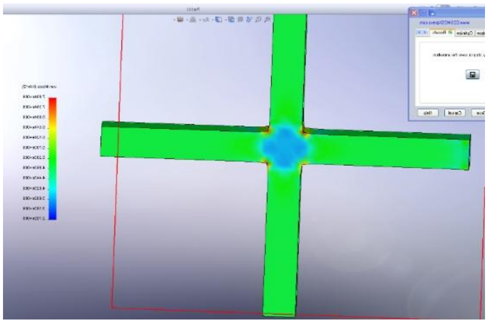

Figure 13 stress distribution (sharp corners)

It is evident that due to sharp corners, high stresses are developed at corners, which can be seen in Figure 13.

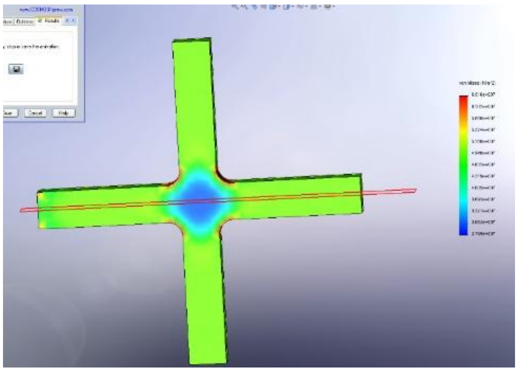

Figure 14 stress Analysis (fillets)

By modifying sharp corners with fillets edges, we can spot that the stress concentration is equally distributed in the corners which can be depicted in figure 14.

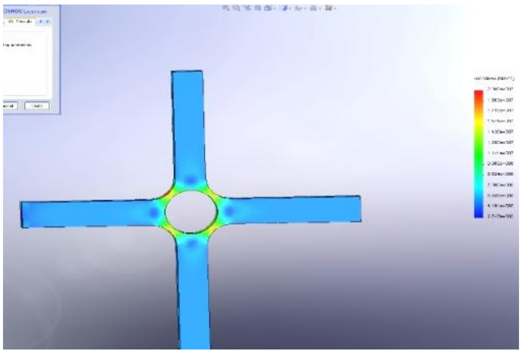

Figure 15 stress analysis with hole along with fillets (Robust design)

The previous two designs (sharp corners versus fillet corners refer figure 13 & 14) have great stress at the corners, as indicated in red. In figure 15 it is evident that the stress concentration is completely minimized by placing a hole in centre. The minimal stress concentration area means the life of component is longer.

VI. GENERIC DESIGN PRINCIPLES FOR ROBUST CASTING

- Section thickness should be uniform and, if variations are necessary, they should be gradual.
- By minimizing the non-functional mass, material can be saved.
- In order to keep maximum strength and stiffness, it is better to avoid sharp corners and keep holes near to ends.
- In order to distribute load uniformly, always keep ribs in compression and plates in tension.
- Extra cores should be placed in thickest sections to reduce the cross-sections.
- In the case of an L or a V section, radii at junctions should be provided so as to make the section thinner than principal width at the junction.
- Sharp corners and abrupt section changes at adjoining sections should be eliminated by employing fillets and blending radii.
- Smoothly tapered sections should be used to eliminate high stress concentrations.

VII. CONCLUSION

A generic database has been compiled with generic principles for robust design against casting. analysis on '+' design was conducted as covered in 'Methodology'. Solid Works was chosen as the analytical tool due to familiarity as well as its ample capability. The part was designed in Catia v5 then imported to Solid Works for analysis. The component was first constrained by specifying necessary data (like load, dimensions and other geometric parameters), then fixed at one end so that it could pulled in all other directions, and the load chosen as 500lb.
The analysis was done on three cases: sharp corners, fillets and fillets with a hole. In the case of sharp corners, high stresses developed at corners, which can be seen in red(figure 13) It was then shown that this can be avoided by using fillets instead of sharp corners (figure 14)and further improved by placing hole at the centre(figure 15). Out of these three fillets with hole is the robust design because of its equal distribution in load and less stress levels.

The following rules will promote directional solidification and reduce shrinkage stresses and distortion:
• Casting walls should preferably be of uniform thickness.
• Casting elements cooling under conditions of reduced heat removal (internal walls) should have smaller cross sections to accelerate their solidification.
• Transition between casting walls of different thickness should be smooth.
• Casting walls should have no abrupt changes but be connected by smooth transitions.
• Local metal accumulation and massive elements should be avoided if possible.
• Sections where casting walls join massive elements should be gradually thickened towards the latter or reinforced with ribs.

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