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Multi Objective Optimization of Lifting Hook Strength for Hitachi Sumitomo Systems Using Cross Sectional Variations

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Abstract

Material handling equipment refers to a broad category of mechanical systems used for the movement, storage, regulation, and safeguarding of materials and products throughout different stages such as manufacturing, distribution, usage, and disposal. These systems form an integral part of industrial operations by facilitating efficient handling processes. Typically, material handling equipment can be grouped into four primary classifications: storage and handling devices, engineered systems, industrial transport vehicles, and bulk material handling systems. Each category serves a specific purpose, contributing to the overall efficiency of material flow within an operation. In this study, the focus is on the design and analysis of a crane hook intended for use in bulk material handling applications. The proposed hook is designed to carry loads up to 63,000 kg and is associated with an open winch drum system. The geometric modelling of the hook is developed using CATIA software, which allows precise control over design parameters. Further improvements are achieved through optimization techniques, where modifications in geometry as well as material selection are explored to enhance performance characteristics. To validate the structural integrity of the design, various analyses are carried out using ANSYS software. These include static analysis to evaluate stress and deformation behaviour, modal analysis to study vibration characteristics, and harmonic analysis to assess response under dynamic loading conditions. The results obtained from these simulations help in verifying the strength of the hook and determining the suitability of the selected materials for sustained operation under heavy loading conditions.

Keywords: Multi objective optimization, Chrome moly Alloy Steel 4340 Material, harmonic analysis, geometry optimization, Composite material, Al 7075 + 7.5%SiC

INTRODUCTION

A Crane hooks are components which are always subjected to failure due to accumulation of large amount of stresses which can eventually lead to its failure. Crane hooks are generally used to lift the heavy load in industries and constructional sites. A crane is a machine, equipped with a hoist, wire ropes or chains and sheaves used to lift and move heavy material. Cranes are mostly employed in transport, construction and manufacturing industry. Overhead crane, mobile crane, tower crane, telescopic crane, gantry crane, deck crane, loader crane, jib crane, are some of the commonly used cranes [1].

LITEREATURE REVIEW

Ms. Mamta .R. Zade *et.al* She designed the hook by analytical method and analysis was done for the different Cross sections by applying same load on

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crane hook like rectangular and trapezoidal [2]. Out those two area Trapezoidal area is selected for further static structural analysis with different materials. Because it gives better results in comparison with other one as because stresses induced are less in trapezoidal cross section. After the analytical method of design and the modelling of crane hook is done in modelling software. The modelling is done using the design calculation from previous work the analysis of hook is done in the FEA software. The aim of the research was the selection the best material from aluminum alloy, structural steel, wrought iron for crane hook from analysis result and fatigue analysis The results of stress analysis calculated from FEA analysis for different material such as Structural Steel, Wrought iron, Aluminum Alloy. For the different Material, it was observed that keeping the tone are same with different Material topology we will get different results, but it is found that the Structural Steel and Wrought Iron gives minimum stress. Further Fatigue analysis was done on the materials by that it was found that wrought iron can withstand the maximum number of fatigue cycles before failure. Hence we can use wrought iron materials for crane hook [3-5].

ANALYSIS OF ORIGINAL MODEL USING CARBON STEEL 1018 MATERIAL

Meshed file

The Figure 1 illustrates the computational grid overlaid on the hook's surface. While performing the meshing in analysis here a relatively fine mesh has been utilized to capture the intricate curvature of the hook’s saddle and shank. The mesh appears uniform, which helps in preventing numerical instabilities during the solving phase [6].

Node Count (175,422): Nodes are the specific coordinate points where the software calculates primary variables like displacement and temperature. Having over 175,000 nodes suggests a high degree of freedom, allowing for a very detailed mapping of the hook's physical response under load.

(a)

Statistics	
Nodes	175422
Elements	101613

(b)

Figure 1. (a) to (b) Details of mesh file from Ansys of original model.

Element Count (101,613): These elements are the individual shapes (likely tetrahedrons or hexahedrons) formed by connecting the nodes. Here we have used hexa mesh for the better quality purpose. A count exceeding 100,000 indicates a refined mesh that balances computational precision with processing time.

The Figure 2 illustrates the **Equivalent Von-Mises Stress** distribution across the Hitachi Sumitomo crane hook after applying a load of **618,030 N**. Utilizing **Carbon Steel 1018** as the primary material, the software generates a color-coded contour map to identify regions of varying mechanical intensity. The chromatic scale on the left indicates that stress levels range from a negligible minimum up to a peak value of **1089.3 MPa**. Most of the hook's body remains in the blue zone, signifying relatively low stress, but specific critical areas show a transition toward lighter blue and green hues, indicating where the internal forces are concentrating due to the massive weight.

A significant observation is the **stress concentration** visible at the inner radius of the hook's curve and near the transition zone below the shank. This high stress intensity likely occurs at sharp geometric transitions or the point of direct contact with the lifting sling [7].

The maximum total deformation obtained from the analysis is around 2.5502 mm, which appears near the hook tip portion represented by the red colored zone. This behavior occurs because the lower open end remains directly exposed to the applied load and lacks sufficient constraint compared with the upper section. The middle region of the hook exhibits moderate deformation values represented through green and yellow shades, indicating gradual structural deflection between the fixed and loaded locations (Figure 3).

The obtained deformation magnitude demonstrates that Carbon Steel 1018 material provides reasonable stiffness under the given loading condition. Even though bending displacement is visible near the hook end, the overall deformation remains within a controlled range for such a high external force. The analysis also indicates that the geometry of the hook distributes the applied load effectively across the curved section, thereby preventing excessive localized displacement at the central body region. The contour outcome further confirms that the hook maintains structural integrity during operation while undergoing elastic deformation due to the heavy lifting load [8].

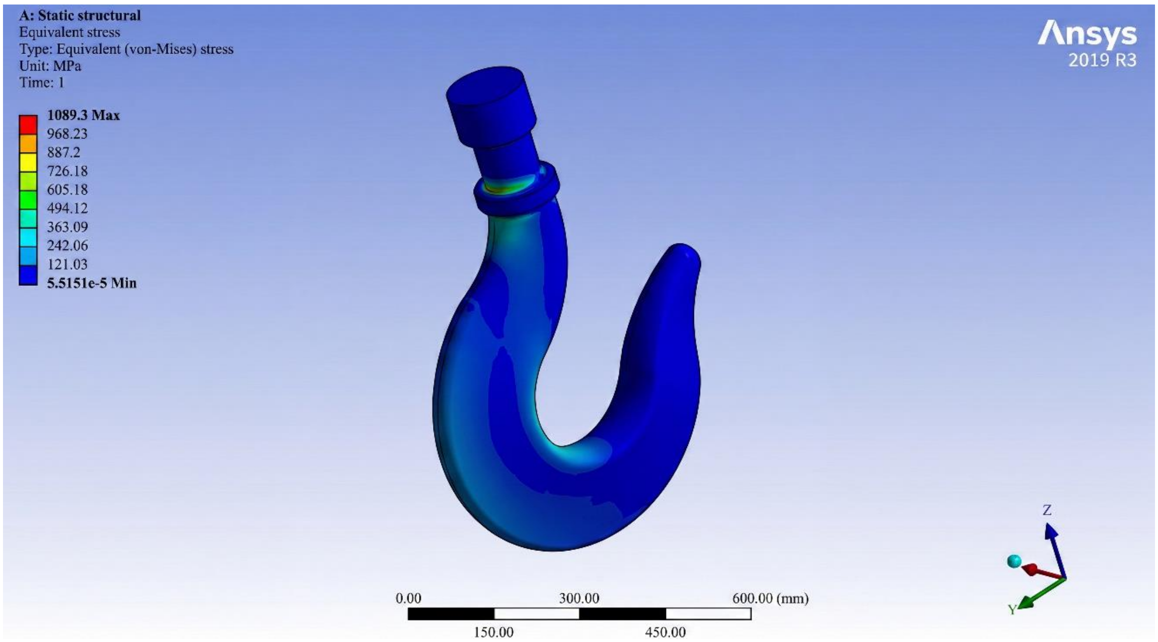


Figure 2. The above fig represents the max stress of original model.

MODAL ANALYSIS RESULTS

From the contour distribution across the four modes, it can be observed that the mounting shank experiences minimal relative motion because that portion is structurally constrained. Due to this fixed support condition, the displacement values near the upper attachment remain consistently low. As vibrational energy transfers through the curved body, the displacement magnitude increases significantly toward the open end. The analysis shows that the hook profile undergoes various bending and twisting motions depending on the specific frequency. These patterns follow the natural harmonic path generated by the geometric stiffness and mass distribution of the 1018 steel material (Figures 4&5).

The maximum relative deformations obtained from these modes vary from 4.7366 mm to 9.157 mm, appearing primarily near the tip or along the outer spine of the hook. This behaviour occurs because the lower section lacks the rigidity of the fixed base, allowing for greater oscillation amplitudes at natural frequencies ranging from 97.495 Hz up to 322.43 Hz. The middle regions exhibit moderate displacement values represented through green and yellow shades, indicating a transition of kinetic energy between the fixed and free ends. The smooth colour gradients across the component body confirm that the vibrational response takes place progressively without sudden mechanical discontinuities [9-11].

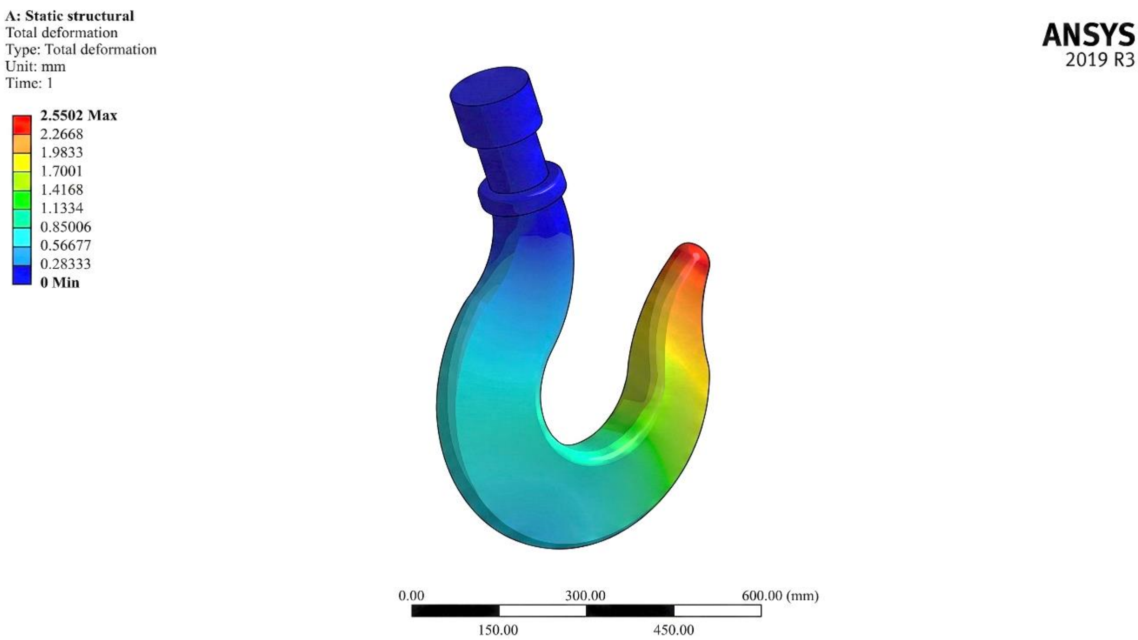
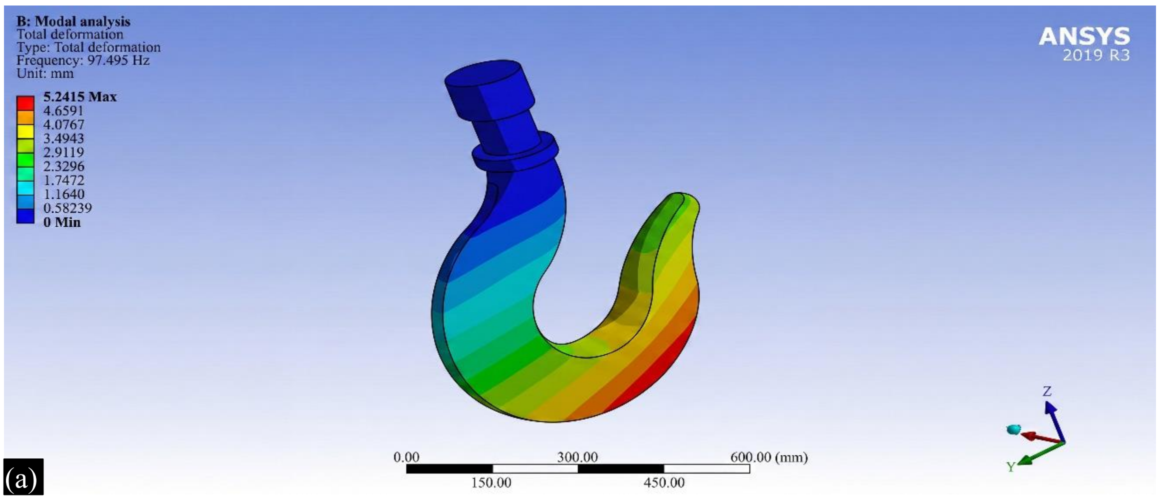


Figure 3. The above fig represents the max deformation of original model.



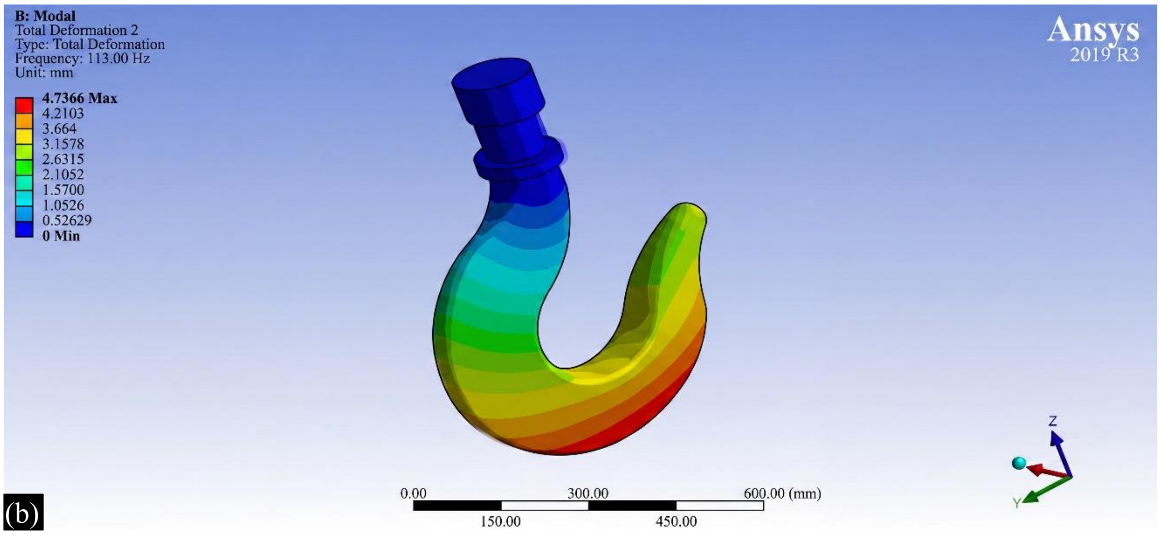


Figure 4. (a) to (b) The above fig represents modal analysis mode – 1&2 of original model.

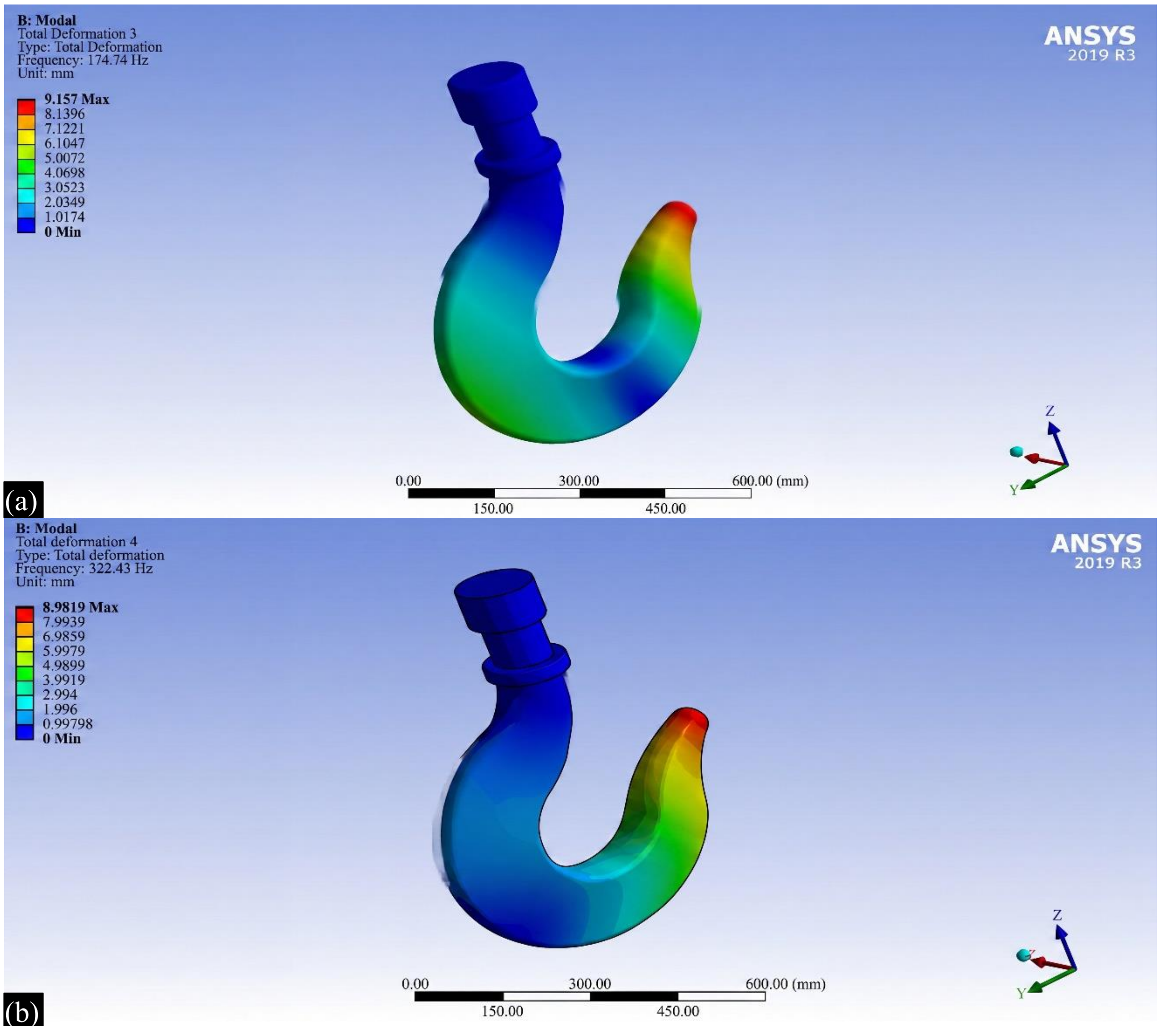


Figure 5. (a) to (b) The above fig represents modal analysis mode – 3&4 of original model.

The obtained frequency values demonstrate that Carbon Steel 1018 provides a specific dynamic signature under the given constraints. Even though significant relative movement is visible in the higher modes, the overall modal response remains within predictable ranges for this industrial geometry. The analysis also indicates that the hook's mass effectively determines these resonance points, which is a critical factor for avoiding catastrophic failure during crane operations. The contour outcome further confirms that the hook maintains its basic shape while responding to internal vibrational excitation caused by the simulated environment.

HARMONIC RESULTS

The maximum frequency response amplitude obtained from the analysis is exactly 8.7749 mm, which occurs at a peak frequency of 322.43 Hz. This peak signifies a resonance condition where the external force frequency matches the natural vibrational mode of the hook tip. According to the phase angle plot, the response remains constant at 180 degrees through most of the range before dropping sharply toward zero at the resonance peak. This sudden phase shift occurs because the structural inertia can no longer keep pace with the rapidly alternating remote force. The numerical table further confirms that the real component of the displacement accounts for the entire amplitude at this critical junction (Figure 6).

The obtained response magnitude demonstrates that Carbon Steel 1018 provides a clear dynamic signature under these specific boundary conditions. Even though the amplitude reaches nearly 8.8 mm at the peak, this information is vital for designing damping mechanisms or modifying the geometry. The analysis also indicates that the hook's cross-sectional design plays a primary role in determining where these peak excitations occur. The graphical outcome further confirms that the hook undergoes significant dynamic stress, emphasizing the importance of your optimization study to shift these resonance points away from common operational frequencies.

The obtained deformation magnitude demonstrates that Carbon Steel 1018 material undergoes significant vibration amplitudes at this specific frequency peak. Even though the displacement is quite large near the hook end, this data is essential for identifying potential resonance risks for such a high external force. The analysis also indicates that the hook geometry distributes the vibrational energy effectively across the curved section, although the tip remains highly sensitive to frequency-based excitation. The contour outcome further confirms that the hook maintains its basic structural form while undergoing cyclic elastic deformation due to the heavy dynamic lifting load [12-14].

ANALYSIS RESULTS OF A CRANE HOOK BY USING CHROMEMOLY ALLOY STEEL 4340 MATERIAL

According to the contour scale, the maximum equivalent stress reaches approximately 1307.2 MPa, while the minimum stress remains nearly zero in regions isolated from direct loading influence. The highest stress region appears around the collar section positioned below the cylindrical mounting stem. This location acts as a geometric transition zone where cross-sectional variation occurs abruptly. During load transfer, the force path experiences directional change at this junction, producing elevated internal resistance (Figure 7).

From a mechanical viewpoint, Chrome–Moly Alloy Steel 4340 contributes significantly to the structural response because of its high strength, toughness, and fatigue resistance characteristics. The material possesses superior hardenability compared with ordinary carbon steel, allowing the crane hook to withstand severe loading environments with reduced risk of sudden deformation. Even though the stress value reaches a high magnitude, the material behaviour remains suitable for heavy-duty lifting systems where large operational forces are encountered repeatedly.

The contour plot further confirms that the upper support section remains structurally stable under the applied constraints. Very low stress values appear around the fixed cylindrical head because displacement in that region remains restricted during simulation. The gradual stress transfer from the constrained zone toward the hook body illustrates efficient force transmission through the component geometry.

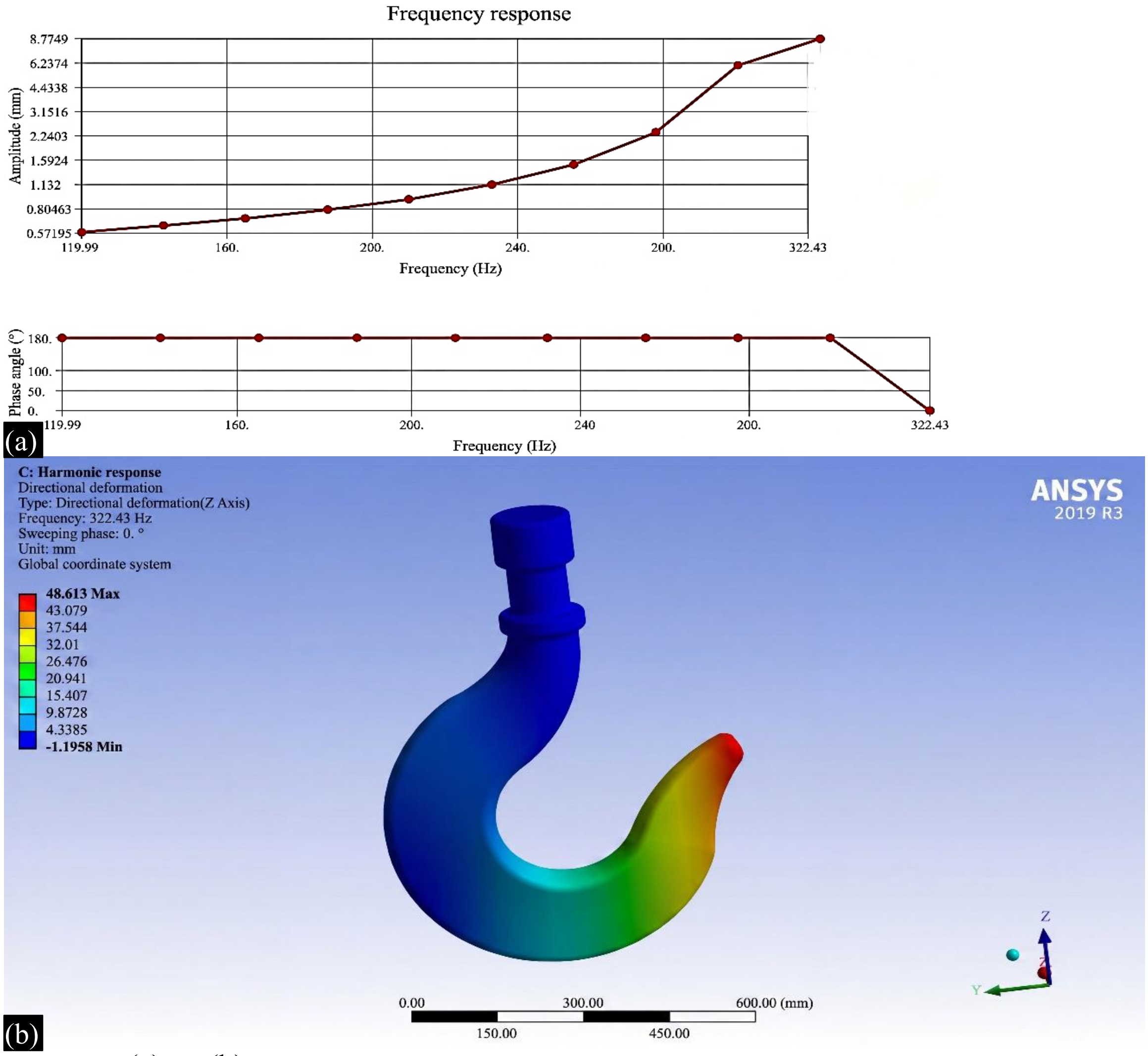


Figure 6. (a) to (b) The fig represents frequency response & max deformation of original model in harmonic response.

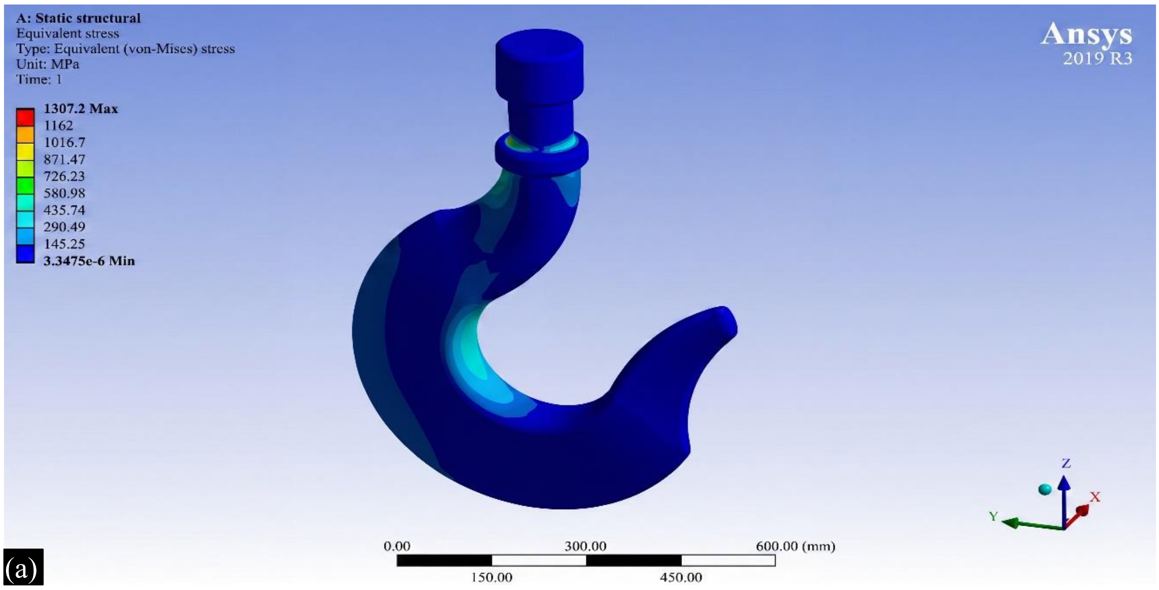


Figure 7. The above fig represents the max stress of modified model – 2.

Overall, the finite element outcome demonstrates that the modified Model–2 crane hook experiences its critical stress concentration primarily near the neck transition and throat curvature under the maximum load of 618030 N. The stress pattern validates the importance of curvature optimization and smooth sectional transitions in crane hook design. The obtained results are useful for evaluating structural safety, fatigue life prediction, and durability assessment in industrial lifting applications involving high-capacity crane systems.

The inner curved section of the hook exhibits moderate deformation because the applied load generates bending moments along the curvature. The deformation pattern confirms that the hook body absorbs the loading effect progressively from the fixed end toward the free end. Even under heavy loading conditions, the deformation distribution remains continuous without irregular concentration over large regions (Figure 8).

The results indicate that Chrome–Moly Alloy Steel 4340 provides sufficient stiffness and load carrying capability for crane hook applications involving high external forces. The limited maximum deformation value suggests that the modified hook configuration maintains dimensional stability during operation. The analysis also identifies the hook tip region as the critical displacement zone, which may be considered for additional geometric strengthening in future design optimization studies.

MODAL ANALYSIS RESULTS

From the contour legend, the maximum directional deformation reaches nearly 39.764 mm, while the minimum value is about −1.0818 mm. The highest deformation is concentrated at the free tip region of the hook, indicated by the red colour zone. This section undergoes larger vibrational displacement because it is positioned farthest from the supported end and receives the maximum dynamic effect generated during harmonic excitation (Figure 9).

HARMONIC RESULTS

The upper shank portion remains dark blue, showing very small displacement near the frictionless support region. As the distance from the support increases, the deformation gradually rises through cyan, green, and yellow shades along the curved profile of the hook. A noticeable deformation concentration appears along the inner curved portion of the hook body. The curved geometry experiences dynamic bending effects under oscillating load conditions, resulting in higher directional displacement around the inner radius. The smooth transition of contour colours indicates stable vibration distribution without abrupt irregularity across the major structural regions (Figures 10 & 11).

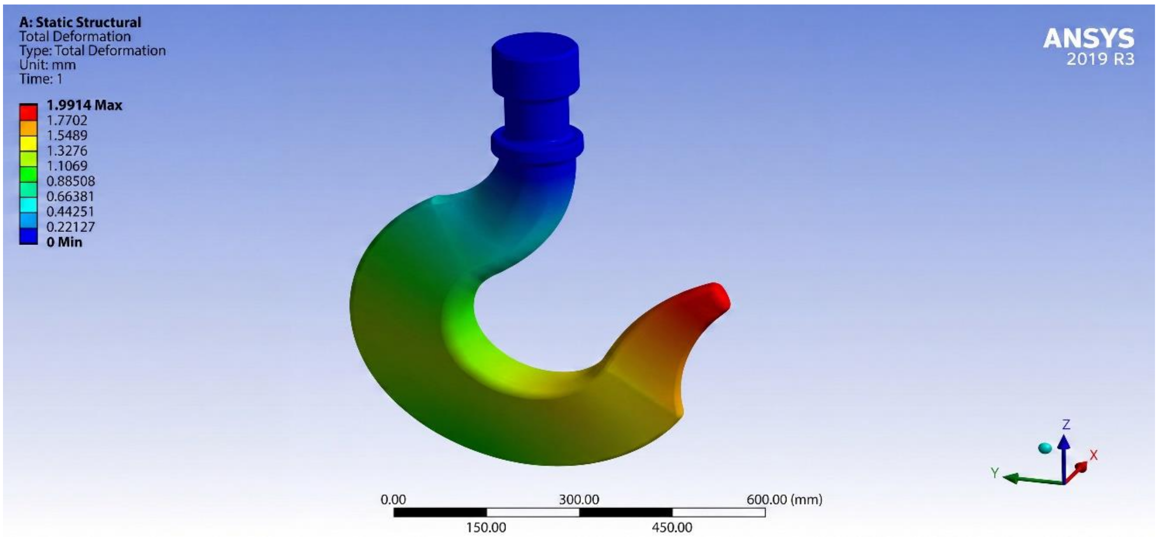


Figure 8. The above fig represents the max deformation of modified model – 2.

The harmonic response results show that Chrome–Moly Alloy Steel 4340 maintains effective structural performance under dynamic loading conditions. Although the free end exhibits larger directional deformation, the remaining portions of the hook maintain comparatively controlled displacement characteristics. The analysis further identifies the hook tip and inner curvature as critical locations where vibration-induced deformation becomes dominant during high-frequency excitation.

The upper Figure 11 illustrates the relationship between excitation frequency and vibration amplitude. The response curve shows that the displacement amplitude increases gradually as the excitation frequency rises from 117.71 Hz to 343.03 Hz. At lower frequencies, the crane hook exhibits comparatively small vibration levels, indicating stable dynamic behaviour. As the excitation frequency increases, the deformation response becomes more significant because the applied harmonic force approaches the natural vibration characteristics of the structure.

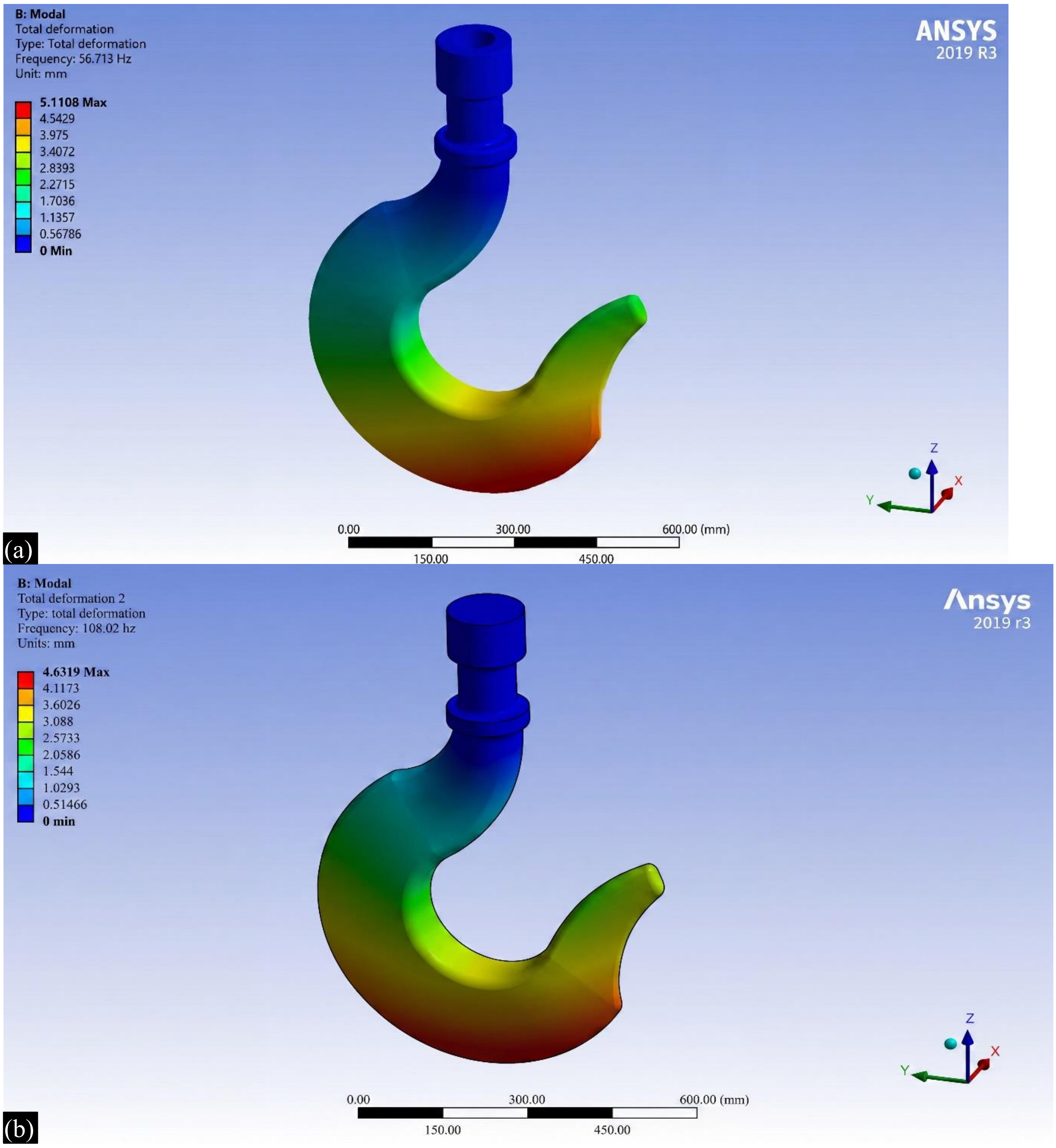


Figure 9. (a) to (b) The above fig represents modal analysis mode – 1&2 of modified model – 2.

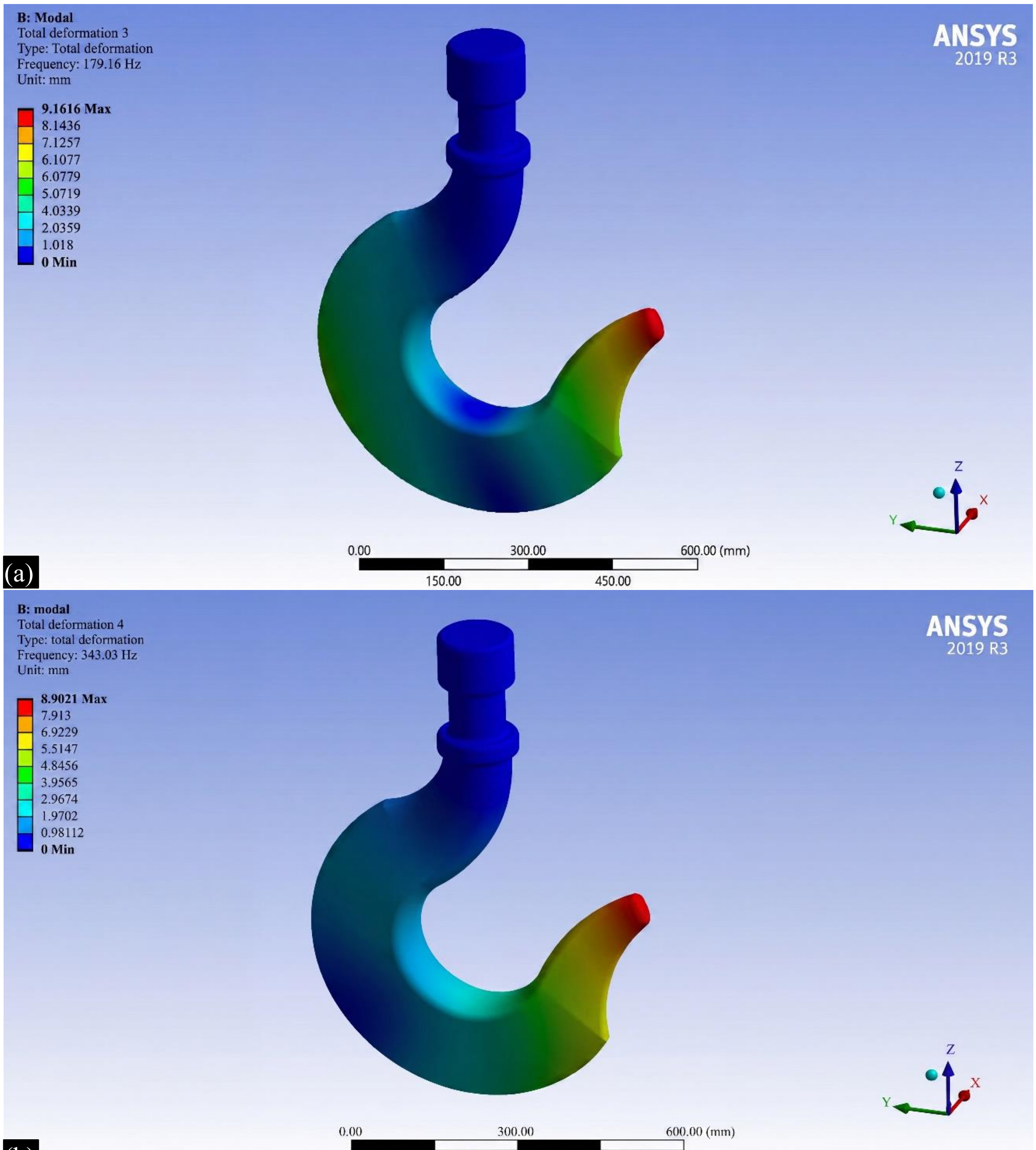


Figure 10. (a) to (b) The above fig represents modal analysis mode – 3&4 of modified model – 2.

The maximum amplitude recorded during the analysis is 12.085 mm at a frequency of 343.03 Hz. A rapid increase in the response curve can be observed near the higher frequency region, indicating resonance-related behaviour. The lower graph represents the variation of phase angle with changing frequency. Throughout most of the investigated frequency range, the phase angle remains approximately 180°, which indicates a stable oscillatory relationship between the applied load and deformation response. Near the critical excitation region, the phase response changes sharply, demonstrating transition behaviour associated with resonance and variation in dynamic stiffness.

The harmonic response data further indicate that the real amplitude reaches 12.085 mm at a phase angle of 0°, while the imaginary component remains 0 mm. This result confirms that the structural response is dominated mainly by the real displacement component, with negligible out-of-phase vibration effects. Such behaviour represents stable harmonic motion during excitation.

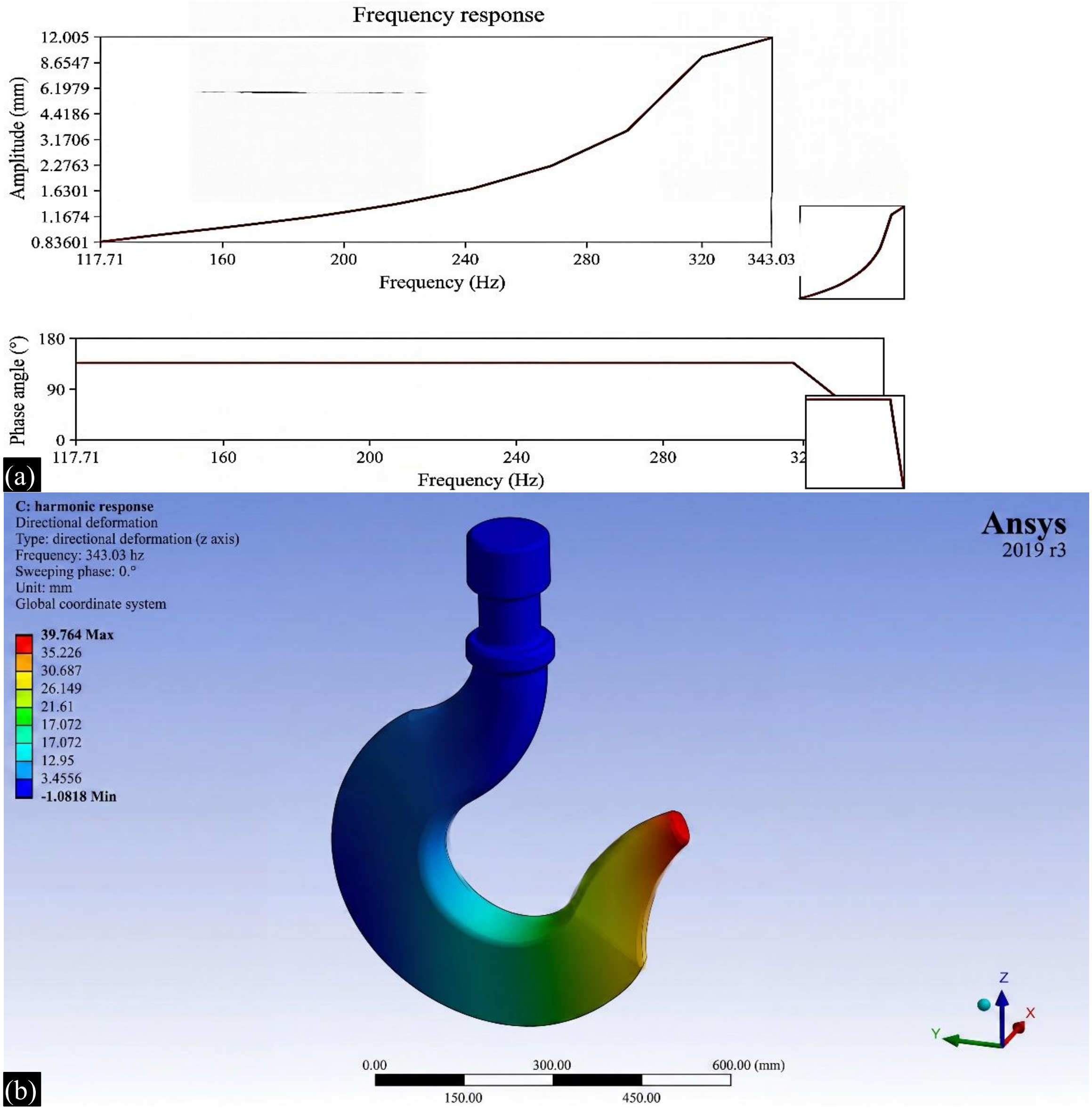


Figure 11. (a) to (b) The fig represents frequency response & max deformation of modified model – 2 in harmonic response

The gradual increase in amplitude demonstrates that the curved free section of the crane hook contributes more strongly to the vibration response compared with the supported upper region. The frictionless support condition permits realistic movement near the mounting section while avoiding excessive structural constraint during simulation.

Chrome–Moly Alloy Steel 4340 provides high strength, improved stiffness, and reliable vibration resistance under fluctuating loading conditions. The material supports controlled deformation behaviour and enhances the dynamic stability of the modified crane hook design. The modified geometry also assists in distributing harmonic forces more uniformly along the hook profile.

Overall, the harmonic frequency response analysis confirms that the modified Model–2 crane hook exhibits acceptable dynamic performance under the applied remote force of 618030 N. The peak vibration response occurs at 343.03 Hz with a maximum amplitude of 12.085 mm. The obtained results demonstrate that the proposed crane hook design is suitable for heavy industrial lifting operations subjected to cyclic and dynamic loading environments.

The harmonic phase response also reflects the capability of Chrome–Moly Alloy Steel 4340 to withstand repeated oscillatory loading while preserving structural integrity. The continuous and uniform waveform indicates balanced energy transfer through the hook geometry during vibration.

Overall, the phase response analysis confirms that the modified model–2 crane hook exhibits stable harmonic behaviour with controlled vibration characteristics under the applied remote loading and support conditions.

RESULTS AND DISCUSSIONS

Al 7075 reinforced with 7.5% SiC may be preferred in situations where lightweight construction is necessary. Even though deformation values are comparatively higher, the material still demonstrated lower stress concentration and improved response after optimization. Therefore, the final selection depends on operational requirements. For maximum strength and stiffness, Modified Model 2 with Chrome-moly alloy 4340 is the best combination. For reduced structural weight with acceptable performance, Modified Model 2 using Al 7075 reinforced with 7.5% SiC can be considered an efficient alternative (Table 1).

HARMONIC RESULTS

The Al 7075 reinforced with 7.5% SiC may still be useful in applications requiring lightweight structures and higher frequency response. However, its larger amplitude and deformation values suggest limitations under heavy-duty harmonic conditions (Table 2). Therefore, for industrial crane hook applications demanding strength, reliability, and vibration stability, Modified Model 2 combined with Chrome-moly alloy 4340 represents the most efficient and optimized solution (Figure 12 – 15).

Table 1. Structural analysis results.

Model	Material	Stress (MPa)	Strain	Total Deformation (mm)	Directional Deformation (mm)
Original Model	Carbon Steels 1018	1089.3	0.0061317	2.5502	0.020845
	Chrome-moly alloy 4340	1089.3	0.0061317	2.5502	0.020845
	Al 7075 + 7.5% SiC	1047.1	0.01063	4.657	0.044333
Modified Model 1	Carbon Steels 1018	1181.7	0.0067743	2.166	0.019116
	Chrome-moly alloy 4340	1181.7	0.006743	2.166	0.019116
	Al 7075 + 7.5% SiC	1131	0.011694	3.9533	0.040918
Modified Model 2	Carbon Steels 1018	1307.2	0.0073733	1.9914	0.01775
	Chrome-moly alloy 4340	1307.2	0.0073733	1.9914	0.01775
	Al 7075 + 7.5% SiC	1264.2	0.012737	3.6326	0.037772

Table 2. Harmonic analysis results.

Model	Material	Max Amplitude (mm)	Frequency (Hz)	Directional Deformation (mm)
Original Model	Carbon Steels 1018	8.7749	322.43	48.613
	Chrome-moly alloy 4340	8.7754	322.84	48.616
	Al 7075 + 7.5% SiC	15.853	397.96	87.998
Modified Model 1	Carbon Steels 1018	8.455	323.2	40.19
	Chrome-moly alloy 4340	8.4562	323.61	40.196
	Al 7075 + 7.5% SiC	15.276	399.03	72.737
Modified Model 2	Carbon Steels 1018	12.09	342.59	39.779
	Chrome-moly alloy 4340	12.085	343.02	39.764
	Al 7075 + 7.5% SiC	21.917	422.95	72.241

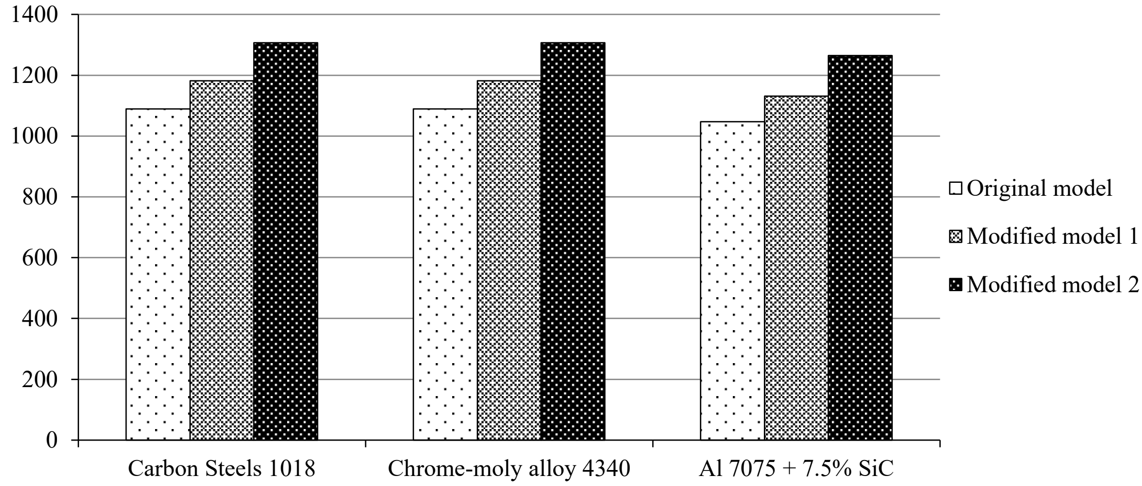


Figure 12. Comparison of stress analysis results.

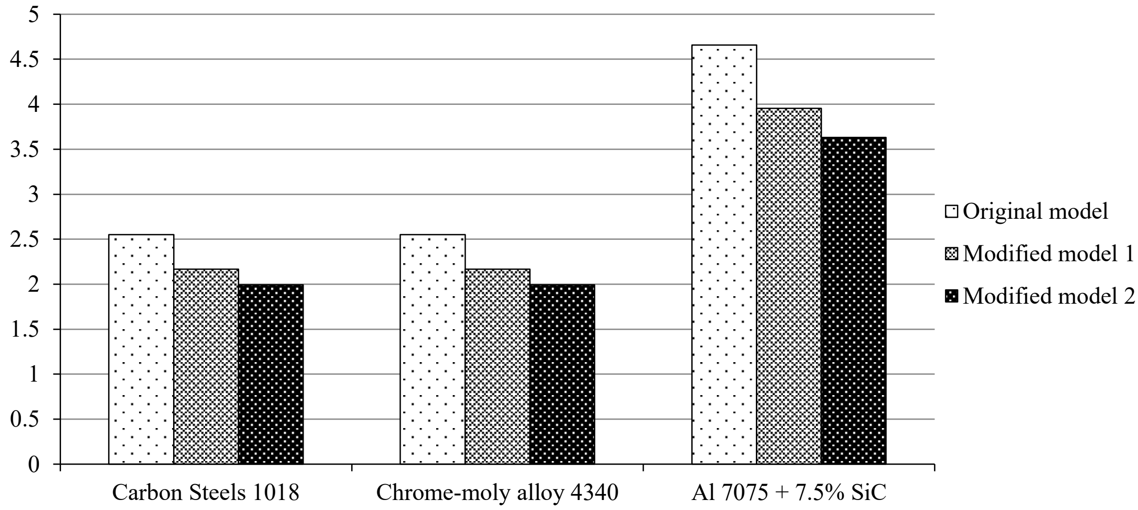


Figure 13. Comparison of deformation analysis results.

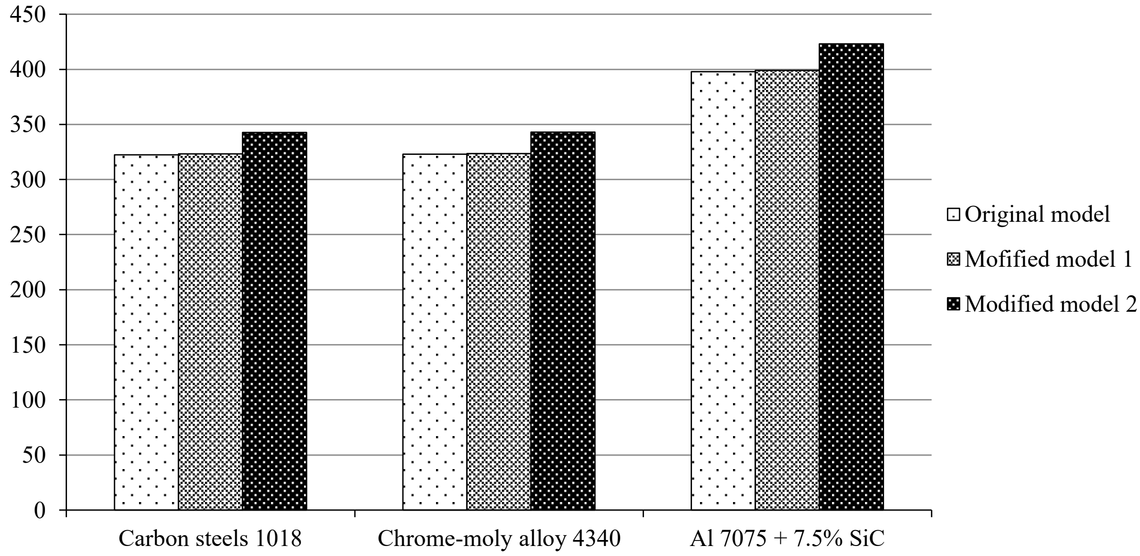


Figure 14. Comparison of harmonic analysis frequency results.

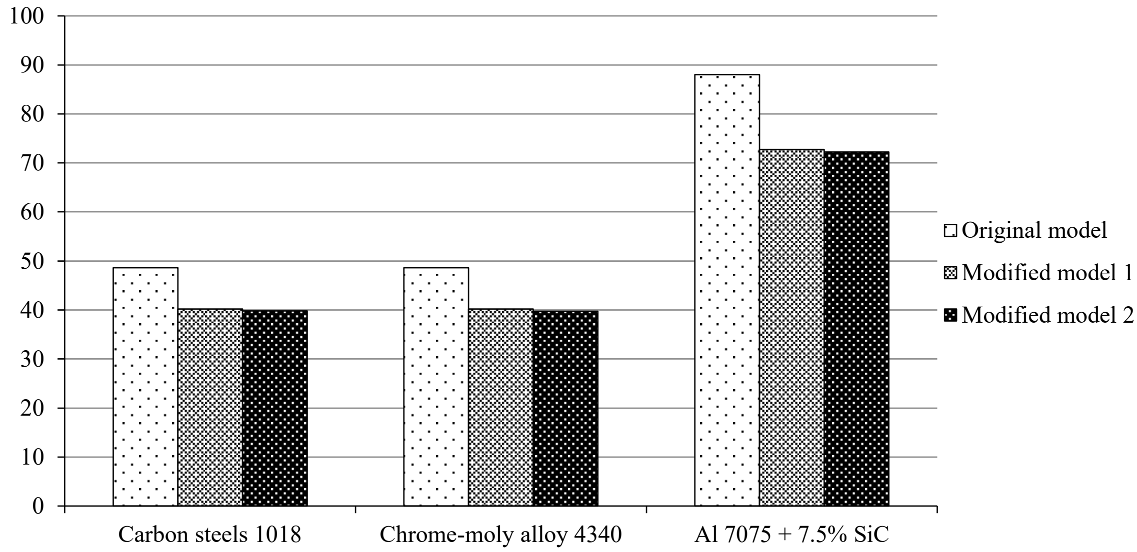


Figure 15. Comparison of harmonic analysis deformation results.

CONCLUSION

The structural analysis showed that cross-sectional modification significantly influenced stress distribution and deformation characteristics. Among all configurations, Modified Model 2 produced the lowest total deformation and directional deformation values, which indicates improved stiffness and enhanced load-carrying capability. The optimized geometry distributed the applied load more effectively and minimized excessive displacement. Carbon Steels 1018 and Chrome-moly alloy 4340 exhibited lower deformation values than the composite material because of their higher rigidity. The Al 7075 + 7.5% SiC combination demonstrated reduced stress concentration, although deformation remained comparatively higher due to its lightweight behaviour.

The comparison of all three analyses clearly indicates that geometric optimization played a major role in improving hook performance. The cross-sectional refinement adopted in Modified Model 2 enhanced stiffness, reduced displacement, and improved resistance against both static and dynamic loading effects. The design also minimized vibration-related instability, which is essential for safe crane operation during lifting cycles.

From the material perspective, Chrome-moly alloy 4340 emerged as the best overall material because it consistently produced lower deformation, stable stress behaviour, and improved vibration resistance in every analysis. The alloy maintained an effective balance between strength and rigidity, making it highly suitable for heavy-duty industrial applications. Carbon Steels 1018 provided satisfactory performance but slightly lower stability compared with Chrome-moly alloy 4340. The Al 7075 reinforced with 7.5% SiC offered the advantage of reduced weight and higher natural frequency, though excessive deformation limited its suitability for severe loading conditions.

Based on the complete numerical investigation, Modified Model 2 can be identified as the best optimized design among all tested configurations. Similarly, Chrome-moly alloy 4340 can be considered the most efficient material for the lifting hook because of its superior structural integrity and dynamic stability. Therefore, the combination of Modified Model 2 with Chrome-moly alloy 4340 represents the most reliable and optimized solution for enhancing the strength, stiffness, and vibration performance of Hitachi Sumitomo lifting hooks used in industrial lifting operations.

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