Analysis and Evaluation of Different Heat Treatment Fixture Designs Inspired from 3D Infill Patterns

P Sasikiran and J Nagarjun

Abstract The heat treatment fixture is a work holding device used to secure the workpiece during heat treatment. Those fixtures fail prematurely due to high thermal and fatigue loads. Thus, alternative fixture design is required in order to improve the life of the fixture. In this paper, the alternative designs that are analysed are inspired from 3D infill patterns. The infill patterns considered and evaluated for the fixture design are honeycomb structure, diamond structure and concentric circular structure. The patterns are modelled with the help of solid works with constant mass and diameter. It is further analysed with coupled thermal structural analysis, factor of safety and fatigue life with the help of ANSYS workbench 18.0 and the best-suited design for the fixture is evaluated.

Keywords Heat treatment fixture · 3D printing patterns · Coupled thermal structural analysis · Factor of safety · Fatigue life · Solid works
ANSYS

1 Introduction

Heat treatment is a discipline of materials and measurement which deals with the change in physical properties of materials when heated above the re-crystallization temperature [1]. The paper deals with the heat treatment fixture made of steel 1010 which supports the suspended grey cast iron jobs subjected to normalizing. A heat treatment fixture is a work holding device used to securely locate and support the position of a workpiece during the heat treatment process. The fixture analysed in this paper is used specifically for normalizing heat treatment process. Normalizing

P. Sasikiran (✉) · J. Nagarjun
Department of Mechanical Engineer, PSG Institute of Technology and Applied Research, Coimbatore, India
e-mail: umasasikiran@psgitech.ac.in

J. Nagarjun
e-mail: nagarjun@psgitech.ac.in

K. S. Vijay Sekar et al. (eds.), *Advances in Manufacturing Processes*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-13-1724-8_38

is one of the predominant heat treatment processes used to decrease the internal stresses and refine the grain structure which increases the ductility and toughness. The temperature commonly used for normalizing is around 1173 K since the recrystallization temperature is above 1073 K. Grey cast iron is one of the important materials used in automobiles and aerospace industries for its low cost and easy manufacturability [2]. The heat treatment fixture, when analysed the working stress, is lesser than the yield strength, and the failure takes place due to fatigue. Fatigue is weakening of the material when it is subjected to repeated loads. Fatigue strength of an object decreases due to grain size, geometry and type of loading [3–6]. Thus, the heat treatment fixtures are replaced frequently which leads to high production cost. Hence, there is a need for finding alternative design which will perform for longer duration. This paper will focus on the alternative design analysis and evaluation which are inspired from the infill patterns of 3D printing [7, 8]. The major constraint of design deals with the dimensions of the pit furnace and weight of the fixture. The alternative designs are designed with equal mass and same fixture diameter. The designs are analysed using finite element analysis (FEA) because it is difficult to use sensors in this kind of application where the temperature can reach as high as 1200 K [9, 10]. The paper initially analyses fatigue life of the current working model (circular design) using FEA, and then it compares with the actual average life of the heat treatment fixture. Then if the accuracy of the FEA is satisfactory, then it is further used for analysing the 3D infill patterns. This paper compares three different standard 3D infill patterns based on its von Mises stress, deformation, factor of safety and fatigue life [11]. Weifang Chen analysed the fixture layout design to optimize the deformation due to clamping force. But analysing heat treatment fixture is uncommon, and further, there is no research on design of heat treatment fixture that is influenced by 3D infill pattern and analysis of the same. Hence, this paper focuses on design and analysis of heat treatment fixture inspired from 3D infill patterns in order to obtain higher life.

2 Design Methodology

The height and diameter of the furnace are 1800 and 700 mm, respectively. The fixture is to be placed in the bath of height 1400 mm and the diameter 650 mm, respectively. The minimum clearance to be maintained between the bath and outer diameter of the fixture is 60 mm. Figure 4a shows that the workpiece in the fixture is suspended away from the central axis of support, and this makes the fixture to act like a cantilever. The loading material for heat treatment is initially moulded with the help of shell moulding, and these parts are tied up in mild steel wires and then hung on the fixture. The fixture designs were modelled using solid works, and it was further imported, meshed and analysed in ANSYS. The concentric circular fixture was meshed into 196,082 elements which were shown in Fig. 1a. And each fixture has 24 points in order to suspend workpieces, and each point is subjected to a load of 70 N which has been shown in Fig. 1b.

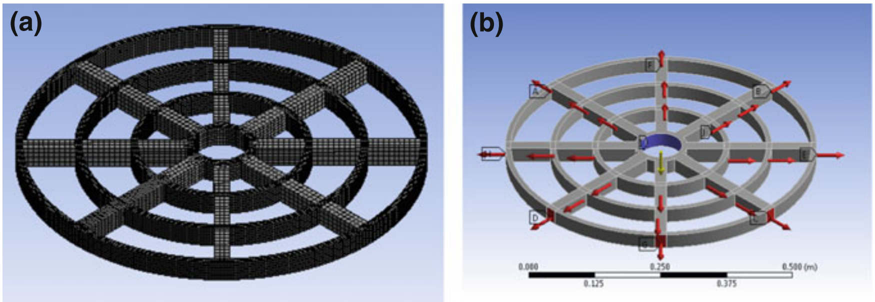


Fig. 1 **a** Meshed concentric circular pattern, **b** forces acting on the fixture

(a) Circular fixture with suspended grey cast iron rocker arm

(b) Circular fixture just after Heat-treatment

Fig. 2 Fixture at work in Indo Shell Cast Company

This heat treatment process is carried out in a pit furnace, where the cast iron is heated to 1173 K. Figure 2b shows the fixture and workpiece at red-hot condition during the heat treatment process. Then the fixture containing the cast iron products is taken out and hung on a rotating shaft which has a prime mover whose rated rpm is 400 rpm. The cooling method used here is blast hair cooling with the help of fans. The fixture is used for heating and cooling alternatively; hence, it is subjected to fatigue. During the process, the fixture is made to rotate at the speed of 400 rpm along with the suspended workpieces due to which the centrifugal force acts on the fixture. The thermal load along with static structural load is also applied, and analysis is carried out for the fixture. It is carried out using ANSYS software which is widely used finite element analysis (FEA) software package. The FEA is a kind of numerical method for solving complex problems of engineering with complicated geometries, different loadings and various material properties where analytical solutions are very difficult to obtain. Thus, the ANSYS is used for the finding the minimum number of revolution that could be attained by the fixture which is 278,220 cycles. The average life of the existing fixture as per the company records is 247,500 cycles. And it is found that the difference between the actual value and ANSYS analysed value is 30,720 cycles which is equal to 12.41%. Thus, the computation method is found effective in the analysis of the fixture.

3 Results and Discussion

3.1 Coupled Thermal Structural Analysis

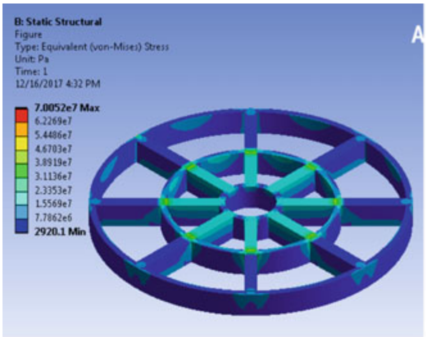
The existing model fails in shorter duration due to adverse working conditions. In order to increase the life of the fixture, different designs of the fixture are considered. The alternative designs are based upon the patterns of 3D printing. The patterns are analysed for its strength, deformation, factor of safety and fatigue life.

3.2 Equivalent Stress Analysis

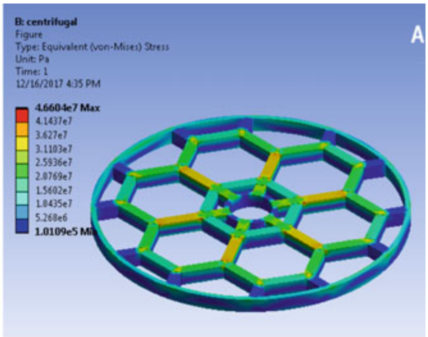
The fixture subjected to heat treatment is affected by both thermal and static stress. A design may commonly fail at the critical position where it is subjugated to maximum stress. Figure 3 shows the difference between the total stress that acting on concentric circle pattern is 26.8% lesser than diamond pattern and 17.23% lesser than honeycomb pattern.

3.3 Deformation Analysis

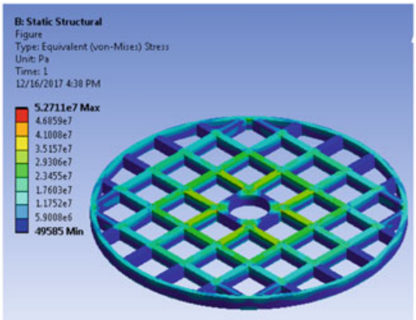
Figure 4 indicates the amount of deformation experienced by the different patterns. Since the bending strength of the design is indirectly proportional to the bending strength of the material, the result indicates that circular pattern experiences the lesser deformation in comparison with the honeycomb and diamond pattern considered.



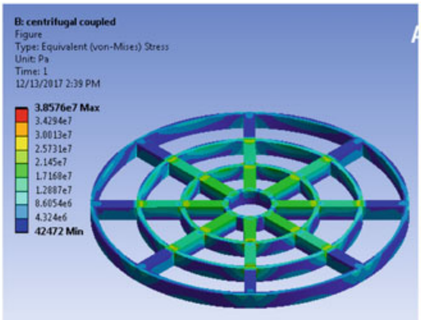
(a) Circular



(b) Honeycomb



(c) Diamond



(d) Concentric

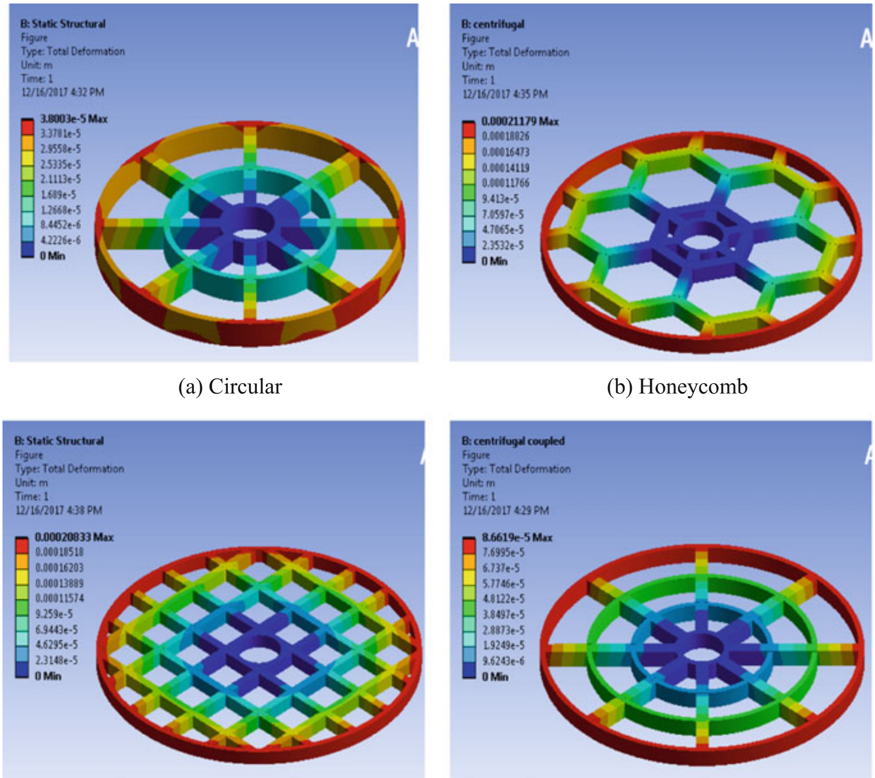
Fig. 3 Equivalent von Mises stress for various designs

3.4 Safety Factor Evaluation

Safety factor is the ratio between yield strength and the maximum stress acting over the material. Hence, it can be used to evaluate the reliability of the design. From Fig. 5, it is further evidence that the circular design is more safe, the safety factor of 7.90 which is 81% more safe compared to the existing design, and also 21 and 37% more safe than honeycomb and diamond, respectively.

3.5 Fatigue Life Analysis

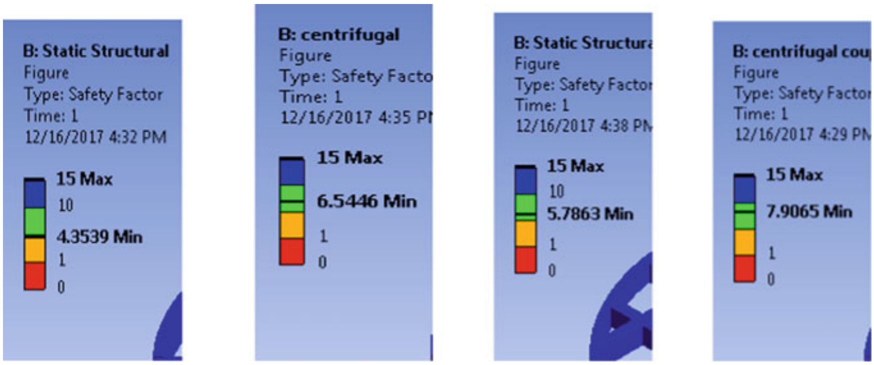
The fatigue life will indicate number of revolutions the fixture will able to withstand before the evidence of first crack or failure. There are a few assumptions to be made before doing the analysis in ANSYS software. The assumptions made are: (i) the surface of the fixtures are finely machined and (ii) the load acting on the fixture is purely axial in nature. As the heat treatment temperature will be as high as 1200 K, here the working temperature is considered the maximum, and reliability factor was



(a) Circular (b) Honeycomb

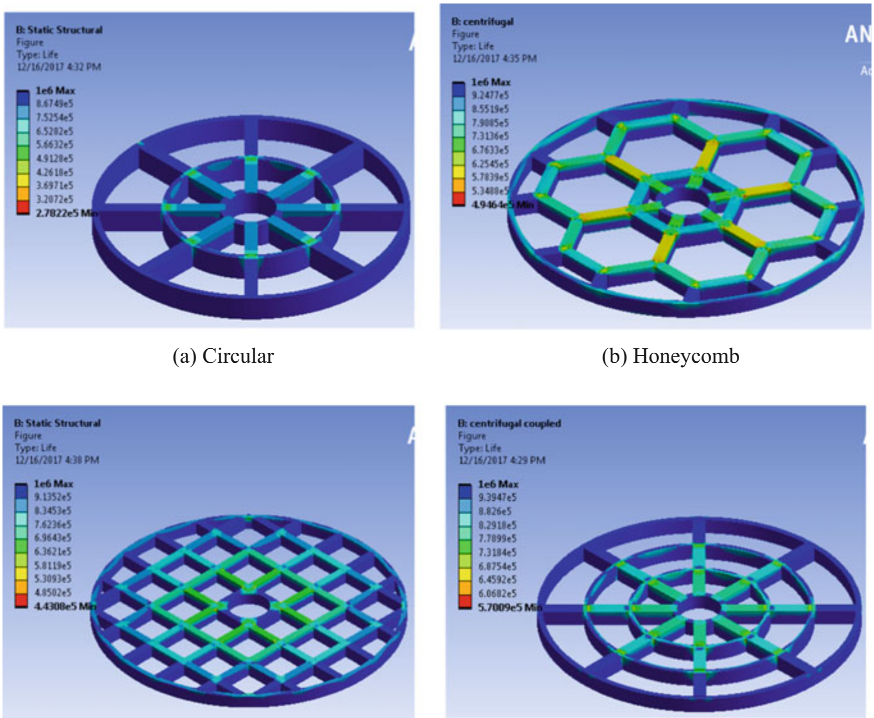
(c) Diamond (d) Concentric

Fig. 4 Deformation of different designs



(a) Existing Design (b) Honey comb (c) Diamond (d) Circular

Fig. 5 Safety factor evaluated for various designs



(a) Circular (b) Honeycomb

(c) Diamond (d) Concentric

Fig. 6 Fatigue life analysis of different designs

chosen as 90%. Based on the equation below, various modification factors were considered and the final fatigue limit was found to be 3.4 MPa. Figure 6 indicates the fatigue life of various designs, it infers the current design will have the minimum revolution of 2,78,220 cycles, whereas the honeycomb and diamond design fixtures have the predicted life of 4,94,640 and 4,43,080 cycles, respectively. The circular pattern when analysed showed the maximum predicted life of 5,70,090 cycles which is 104% more than the current design being used.

$$S_e = k_a k_b k_c k_d k_e k_f S'_e.$$

k_b represents the size modification factor,
k_c represents the load modification factor,
k_d represents the temperature modification factor,
k_e represents the reliability factor,
k_f represents any other miscellaneous effects,
S'_e is the endurance limit,
S_e is the fatigue limit.

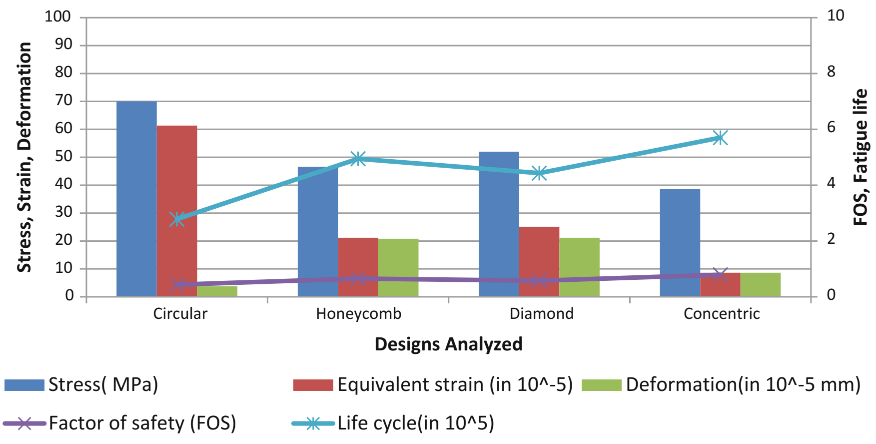


Fig. 7 Consolidated results of various analyses

4 Conclusion

The results of the analysis are consolidated in the graph as shown in Fig. 7. From the graphs, it is evident that the stress, strain and deformation are less for concentric circular design fixture in comparison to other considered designs for the heat treatment fixture. The results are further justified by the safety factor and fatigue life evaluation which also inferred that concentric circular design is the most safest and reliable structure. The research can be further extended by analysing other types of 3D infill patterns such as Archimedean chords, Cast fill, Moroccan star patterns, etc., in finding the robust design for the heat treatment fixture.

Acknowledgements The authors are grateful to Indo Shell Cast for their support towards the completion of the research in finding robust design for the heat treatment fixture.

References

1. Moonesan, M., Honarbakhsh, A., Madah, F., Habibollah, A.: Effect of alloying elements on thermal shock resistance of gray cast iron. J. Alloys Compd. **520**, 226–231 (2012)
2. Thornton, R., Slatter, T., Jones, A.H., Lewis, R.: The effects of cryogenic processing on the wear resistance of grey cast iron brake discs. Wear **271**, 2386–2395 (2011)
3. Park, B.H.: Bogie frame design in consideration of fatigue strength and weight reduction. J. Rail Rapid Transit **220**(3), 201–206 (2006)
4. Fouvry, S., Kapsa, P., Vincent, L.: A multiaxial fatigue analysis of fretting contact taking into account the size effect. Fretting fatigue: current technology and practices, ASTM STP 1367, PA, pp. 167–182 (2000)
5. Araújo, J.A., Nowell, D.: The effect of rapidly varying contact stress fields on fretting fatigue. Int. J. Fatigue **24**, 763–775 (2002)

6. Araújo, J.A., Nowell, D., Vivacqua, R.C.: The use of multiaxial fatigue models to predict fretting fatigue life of components subjected to different contact stress fields. Fatigue Fract. Eng. Mater. Struct. **27**, 967–978 (2004)
7. Meisel, N, Williams, C.: An investigation of key design for additive manufacturing constraints in multimaterial three-dimensional printing. J. Mech. Des. **137**(11), 111406 (2015)
8. Gopsill, J.A., Shindler, J., Hicks, B.J.: Using finite element analysis to influence the infill design of fused deposition modelled parts, Progress in Additive Manufacturing, Springer International Publishing, pp. 2363–9512 (2017)
9. Yoon, Y.-J., Moon, S.K., Hwang, J.: 3D printing as an efficient way for comparative study of biomimetic structures—trabecular bone and honeycomb. J. Mech. Sci. Technol. **28**(11), 4635–4640 (2015)
10. Mosekilde, L., Ebbesen, E.N., Tornvig, L., Thomsen, J.S.: Trabecular bone structure and strength—remodeling and repair. J. Musculoskelet. Neuronal Interact. **1**(1), 25–30 (2000)
11. Neelakandan, V., Kumar, B., Ganesan, T., Rao, P.C.: Analysis and design optimization for improved fatigue life of one-way clutch drive used in starter motor. In: Seetharamu, S., Rao, K., Khare, R. (eds.) Proceedings of Fatigue, Durability and Fracture Mechanics. Lecture Notes in Mechanical Engineering. Springer, Singapore, 978-981-10-6001-4 (2018)