



DESIGN AND ANALYSIS OF A FORK LIFT



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1. Introduction

A forklift truck (also called a lift truck, a fork truck, or a forklift) is a powered industrial truck used to lift and move materials short distances. The forklift was developed in the early 20th century by various companies including the transmission manufacturing company Clark and the hoist company Yale & Towne Manufacturing. Following World War II the use and development of the forklift truck has greatly expanded worldwide. Forklifts have become an indispensable piece of equipment in manufacturing and warehousing operations. ^{[1][2][3]}.

Forklifts are primarily used for lifting and transferring heavy loads to stations or locations in warehouses, shops or construction sites. Usually there are two forks in the front of a forklift (some type of forklifts have the forks on the side) that are used to lift loads that may weigh up to thousands of pounds. These forks can be moved forward and backward, and also up and down for lifting and moving cargo.

Forks are classified into 4 different groups depending on the spacing between the fork hooks, i.e. Class I (Rated for loads up to 2000 lbs. with the spacing at 13 inches), Class II (Rated for loads up to 5,550 lbs. with the spacing at 16 inches), Class III (Rated for loads up to 10,000 lbs. with the carriage bar spacing at 20 inches), and Class IV (Rated for loads up to 15,500 lbs. with the spacing at 25 inches).^[4]

Forks are responsible for picking up the load and carry it during the transportation. In this process, there are two kinds of failure: sudden fracture due to the heavy load and fatigue fracture due to the vibration caused by uneven ground during the transportation. These can be effectively analyzed using FEA.

This project deals with the design analysis of a Class II Forklift under sudden loading conditions. The load used is a crate of dimensions 6'x5'x4', weighing 4000 lbs. Using ANSYS a pair of forks is modeled that attaches to the forklift with two surface areas A*W on each fork that are B apart and at a distance of C from the fork uprights.

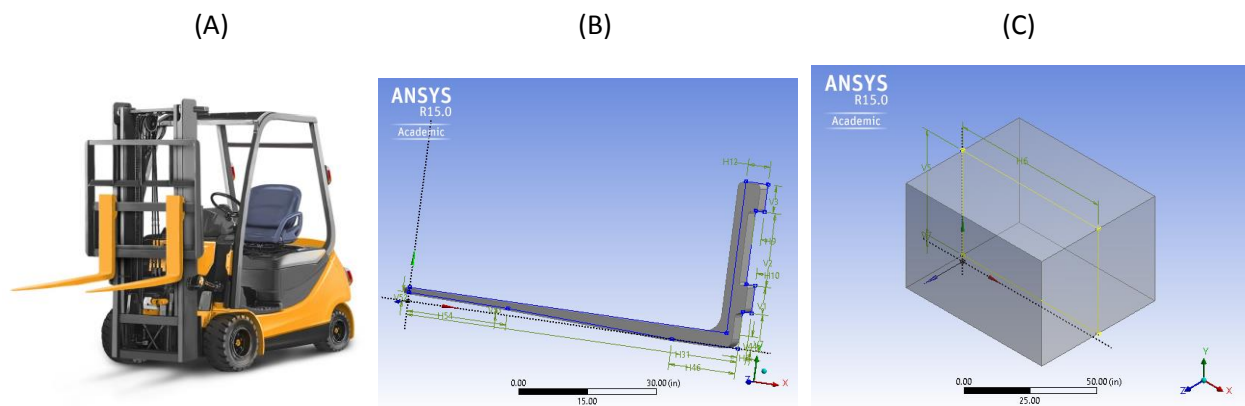


Fig 1: A) A typical fork lift. B) The dimensions for the fork in this project where the hook dimensions were specified and total Height (H), Length (L), Thickness (T) and Width (W) were user defined. C) The 4000lb uniform crate (Length= 6', Width= 5', Height=4') that will be held in static equilibrium by two forks on the fork lift.

The dimensions H, L, T and W were intuitively defined and the fork is analyzed for stresses, strains and maximum deformation for each case and for different fork materials.

2. Methods

The model development was accomplished in 6 steps: (a) Material Selection (b) Geometry (c) Meshing (d) Boundary conditions (E) Loading and (f) Output analysis.

a) Material Selection:

An important parameter for design is the material used. The material can be selected based on its properties. For the fork the material selected should be hard enough to withstand the design load and it should be ductile enough so that it does not fracture under a sudden application of force. The materials that are compared in this project are Stainless steel, structural steel and Aluminum alloy.

b) Geometry:

Using the ANSYS DesignModeler, The following geometry was created.

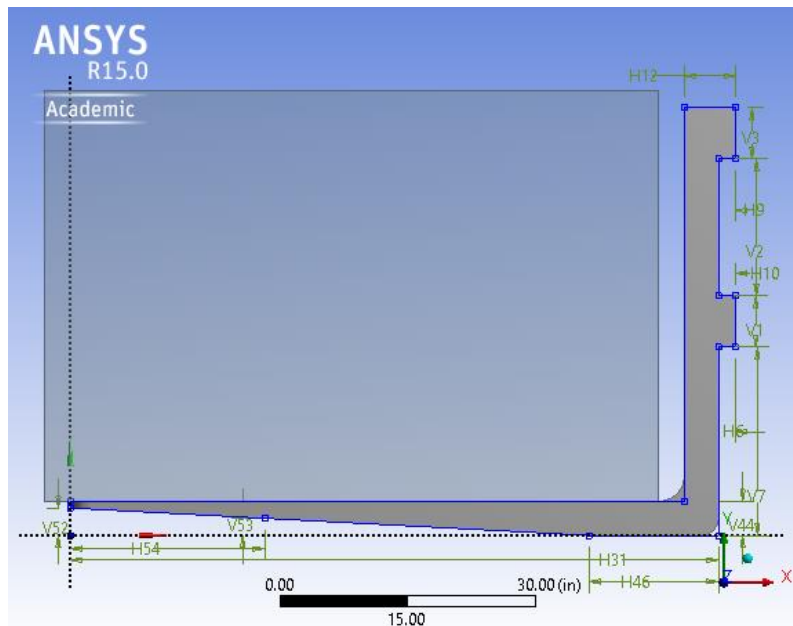


Fig 2: Fork pair holding the crate of given dimension. Here the height, Length, Thickness, Width and inner fillet radius are taken as, 36 75, 2, 6 and 4 inches respectively

The total outer length of the fork is taken to be 75 inches, but the inner length (i.e. the face which takes the load) is taken as 72 inches. Although to analyze the fork completely, the length was varied in order to see the effect of the fork length on the stress distribution and total deformation, a length of 72 was taken in the final design based on the dimensions of the given crate. Fixing the length of the fork to 72 inches, enables the fork to lift the crate oriented in any direction. A smaller length would give different stress and displacement values depending on the orientation of the crate. Thus the fork length is taken as 72 inches and is modeled for the worst case scenario.

There is a two stage taper factored into the blade design. 20% of the blade near the inside heel is kept at full thickness to provide more rigidity, and 30% from the tip of the fork is kept at 50% of the full thickness of the blade to reduce the deflection. This is also useful in reducing the material weight.

The sharp edges are filleted out to reduce stress-concentration. The inner heel is given a larger fillet radius than the outer heel to provide greater rigidity.

c) Meshing:

The crate is meshed using relatively large hexahedrons and the forks are meshed using tetrahedral elements of element size 0.8 inch, with inflation applied at the 'L' bend and the hook faces. This differential meshing increases efficiency and thus reduces computational time.

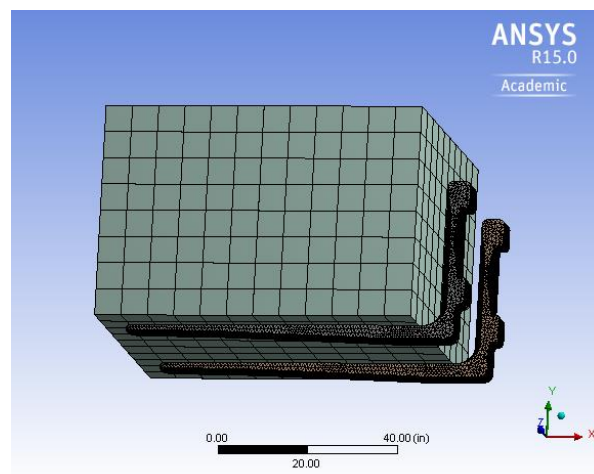


Fig 3: 1 inch mesh on the fork pair.

d) Boundary Conditions:

To constrain the forks, the inside faces of the 'C' hooks was fixed to represent the forks latching onto the carriage in a fork lift. This prevented the forks from 'flying-out' under the application of the load.

e) Loading:

The crate placed on the hooks has a load of 4000lbs. which applies a force of 4000 lbf distributed on both the forks evenly. This was accomplished by applying a negative force on the bottom face of the crate (the face which is in contact with the forks) of magnitude 4000 lbf.

f) Output Analysis:

Total deformation, equivalent (von-mises) stress, equivalent strain, maximum shear stress and safety factor (based on maximum shear stress theory with a tensile yield stress limit type) were examined on solving the model. Color contour plots, numerical tabulations, and graphs were employed to aid in the evaluation of data output. The steps were repeated for each of the materials chosen and for different fork dimensions.

3. Results

The total length (inner length) of the fork was 72", thickness 3", width 5", height 34". These dimensions were found to be the ideal dimension of the fork based on the discussions below. The fork material used in this case was Stainless steel, but it is suggested to use Aluminum Alloy instead. The contours of total deformation, von-mises stress, equivalent strain, maximum shear stress and FOS based on yield strength were found. These are shown below.

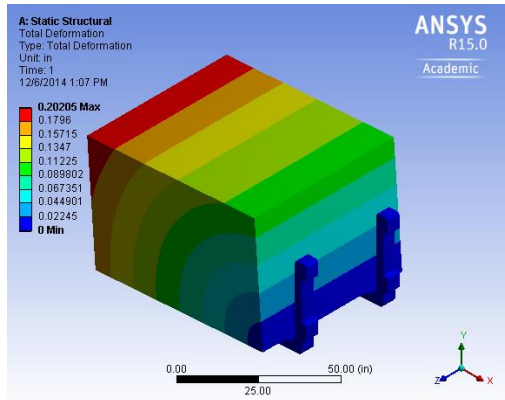


Fig 4: Total Deformation of the forks

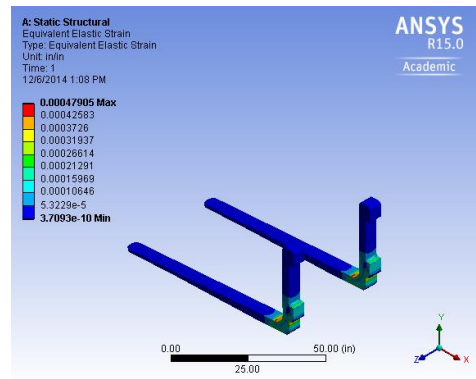


Fig 5: Equivalent elastic strain of the forks

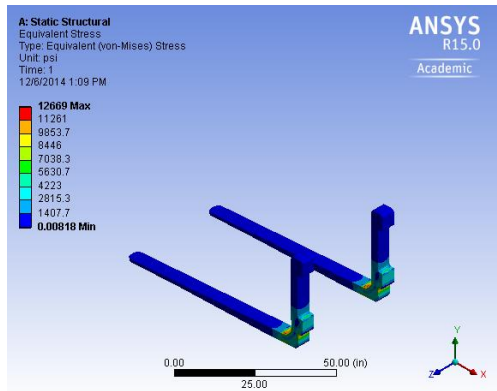


Fig 6: Von-Mises Stress in the fork

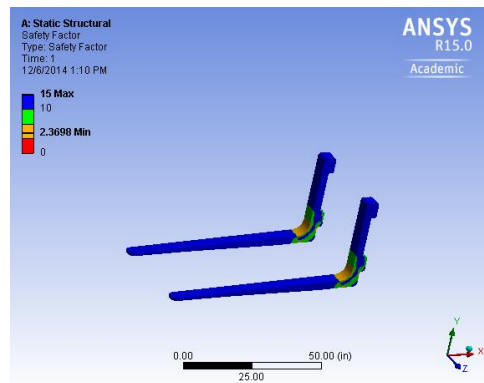


Fig 7: Factor of safety for the fork

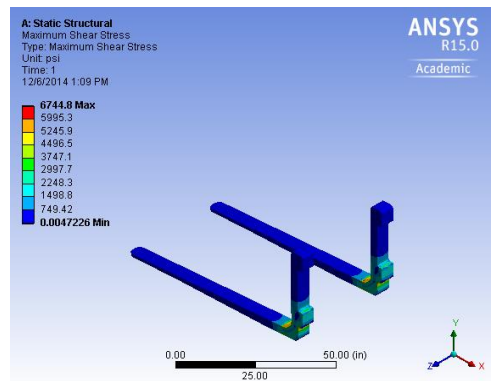


Fig 7: Maximum shear stress in the fork.

The maximum deformation was observed to be 0.20205 inches, the maximum von-mises stress was observed as 12669 psi, Maximum elastic strain was 0.00047905, Maximum shear stress was 6744.8 psi, and minimum FOS based on maximum shear stress (for yielding) was found to be 2.3698.

Stresses (both equivalent and shear) were observed to be maximum at two areas, the heel of the fork and the fixed hook, as expected. The remaining areas are relatively stress free. Maximum deformation was found to be at the far end of the crate. The total deformation is 0.3% of the total length of the fork.

Effect of fork material

The same analysis was carried out for structural steel and aluminum alloy. The results are in table 1.

| Material | stainless steel | Structural Steel | Aluminum Alloy |
|-------------------------------|-----------------|------------------|----------------|
| Total Deformation (in) | 0.20205 | 0.19556 | 0.51183 |
| Elastic strain | 0.00047905 | 0.00046388 | 0.0012632 |
| Von mises stress (psi) | 12669 | 12717 | 12056 |
| Max shear stress (psi) | 6744.8 | 6744 | 6513.2 |
| FOS | 2.3698 | 2.8512 | 3.3685 |

Table 1: Comparison of stainless steel, structural steel and aluminum alloy with all dimensions of the fork remaining the same

Effect of fork parameters

The base length taken was 60", Height 46", width 5", thickness 3" and fillet radius 3". Each parameter was varied one-by-one and the results are shown in table 2.

| Change in L | Stress (psi) | Max Shear stress (psi) | Strain | Deflection (in) | FOS |
|-------------|--------------|------------------------|----------|-----------------|---------|
| 72 | 14040 | 7328.1 | 0.000514 | 0.49285 | 2.1384 |
| 60 | 11979 | 6175.8 | 0.000441 | 0.36349 | 2.506 |
| 48 | 10006 | 5290.43 | 0.000365 | 0.28777 | 3.0005 |
| Change in H | | | | | |
| 50 | 12055 | 6179.1 | 0.000439 | 0.43031 | 2.49006 |
| 46 | 11979 | 6175.8 | 0.000441 | 0.36349 | 2.506 |
| 42 | 11952 | 6234 | 0.00044 | 0.2975 | 2.5119 |
| Change in T | | | | | |
| 5 | 6018.1 | 3124.9 | 0.00022 | 0.093331 | 4.9888 |
| 4 | 7364.2 | 3890.8 | 0.000273 | 0.1681 | 4.0769 |
| 3 | 11979 | 6175.8 | 0.000441 | 0.36349 | 2.506 |
| change in W | | | | | |
| 4 | 15348 | 7981 | 0.000582 | 0.44902 | 1.9562 |
| 5 | 11979 | 6175.8 | 0.000441 | 0.36349 | 2.506 |
| 6 | 10680 | 5536.5 | 0.000403 | 0.30604 | 2.8111 |
| Change in R | | | | | |
| 1 | 16872 | 9272.9 | 0.000608 | 0.38459 | 1.7795 |
| 2 | 12879 | 6686.4 | 0.000461 | 0.34647 | 2.3312 |
| 3 | 12754 | 6618.2 | 0.000481 | 0.32785 | 2.3539 |

Table 2: Effect of change in fork parameters

4. Discussion

The effect of each parameter on the total deformation, von-mises stress, equivalent strain, maximum shear stress and FOS based on yield strength was checked.

Effect of Length

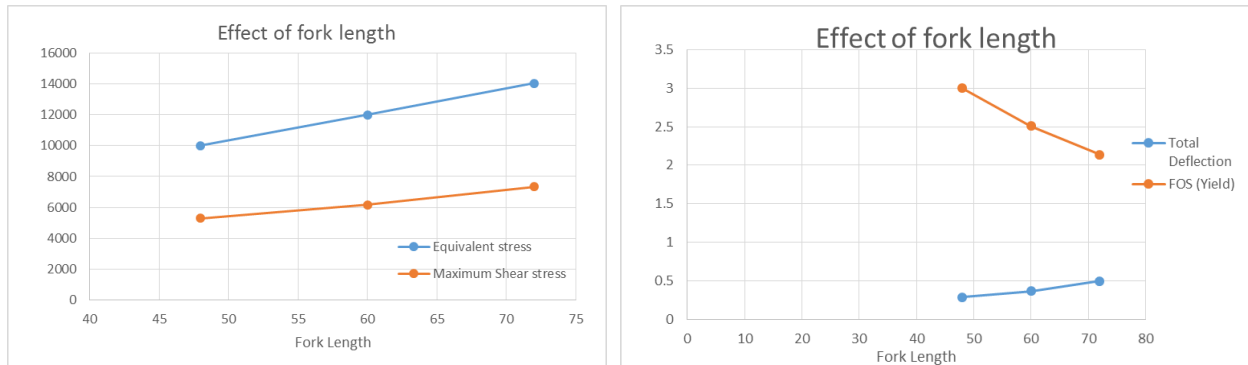


Fig 8: Effect of Change in fork length on the results observed (data taken from table 2)

As the length of the fork is increased, the equivalent (von-mises) stress, maximum shear stress and total deformation increases linearly. This is because with an increase in length the moment applied on the fork heel increases. This causes an increase in the above results. The deformation still remains under the prescribed value of 3% ^[5] of the total fork length and thus is safe for use.

Effect of Fork Height

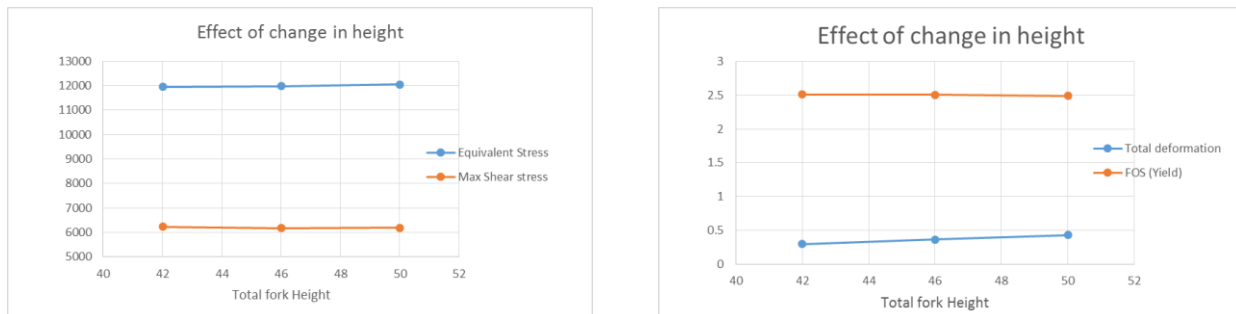


Fig 9: Effect of Change in fork height on the results observed (data taken from table 2)

The fork height does not appreciably change the stresses in the fork. But an increase in fork height increases the total deformation of the fork. Thus it is advantageous to use a fork with a smaller height. A smaller height would decrease the overall weight and thus the overall cost of the fork. Therefore it is doubly beneficial to make the fork height as small as possible.

Effect of Fork Thickness

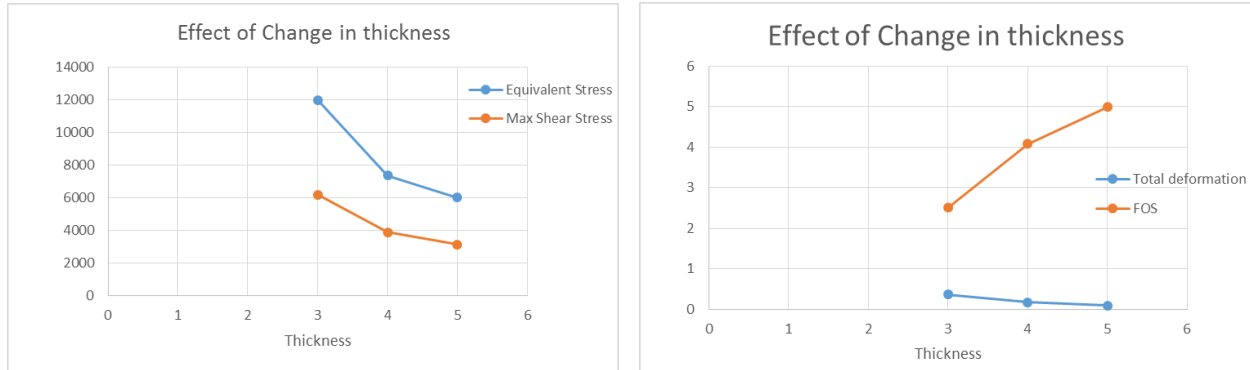


Fig 10: Effect of Change in fork thickness on the results observed (data taken from table 2)

The thickness of the fork is an important parameter to consider. As the thickness increases the stresses, strains and deformations decrease. But an increase in thickness would result in an increase in weight and thus an increase in the total cost of the fork. The FOS increases sharply with an increase in thickness. So it might be beneficial to go for a greater thickness which would provide more reliability, even though the cost would be higher.

Effect of Fork Width

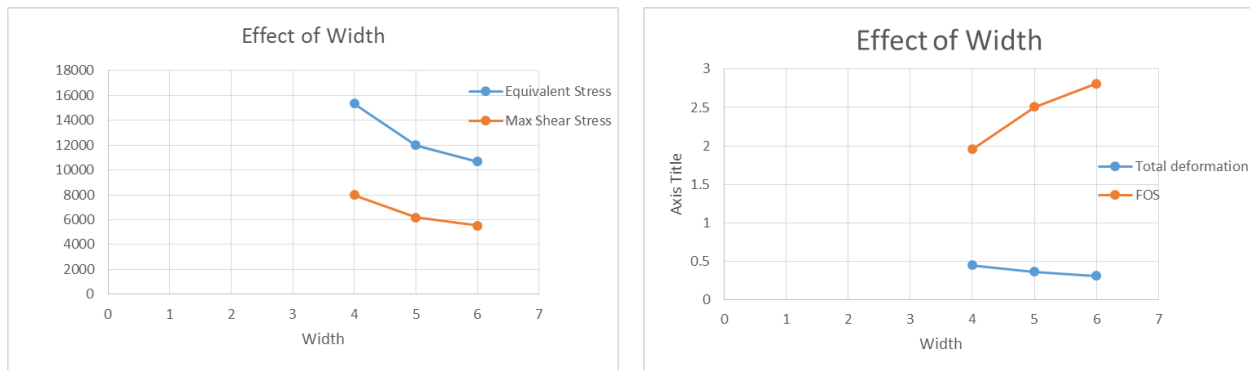


Fig 11: Effect of Change in fork width on the results observed (data taken from table 2)

As seen from the plots, the stresses and deformation decrease with increasing width and FOS increases with width. Again, it is important to weigh in the cost aspect. Greater width would mean more material which would increase the cost. But reducing the width too much in order to reduce the cost would cause the forks to fail.

Effect of Fillet radius

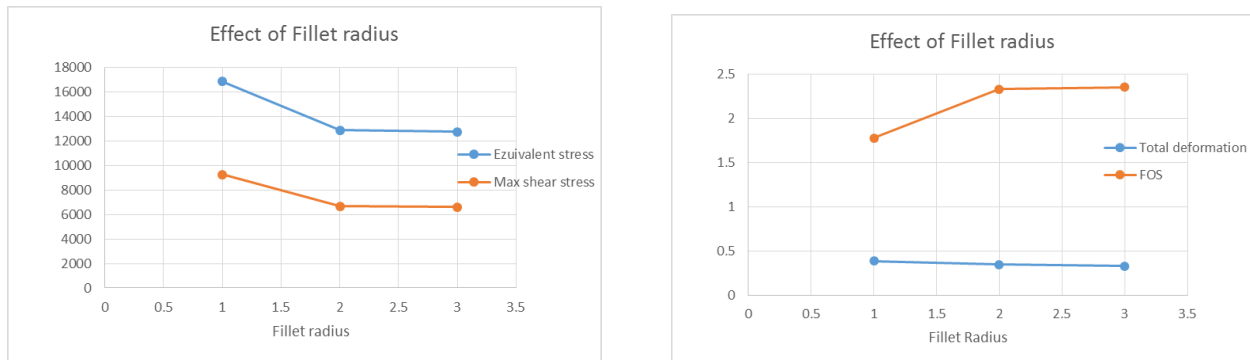


Fig 12: Effect of Change in fillet radius on the results observed (data taken from table 2)

Fillets are used to reduce the stress concentration at the edges of the fork. From the simulations it was found that a good fillet radius is about the same size as the thickness of the fork. Fillets increase the manufacturing cost, but this is a necessary cost. Fillets reduce the stresses and thus increase the life of the forks.

Manufacturing Cost

In general, the cost of manufacturing is proportional to the weight of the material to be used. The weight of the forks for different materials are as tabulated in table 3.

| Fork material | Weight (Lbs) for a fork pair |
|------------------|------------------------------|
| Stainless Steel | 773.6 |
| Structural Steel | 783.58 |
| Aluminum Alloy | 276.5 |

Table 3: Weights of Fork in pounds

From Tables 2 and 3, it is seen that Aluminum Alloy is a good choice for the fork material due to its cost effectiveness. Even though aluminum alloy has greater deformation than the other two materials, it is a better choice since the deformation is within the safe 3% limit. A deformation of 0.5 inches when compared to the length of 72" is very small and tolerable. It also has a much higher FOS as compared with the other two materials. Since Aluminum alloy is light and easier to machine, it will further reduce the cost of the fork.

5. Conclusion

This project dealt with the structural analysis of a pair of forks in lifting a crate weighing 4000lbs. The parameters that define the fork arms were analyzed to design the fork effectively, while considering the cost and FOS based on yielding. A good dimension for the fork, considering all the causes, effects and restrictions was found. The material suggested for the fork was Aluminum Alloy. The visual results obtained were as expected and the simulations gave a good idea of where to expect failure.

Due to the license agreement, a mesh size smaller than 0.8 inches could not be used. In the future, smaller mesh sizes could be used to verify the results and get a more accurate solution. Furthermore, as was observed in results and discussions, there was minimal stress concentration along the length of the fork, towards the tip, and also, between the hooks. So, the edges were filleted out to try and reduce the weight. Another option to reduce the weight would be to counter-sink a hole on the fork arm. This would drastically reduce the weight and thus the cost of the fork.

This report covered the basic initial setup for the design of fork arms and can be used as a base parameter setup for further complicated iterations.

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