



Effect of Fillet Radius at the Shank-to-Body Transition on the Local and Global Structural Responses of a Lifting Hook

Adriansyah^{1*}, Khaidir², Muhammad Riza³, Chiena L. Palconite⁴, Risal Abu⁵

¹ Department of Mechanical Engineering, Politeknik Negeri Padang, Indonesia

² Department of Mechanical Engineering, Universitas Bung Hatta, Indonesia

³ Department of Mechanical Engineering, Universitas Bandar Lampung, Indonesia

⁴ Department of Environmental Engineer, University of Science and Technology of Southern Philippines, Philippines

⁵ Department of Mechanical Engineering, Universitas Ekasakti Padang, Indonesia

*Corresponding author: adriansyah, adriansyah1964@gmail.com

ABSTRACT

Geometric modifications of lifting hooks are generally evaluated based on changes in stress at the modified region; however, a reduction in local stress does not necessarily produce a corresponding change in the global response of the hook. This study evaluates the effect of fillet radius at the transition between the shank and hook body on the local and global structural responses. Four fillet radii, namely 5, 10, 15, and 20 mm, were analyzed using the finite element method in ANSYS Static Structural with AISI 1045 Hot Rolled steel under a static load of 49,050 N. The reliability of the model was evaluated through mesh convergence analysis and comparison with an analytical stress concentration factor approach. The results show that increasing the fillet radius from 5 to 15 mm reduced the local stress at the fillet by 15.59%, from 68.49 MPa to 57.81 MPa, whereas a further increase to 20 mm did not produce an additional reduction. In contrast, the maximum global stress occurring at the inner bowl surface changed by only 0.25%, from 138.15 to 138.49 MPa, resulting in a relatively constant factor of safety in the range of 2.383–2.389. The maximum deformation also changed by only 0.69% across the range of fillet radii. These results indicate that the fillet radius has a more pronounced effect on the local stress response than on the global structural response. Therefore, a reduction in stress at the fillet region alone is insufficient to demonstrate an improvement in the overall strength of the lifting hook, particularly when the modified region is not the location of maximum stress. Evaluation of geometric modifications in lifting hooks should therefore consider the location of critical regions and distinguish between local and global structural responses.

KEY WORDS : Lifting hook; fillet radius; finite element method; von-Mises stress; factor of safety.

1. INTRODUCTION

The lifting hook is a primary component of a lifting system that transfers the load from the lifted object to the crane. Hook failure can result in load dropping, equipment damage, and workplace accidents, making lifting safety an important consideration in crane design and monitoring [1]. Therefore, finite element analysis (FEA) is widely used in conjunction with physical testing to evaluate the ability of lifting components to withstand their working loads [2]. One of the important issues in hook design is stress concentration in regions where geometric changes occur. FEA has been used to investigate the effects of cross-sectional geometry [3], modifications to the hook cross-section and longitudinal profile [4], stress concentration factors in trapezoidal cross-section notches [5], and topology optimization [6]. Similar approaches have also been applied to other types of hooks, such as aircraft tow hooks [7]

and coil-lifting C-hooks [8]. These studies demonstrate that geometric modifications can affect the stress distribution and structural response of hooks.

The fillet radius is one of the geometric parameters that can affect stress concentration in transition regions. A study [9] conducted a parametric analysis of a crane hook supported by mesh convergence analysis and analytical verification using curved beam theory. Their results showed that the inner bowl radius had a significant influence on the hook response, with a 15% increase in the inner radius resulting in an approximately 40% increase in the factor of safety (FoS). Another study [4] also showed that introducing a fillet at a stress concentration region, together with modifications to the hook geometry, can reduce the maximum stress. In both studies, the modified regions were located at or near the critical region of the hook, particularly the inner bowl curvature where the maximum stress occurred.

This condition may not necessarily apply to a fillet located away from the critical region, such as the fillet at the transition between the shank and the hook body. For a stepped transition, stress concentration factor theory for stepped round bars indicates that the peak stress tends to decrease as the radius-to-diameter ratio increases [10]. However, the applicability of this trend to a three-dimensional lifting hook with a curved geometry needs to be evaluated because its geometric configuration differs from that of a stepped round bar. It is also necessary to determine whether a reduction in local stress at a fillet that is not the location of maximum stress produces a meaningful change in the global response of the hook, including maximum stress, FoS, and deformation.

This question is important because a geometric modification in a local region does not necessarily produce a corresponding change in the overall structural response. If the modified region is not the location governing the maximum stress, a reduction in stress at that region may not improve the global safety margin. Therefore, evaluating the effect of fillet radius requires consideration of both local and global responses to provide a more comprehensive assessment of the effect of geometric modification.

Based on these considerations, this study aims to evaluate the effect of fillet radius at the transition between the shank and hook body on the local and global structural responses of a lifting hook. The fillet radius was varied at 5, 10, 15, and 20 mm, while the remaining geometry, material, loading, and boundary conditions were kept constant. The evaluated responses include total deformation, local von-Mises stress at the fillet, maximum global stress and its location, and FoS. The reliability of the results was evaluated through mesh convergence analysis and comparison with an analytical stress concentration factor approach. This study is not intended to determine an optimum fillet radius, but rather to quantify the relationship between changes in local fillet stress and the global response of the lifting hook. The results are expected to provide a clearer basis for determining whether a geometric modification merely reduces local stress concentration or also produces a change in the overall structural response.

2. METHODOLOGY

The study was conducted in three stages: modeling of the lifting hook geometry with four fillet radius variations (5, 10, 15, and 20 mm) using SolidWorks; static structural analysis in ANSYS, preceded by a mesh convergence study; and analytical verification of the results. For all models, only the fillet radius was varied, while the remaining geometry, material, loading, boundary conditions, and mesh settings were kept constant to ensure that changes in the structural response could be attributed to the effect of the fillet radius.

2.1 Geometry and Fillet Radius Variations

The fillet was introduced at the transition between the 42 mm diameter shank and the 52 mm diameter lower section of the hook. The transition has a step height of 5 mm and is located 70 mm from the upper end of the shank, as shown in Figure 1. Four fillet radii were considered in the analysis: 5, 10, 15, and 20 mm.

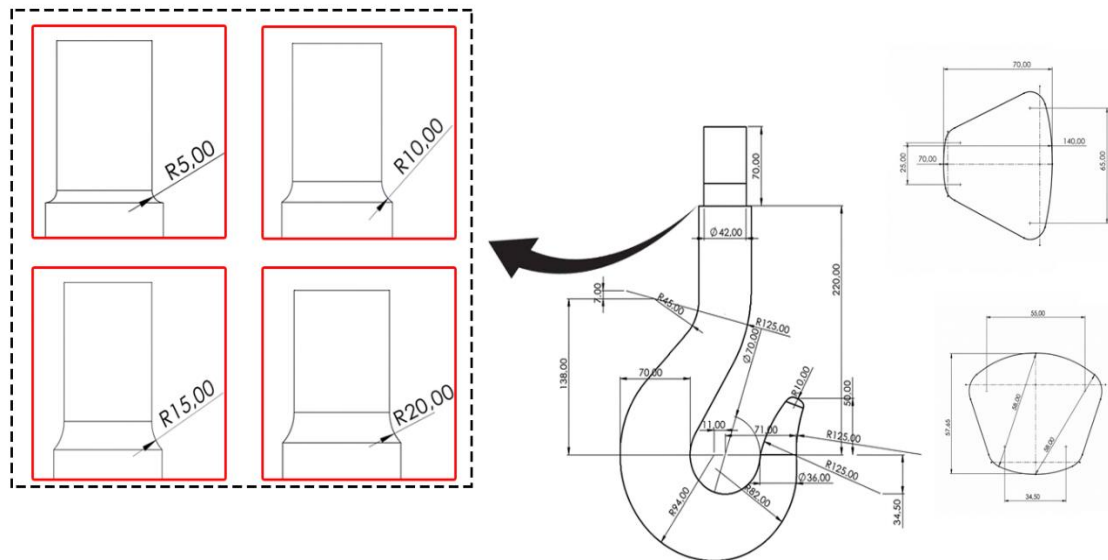


Figure 1. Geometric dimensions of the lifting hook and details of the fillet radius variations (R = 5, 10, 15, and 20 mm).

To characterize the fillet size relative to the surrounding geometry, the radius-to-shank diameter ratio (r/d) ranges from 0.119 to 0.476, while the radius-to-step height ratio (r/h) ranges from 1 to 4. Only the radius of the transition region was modified among the models. The shank diameter, lower-section diameter, bowl dimensions, and other geometric features were kept identical so that differences in the structural response could be attributed to the variation in fillet radius.

2.2 Material

The material used in this study was AISI 1045 Hot Rolled (HR) steel. This material was selected because it has been used in previous studies on crane hook analysis using the finite element method [10], [6]. Using the same material allows the present study to focus the comparison on the effect of fillet radius variation without introducing differences associated with material properties. The mechanical properties of AISI 1045 Hot Rolled used in the analysis are presented in Table 1.

Table 1. Mechanical properties of AISI 1045 Hot Rolled steel

Property	Value
Density	7800 kg/m ³
Young's Modulus	190 GPa
Poisson's Ratio	0,29
Yield Strength	330 MPa
Ultimate Tensile Strength	620 MPa

2.3 Boundary Conditions and Loading

The boundary conditions and loading applied to the model are shown in Figure 2(b). A fixed support (A) was applied at the upper end of the shank to represent the restraint provided by the hook block. A load of 49,050 N, corresponding to a 5,000 kg load, was applied vertically downward and distributed over the load-bearing surface on the inner side of the bowl (B). This surface represents the load-contact area of the hook. The fillet is located 70 mm from the upper end of the shank, separating the analyzed region from the support surface. The same boundary conditions and loading were applied to all models so that the observed differences in structural response could be attributed to the variation in fillet radius. The fillet surface (C) was defined as a named selection for extracting the local stress.

2.4 Meshing

The model was discretized using 10-node quadratic tetrahedral elements (SOLID187) with a global element size of 3 mm. To improve the mesh resolution in the stress concentration region, a local edge sizing of 1 mm was applied to the two circular edges of the fillet, as shown in Figure 2 (a). The mesh sizes were selected based on the mesh convergence study and subsequently applied consistently to all four models. Differences in the number of elements and nodes among the models resulted solely from the changes in fillet geometry. The mesh statistics and quality metrics for each model are presented in Table 2.

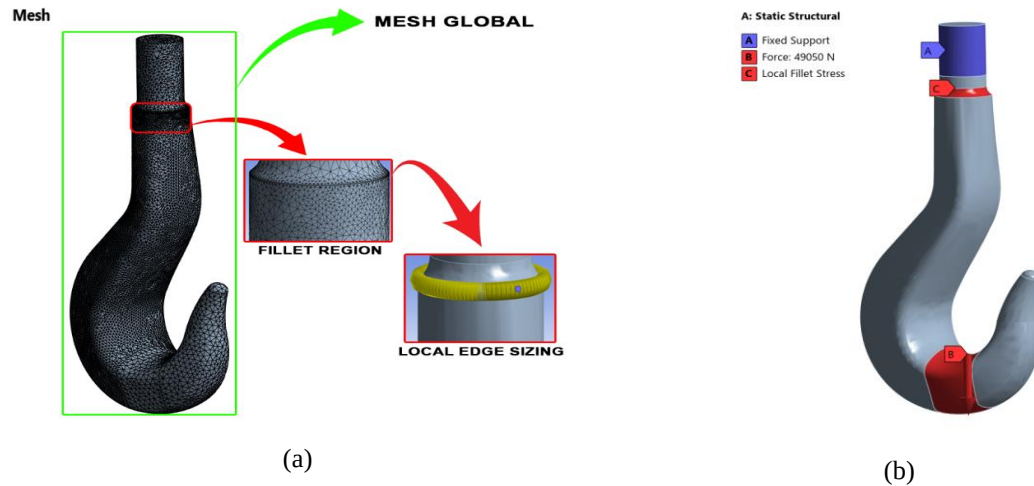


Figure 2. (a) Global mesh and local edge sizing in the fillet region; (b) boundary conditions and loading consisting of fixed support (A), 49,050 N load (B), and named selection at the fillet region (C).

Table 2. Mesh statistics and quality metrics for a global element size of 3 mm and local edge sizing of 1 mm.

Fillet radius	Number of elements	Number of nodes	Minimum element quality	Maximum element quality	Average element quality
5 mm	55.436	94.505	0,107	1,000	0,697
10 mm	56.346	96.037	0,144	1,000	0,696
15 mm	57.979	98.488	0,172	1,000	0,697
20 mm	57.809	98.283	0,173	1,000	0,697

2.5 Mesh Convergence Study

The mesh convergence study was performed on the R = 5 mm model, which has the sharpest transition and is therefore expected to be the most sensitive to mesh size. The mesh was considered converged when the relative difference in stress from the finest mesh was less than 1%, calculated using Equation (1):

$$\varepsilon = |\sigma_i - \sigma_{ref}| / \sigma_{ref} \times 100\% \quad \dots\dots\dots (1)$$

where σ_i is the stress obtained from the ke-i dan σ_{ref} is the stress obtained from the finest mesh [11], [12]. Because the model uses two mesh size settings, namely the global element size for the entire model and the local edge sizing at the fillet, each setting was evaluated separately. First, the global element size was varied from 7 mm to 3 mm while monitoring the maximum global stress. A global element size of 3 mm was selected because it satisfied the convergence criterion and was the smallest size that could be run using the ANSYS Student license. Second, with the global element size fixed at 3 mm, the local edge sizing was varied from 3 mm to 0.2 mm while monitoring the maximum local stress at the fillet. A local edge sizing of 1 mm was selected because it satisfied the convergence criterion while requiring fewer elements than the finer mesh configurations. The results of both convergence stages are presented in Figure 3, with the selected mesh sizes indicated by red circles.

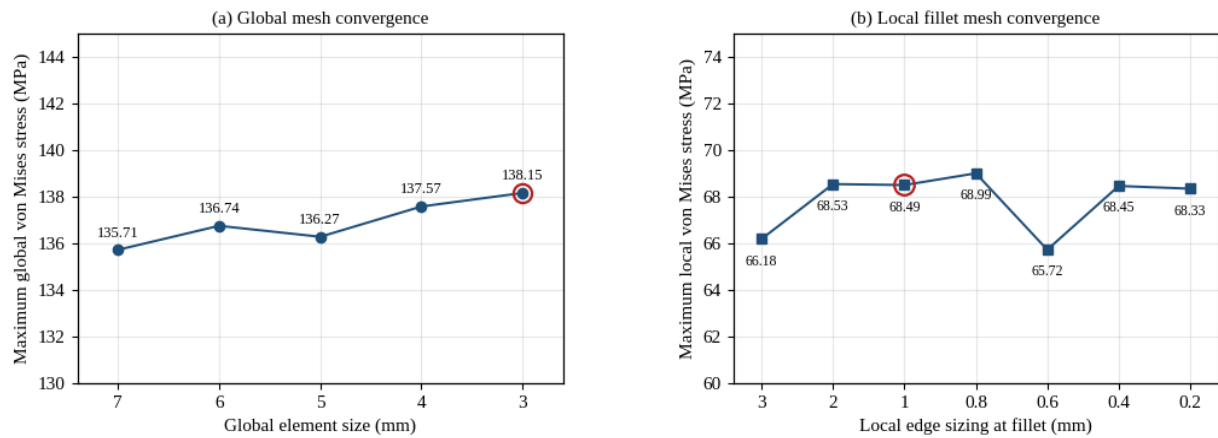


Figure 3. Mesh convergence study for the R = 5 mm model: (a) global element size versus maximum global stress; (b) local edge sizing versus maximum local stress at the fillet.

2.6 Structural Response Parameters

The structural responses evaluated in this study include total deformation, equivalent von-Mises stress, and factor of safety (FoS). The von-Mises stress was evaluated at three levels: local stress, namely the maximum averaged nodal stress on the named selection at the fillet (C); and global stress, namely the maximum stress throughout the model. The FoS was calculated using Equation (2) [13], [14]:

$$\text{FoS} = \sigma_y / \sigma_v^M, \max \quad (2)$$

where $\sigma_y = 330$ MPa is the yield strength of the material and $\sigma_v^M, \max$ is the maximum global von-Mises stress. The local FoS at the fillet was calculated using the corresponding local stress.

2.7 Numerical Model Verification

The reliability of the FEA results was evaluated using two approaches. First, the local FEA stress was compared with the analytical stress concentration factor, K_t , using a nominal stress calculated as $\sigma_{\text{nom}} = 4F/(\pi d^2)$. The K_t values were obtained from the stress concentration curves for stepped round bars subjected to tensile loading [10]. Second, the location of the maximum global stress was compared with the critical location reported in previous crane hook studies.

3. RESULTS AND DISCUSSION

The reliability of the FEA model was first evaluated by comparing the stress results with an analytical approach and with previous studies. The subsequent analysis covers total deformation, local stress at the fillet, maximum global von Mises stress, and factor of safety in order to identify the effect of fillet radius variation on the structural response of the lifting hook.

3.1 Numerical Model Verification

The nominal stress in the 42 mm diameter shank under a load of 49,050 N is 35.40 MPa. The stress concentration factor K_t for each fillet radius was determined from the curves for a stepped circular bar with a shoulder fillet in Peterson's Stress Concentration Factors [10]. These values were then compared with the local FEA stress in the fillet region, as shown in Table 3.

Table 3. Analytical verification of the local stress at the fillet.

Fillet radius (mm)	r/d	K_t [10]	$K_t \cdot \sigma_{\text{nom}}$ (MPa)	Local FEA stress (MPa)	Difference (%)
5	0.119	1.653	58.51	68.49	+17.1
10	0.238	1.432	50.71	61.02	+20.3
15	0.357	1.336	47.30	57.81	+22.2
20	0.476	1.279	45.29	59.93	+32.3

For radii of 5–15 mm, the FEA results show the same trend as the analytical approach, namely that the local stress decreases as the fillet radius increases. However, the FEA values are approximately 17.1–22.2% higher than the analytical results. This discrepancy arises from the differences between the analytical model and the geometry of the lifting hook. The curves in Peterson's Stress Concentration Factors were developed for stepped round bars under axial tension, whereas in the lifting hook the section beyond the fillet is directly connected to the curved hook body, and the load applied at the bowl can induce a bending component in the shank. Therefore, the analytical approach is used as a reference for evaluating the trend and order of magnitude of the local stress, rather than as a value that the FEA results are expected to match exactly. At a radius of 20 mm, the difference between the FEA and analytical results increases to 32.3%.

In all four models, the maximum global stress occurs on the inner surface of the bowl. This location is consistent with the findings of [9], which showed that the inner curvature of the bowl is the critical region of a crane hook. Study [3] also demonstrated agreement between FEA results and the analytical approach in the critical cross-section of the hook. The similarity between the local stress trend and the analytical approach, together with the agreement of the maximum stress location with previous studies, supports the plausibility of the numerical results obtained in this study.

3.2 Total Deformation

The total deformation distributions for the four radius variations are presented in Figure 4. In all models, the maximum deformation is located at the lower part of the bowl near the hook tip, whereas the displacements in the shank and fillet region are relatively small. This indicates that the deformation response is governed mainly by bending of the bowl.

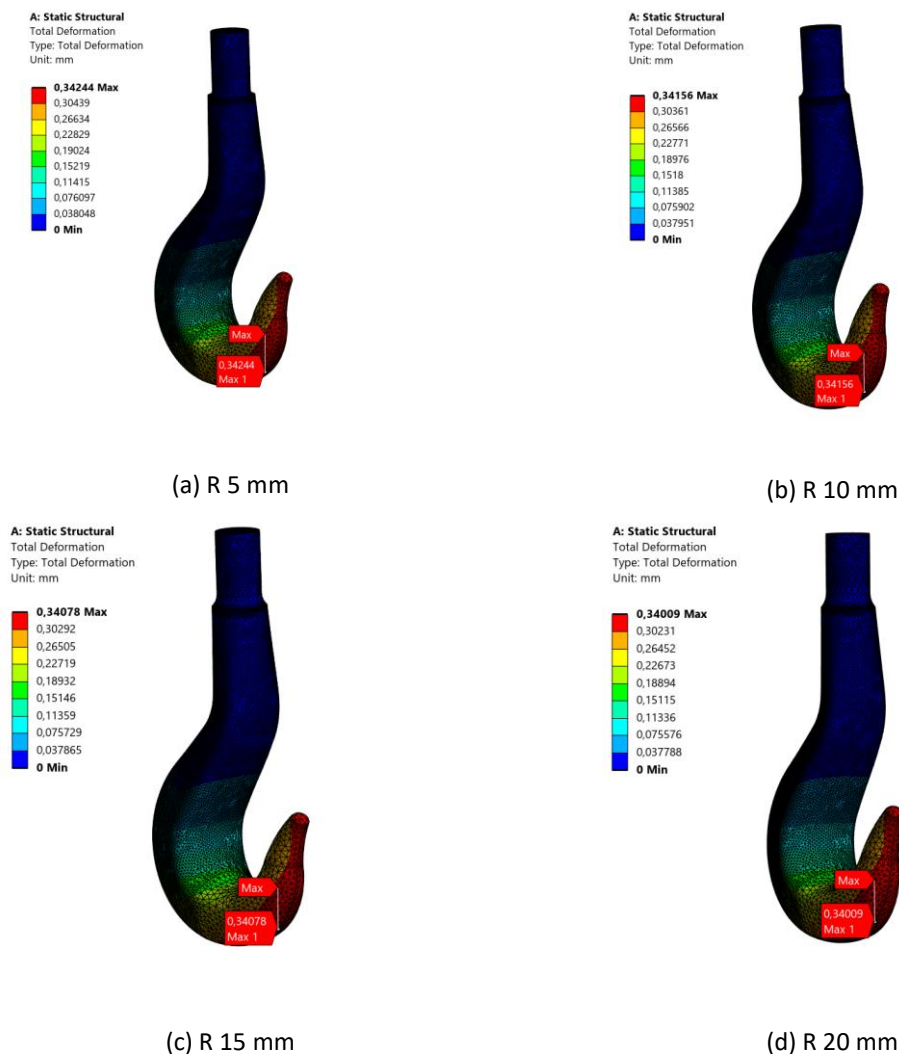


Figure 4. Total deformation distribution: (a) R 5 mm, (b) R 10 mm, (c) R 15 mm, and (d) R 20 mm.

The maximum total deformation is 0.34244 mm at a radius of 5 mm and decreases to 0.34156 mm, 0.34078 mm, and 0.34009 mm at radii of 10, 15, and 20 mm, respectively. The relationship between fillet radius and maximum total deformation shows a consistent decrease, as shown in Figure 5. However, the overall change from a radius of 5 mm to 20 mm is only 0.00235 mm, or 0.69%.

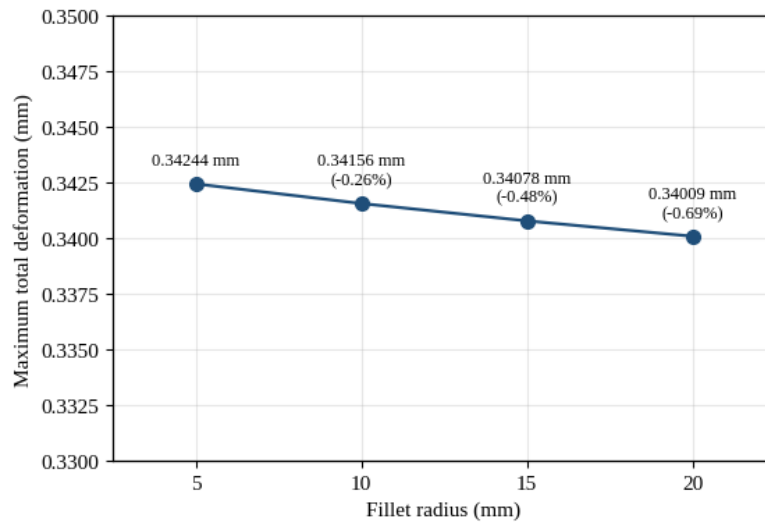


Figure 5. Relationship between fillet radius and maximum total deformation.

Changing the fillet radius modifies only the transition region of the shank without altering the main cross-sections of the shank and bowl. Consequently, the change in the global stiffness of the hook is relatively small, resulting in only a limited change in deformation. This indicates that fillet radius variation is not a dominant factor in determining the global deformation of the analysed geometry. This finding is in line with study [8], which showed that the structural response of lifting hook components can be influenced by the applied loading conditions and should be evaluated through several parameters, including deformation and stress.

3.3 Local Stress at the Fillet

The maximum local stresses in the fillet region are 68.49 MPa for R5, 61.02 MPa for R10, 57.81 MPa for R15, and 59.93 MPa for R20. Compared with R5, these values represent reductions of 10.91%, 15.59%, and 12.49% for R10, R15, and R20, respectively. In all models, the maximum local stress is located at the upper edge of the fillet, i.e., the transition between the fillet and the 42 mm diameter shank. This relatively consistent location indicates that changing the radius does not shift the critical region but rather changes the magnitude of the stress developed in that transition region. The von Mises stress distributions in the lifting hook for each radius variation are shown in Figure 6.

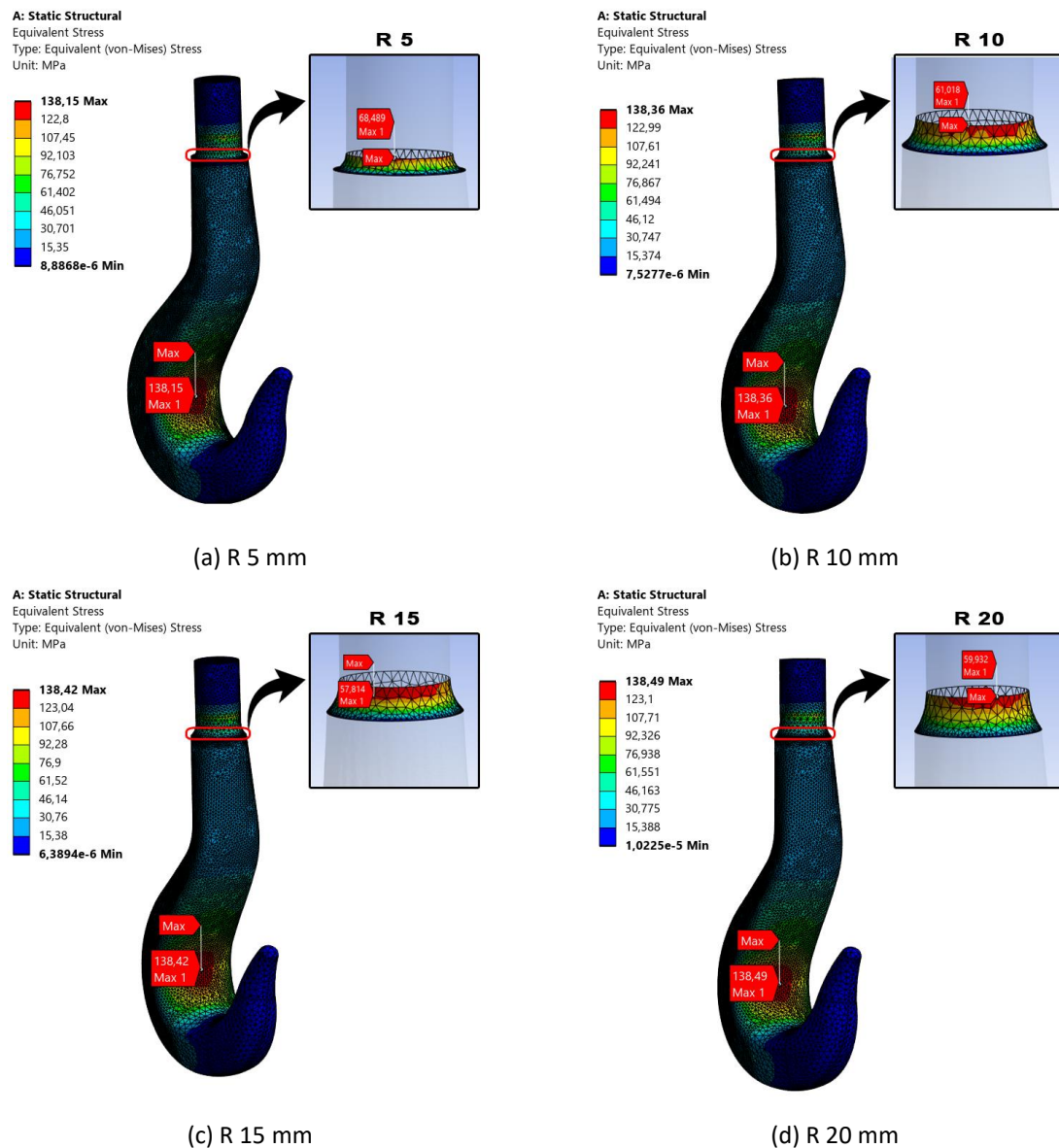


Figure 6. Equivalent von Mises stress distribution and stress detail in the fillet region: (a) R 5 mm, (b) R 10 mm, (c) R 15 mm, and (d) R 20 mm.

These results show that the maximum global von Mises stress in all four models lies within a nearly identical range of 138.15–138.49 MPa. This similarity allows the stress distribution patterns to be compared directly between models without differences in contour scale that could affect visual interpretation. Meanwhile, the detail views of the fillet region reveal clearer changes in stress intensity, particularly between R5 and R15. This indicates that the stress response in the fillet region is more sensitive to changes in radius than the global stress response.

The relationship between fillet radius and maximum local von Mises stress is shown in Figure 7. The stress decreases from 68.49 MPa at R5 to 61.02 MPa at R10 and reaches its lowest value of 57.81 MPa at R15. This reduction indicates that increasing the radius within the 5–15 mm range reduces the abruptness of the geometric change in the shank transition region. Mechanically, a smoother transition produces a more gradual change in cross-sectional area, thereby lowering the stress gradient around the fillet.

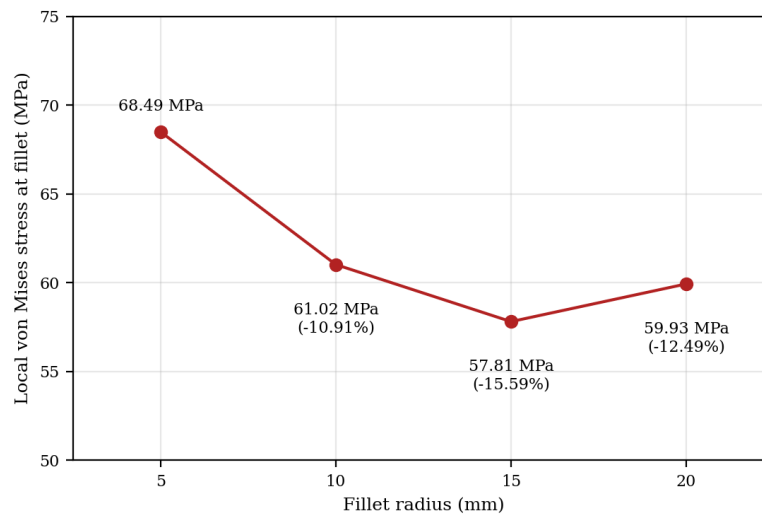


Figure 7. Relationship between fillet radius and maximum local von Mises stress at the fillet.

This trend is consistent with the stress concentration factors obtained from the analytical approach in Table 3. The decrease in K_t indicates that the stress concentration effect diminishes as the ratio of radius to shank diameter increases. However, the magnitude of the reduction in the FEA local stress does not follow the change in K_t proportionally. The reduction from R5 to R10 reaches 10.91%, whereas that from R10 to R15 is only 5.25%. This pattern indicates that the benefit of increasing the radius diminishes at larger radii, consistent with K_t approaching the condition of no stress concentration.

At R20, the local stress increases to 59.93 MPa, which is 3.66% higher than at R15. This result indicates that increasing the radius does not lead to a continuous reduction in stress. With a step height of only 5 mm, a radius of 20 mm yields an r/h ratio of 4, so that the fillet becomes a relatively long transition compared with the step height. Under this condition, the region of maximum stress is no longer influenced solely by the fillet curvature but also by the response of the shank, which is subjected to combined stresses from axial force and bending effects. Consequently, increasing the radius from 15 mm to 20 mm does not produce any further reduction in local stress.

Overall, radius variation has a clear effect on the local stress in the fillet region, but this effect is not linear over the entire range of radii analysed. The 15 mm radius produced the lowest local stress among the variations tested, whereas a further increase to 20 mm provided no additional reduction. These results therefore indicate that the benefit of increasing the fillet radius is limited for the analysed lifting hook geometry, and that the evaluation of the radius effect should consider the actual response in the transition region rather than relying solely on the theoretical trend of the stress concentration factor.

3.4 Maximum Global Stress

Unlike the local stress at the fillet, the maximum global von Mises stress remains nearly unchanged with radius variation, as shown in Figure 8(a). The values are 138.15, 138.36, 138.42, and 138.49 MPa for radii of 5, 10, 15, and 20 mm, respectively. The largest change is only 0.25%, which is smaller than the 0.42% change observed in the final stage of the global mesh convergence study. In all models, the maximum stress remains on the inner surface of the bowl, making this region the location that governs the global stress response.

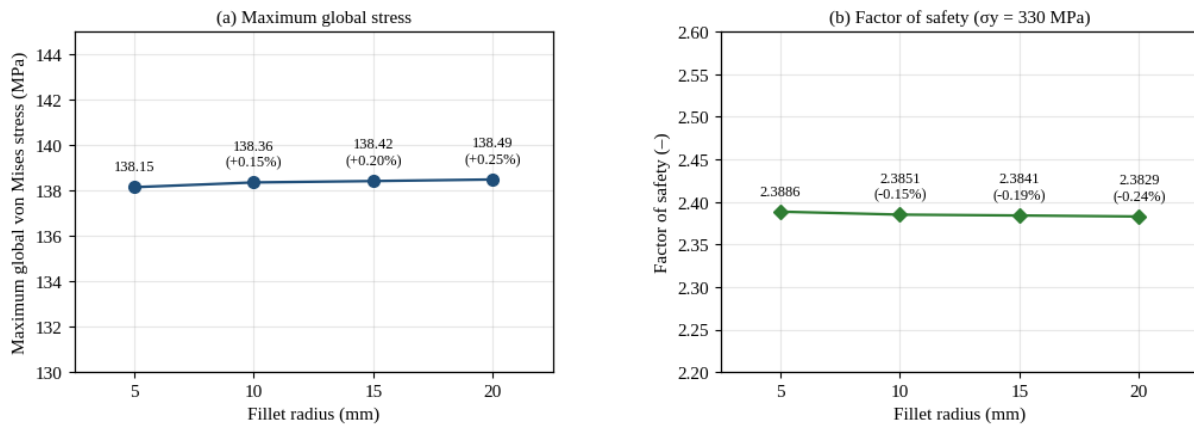


Figure 8. (a) Relationship between fillet radius and maximum global von Mises stress; (b) relationship between fillet radius and factor of safety.

This behaviour is related to the location of the geometric modification, which is limited to the shank transition. The fillet radius affects the local stress distribution but does not alter the geometry of the bowl, which carries the main load. As a result, changing the radius does not produce a significant change in the global stress. This result differs from that of [9], which showed that changing the inner radius at the critical region of the bowl can have a greater effect on the global response. Study [3] also showed that changes in the main cross-section of the hook produce more pronounced differences in stress. Meanwhile, study [4] reported a reduction in maximum stress after fillet modification in a stress concentration region. This comparison indicates that the effect of geometric modification on the global response depends strongly on the location of the modified geometry relative to the critical region. Therefore, for the geometry and loading used in this study, fillet radius variation mainly affects the local stress, whereas the maximum global von Mises stress remains governed by the inner region of the bowl.

3.5 Factor of Safety

The factor of safety (FoS) in Figure 8(b) is approximately 2.38 for all radius variations. The highest value of 2.3886 is obtained at R5, which then decreases slightly to 2.3851 at R10, 2.3841 at R15, and 2.3829 at R20. The overall reduction is only about 0.24%; hence, changing the fillet radius has no significant effect on the global FoS. This change in FoS follows the pattern of the maximum global von Mises stress discussed above. Because the FoS is calculated as the ratio of yield strength to the maximum von Mises stress, a very small change in the global stress results in an equally small change in FoS. Thus, although the fillet radius alters the stress in the transition region, this change does not affect the overall safety margin of the hook against yielding.

These results also show that the assessment of global safety cannot be based solely on changes in local stress. In this study, the local fillet stress varied more considerably, whereas the global FoS remained within the same range because the maximum stress consistently occurred in the bowl region. Therefore, the global FoS better represents the response of the region that governs the overall strength of the hook, while the local stress is used to capture the direct effect of radius variation on the fillet region.

4. CONCLUSION

This study evaluated the effect of the fillet radius at the transition from the shank to the body of a lifting hook ($R = 5, 10, 15$, and 20 mm) on the local and global structural response under a static load of $49,050$ N. Based on the simulation results, which were verified through a mesh convergence study and comparison with an analytical solution, the following conclusions can be drawn:

1. The fillet radius has no significant effect on the global deformation of the hook. The maximum deformation decreased by only 0.00235 mm, or 0.69% , from a radius of 5 mm to 20 mm. This small change is attributed to the dominance of bending in the bowl, whose geometry remained unchanged.
2. The fillet radius has a clear effect on the local stress. The stress at the fillet decreased from 68.49 MPa at $R = 5$ mm to 57.81 MPa at $R = 15$ mm, a reduction of 15.59% , following a trend consistent with stress concentration factor theory. At $R = 20$ mm, the local stress increased by 3.66% relative to $R = 15$ mm. As this change lies within the $\pm 4\%$ numerical variation obtained from the convergence analysis, the increase

does not represent a meaningful change. Therefore, for the analysed geometry, increasing the radius beyond approximately 15 mm provides no further reduction in local stress.

3. The maximum global stress and factor of safety showed no significant change with fillet radius variation. The maximum global stress remained on the inner surface of the bowl, with values of 138.15–138.49 MPa, corresponding to a change of about 0.25%, while the global FoS ranged from 2.383 to 2.389. These results indicate that the bowl region remains the location governing the global response and the safety margin against yielding for all radius variations.

This study is limited to four fillet radius variations and a single static loading condition. Future work could extend the range of radii and loading conditions, adopt more realistic support and contact models, and perform experimental validation through strain measurements or proof-load testing.

Author Contributions

A. and **K.** contributed to the conceptualization of the study, methodology development, supervision, formal analysis, data validation, as well as writing the original draft and reviewing the manuscript. **K.** and **M.R.** were responsible for investigation, data curation, formal analysis, data visualization, and preparation of the original draft. Meanwhile, **C.L.P.** and **R.A.** contributed to project supervision, project administration, and manuscript review and editing.

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