Optimizing the Weight of Crawler Chain System at Quarry during Cement Manufacturing Process.

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Abstract

Cement manufacturing process is not stable and efficient due to the bulk nature of the crawler chain system. The bulk nature of the crawler chain during operation uses high energy that is also a major concern during operation. For decades now, researchers have used several approaches to optimize the design of crawler chain system to improve stability, efficiency and energy during cement manufacturing. The weight of the crawler chain design is still heavy with several operational problems reported during cement manufacturing. It is therefore imperative to optimize the current design of crawler chain system such that the system operates with speed at optimal weight, which will not lead to mechanical failures. As such, optimal weight, low operational cost and low operational energy will be achieving during operation. In the current study, the tool of finite element analysis was used to optimize the weight of the crawler chain design during operation. The effects of material used and their impact on weight were modelled theoretically and validated by finite element analysis. The following were revealed after theoretical model and finite element analysis (1) it showed there was an optimal weight that gave optimal performance during cement manufacturing process. (2) It also revealed that to improve on performance and speed, the weight of the crawler design must be minimised. Study showed a close correlation between theoretical model results and results of finite element analysis.

Keywords: PCD –pitch circle diameter; crawler chain; F- Force; T –Torque; r -radius; finite element analysis.

1. Introduction

The continuous miner is one of the major product lines that globally sells to the underground coalmine or quarry blasting in cement industry. The equipment consists of 4 main sections namely mainframe, cutter frame, conveyor and gathering head/spade. The machine provides a full cutting and loading solution on one machine. The cutter frame cuts the coal in a process called sumping. The tips on the cutter case breaks the call into small chunks. These chunks fall onto the gathering head/ spade that have a set of continuous loading arms. The CLAs push the chunks into the conveyor that runs on the center of the machine all the way to the back. At the back, a shuttle car will stand to be loaded just as a front-end loader will fill a dump truck. On the mainframe, a gearbox drives the traction chain. This chain moves the chain forward and back as well as turning the machine. This gearbox is called the traction reducer.

Furthermore, during the maintenance session, it takes the maintenance teams several hours to dismantle the link chain due to heavy link chain and that is why the proposed is been raise to design the light weight chain link for effective running and reduce downtime wastage during the maintenance activities.

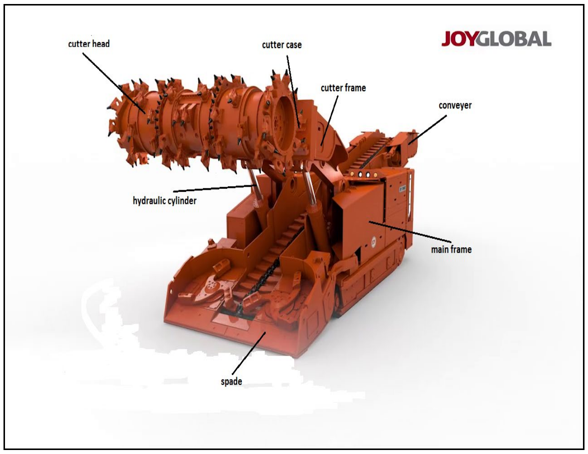

Figure 1: Description of the Continuous Miner and its components

1.1 Test bench

The test bench is made from a steel frame. The frame consists of mostly channels and angle irons bolted together. Each of the traction reducer ends can be mounted using bolts. The two traction reducers are linked with a crawler chain. The sprockets at the bottom side of the traction reducers grab the chain. On top of the traction reducer, a hydraulic pump is mounted to the one reducer and a hydraulic motor is mounted on the second reducer. The hydraulic pump is restricted to induce a hydraulic load on the traction reducer. This load enables the gears and bearings inside the reducer to run under the load. The hydraulic motor will induce the torque needed to overcome the hydraulic load induced by the hydraulic pump. The chain then transfers the torque induced.

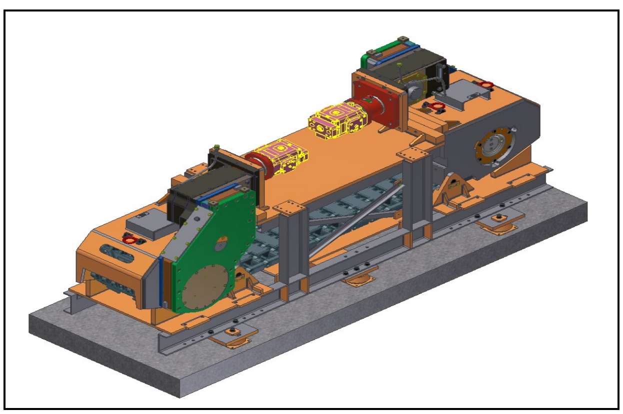

Figure 2: Shows the Traction reducer test bench fully assembled

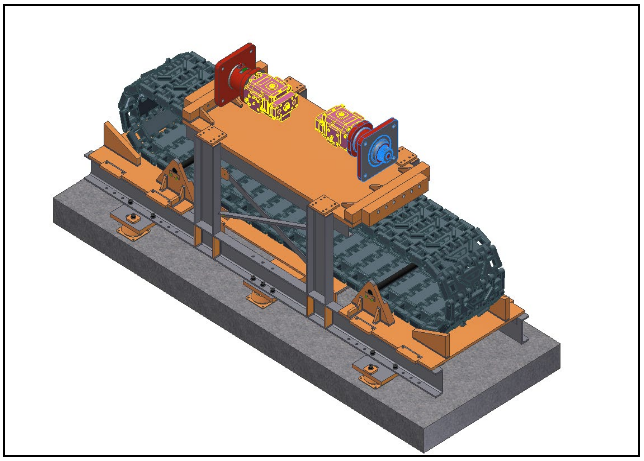

Figure 3: Test bench chain configuration

1.2 Finite Element Analysis

The finite element is a numerical technique used to solve mathematical problems in engineering field. This is used to predict the structural behaviour of many assembles or sub assembles. It allows design for fatigue and saves on costs by not overdesigning machines, similar to how it was in the olden days [Chandrupatla et al]. Most projects were trial and error and that had huge cost implications and including lives lost in some of the failures. However, software can simulate the responses of the body to the applied forces on it.

2. Chain Link Perceptions and Scheme

2.1 Existing Chain Link Model

The existing chain model is 558mm wide, 216mm long and 65mm thick. These are physical dimensions of the scope of work or boundary dimensions. The existing production model is designed to be bulky in order to be able to handle the 90 tons of continuous miner and be able to transfer the torque to the ground effectively. The chain link has two holes that link up with the sprocket on opposite ends of the chain. These two points are high stress areas as the 117.32kN per tooth is transferred on those points. There are guide pins designed to join the chain links. These go in between the loops that are across the chain link. The rings also can practice some strain if the chain is fitted wrongly or when the chain bottlenecks while in operation.

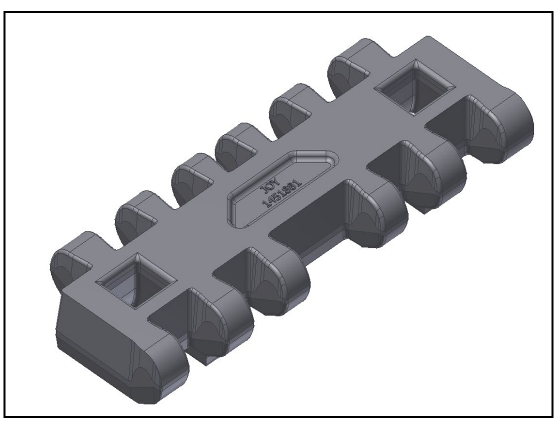

Figure 4: Existing model of the chain link.

3. Different Material Option

3.1 Carbon Fiber concept

In efforts to reduce the weight, a thorough research and consultation was done on several occasions to find the best-suited material to execute new design. The chain was refined in order to reduce the cost of manufacturing. The fillets were removed from the design and the overall shape had to be changed. The overall design dimensions had to be maintained as well as the dimensions of the sprocket holes in order to retrofit it into the traction reducers to be tested.

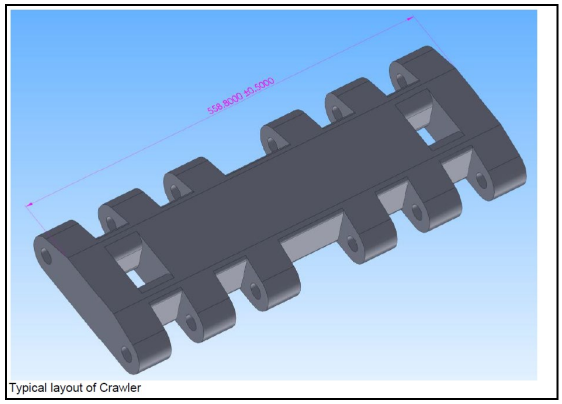

Figure 5: Illustrative design picture of the carbon fiber concept.

3.2 Steel concept

A substitute to the carbon fiber is required as the cost of manufacturing the die and the mould evidenced to be expensive in carbon fiber concept. The intention was to reduce the weight by at least 50% from the original 30kg weight of the production chain link. The grey part in the figure below shows the area that could be eliminated as part of reducing the weight [Budynas]. Bulk of the area does not transfer the torque from the sprocket but helps in keeping the chain perpendicular to the sprocket and also assists in applying the tractive effort to the ground. The test bench only needed the torque transferred in between the two traction reducers linked together; therefore, that portion serves no purpose to the bench testing. The figure 6 below shows the concept that was chosen to be refined. The steel concept proved to be cheaper than the carbon fiber concept though some of the fillet would have being difficult to machine.

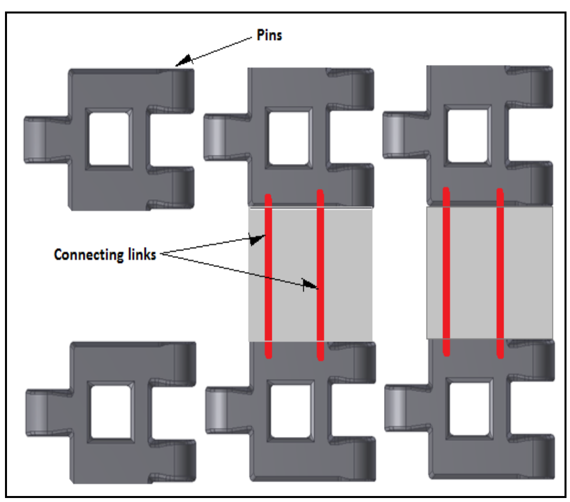

Figure 6: Descriptive picture of the steel chain concept and possible eliminated areas.

4. Final Design Modelling of Test Bench Chain

After criticizing both material options suggested, the second option concept, which is steel chain, further needed refining in order to reduce the manufacturing cost of the chain.

The production link of the chain was divided into two separate links that are connected through rods. The chain takes the shape of the original link, which was modified to a smaller component. However, it will not reduce or affect the performance operation.

There have been grooves that used to insert the rods. These rods are for stability, to keep the two links parallel. This will avoid one of the links moving in front of the other opposite to it. The figure 7 below shows the final design of the model chain.

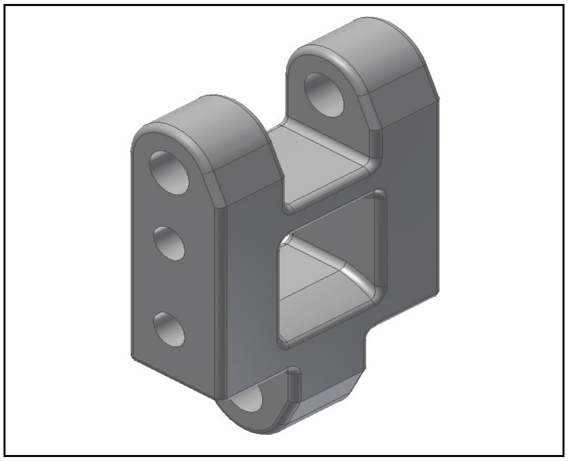

Figure 7: Model of the final chain link.

However, the Figure 8 below shows the full model of the complete chain link with the locating/ stabilizer pins. The links are symmetrical so they can be used on either side of the connecting rods/links. This makes it easier when casting is required.

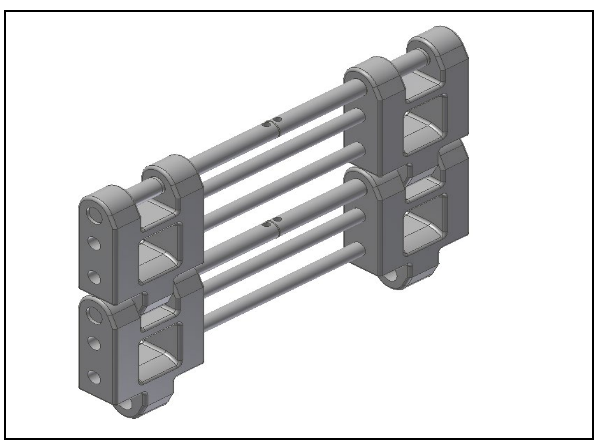

Figure 8: Model of the complete chain

It is pivotal that the link be checked properly and see if it is aligned with the sprocket teeth to avoid premature failures or damages on the sprockets on the traction reducers. The smooth transition of the chain linking up with the sprocket will aid in the gradual application of the force. igure 9 below shows the detailed view of the chain to pattern the sprocket link.

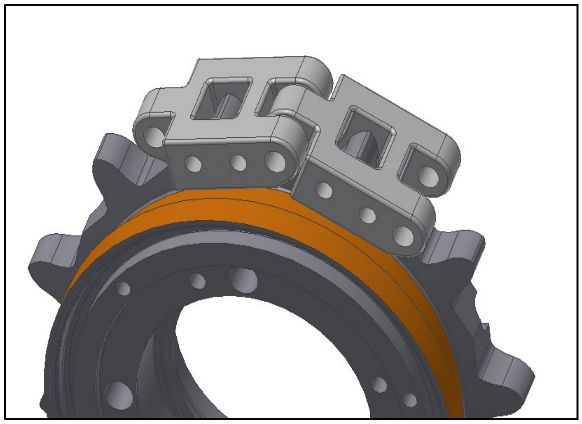

Figure 9: Link spacing and fitment check

The diagram below, Figure10, analyzes the cut section view of the sprocket and chain link. The sprocket teeth are well within the envelope of the chain holes. The chain is able to sit flush against the sprocket profile. This proves that the dimensions of the chain are correct.

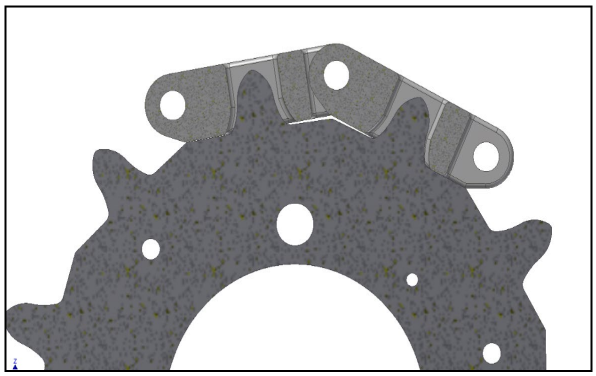

Figure10: Cross-sectional view of the link and sprocket

4.2 FEA on the Chain

After fitment checks on the model proved the physical dimensions of the chain within the specified design parameters, the next phase was to check if the chain could handle the loads applied by the traction reducer. Mathematical calculations were done to ascertain the perpendicular forces transferred by the sprocket to the chain. The calculations are shown below:

4.2.1 Torque and perpendicular force calculations

Test motor torque = 420Nm

Service factor = 2

New motor torque = 840 Nm

Ratio = 229.4:1

Torque on sprocket =192 696Nm

PCD on the sprocket: $PCD = \frac{P}{\sin\left(^{180}/_{n}\right)}$ (where PCD refer to as Pitch Circle diameter)

Pitch is 6.375”

Number of teeth {n} =11

$$PCD = \frac{6.375 \times 25.4}{\sin(^{180}/_{11})}$$

PCD= 574.75mm

$T = F \times r$ (where T is Torque, F is Force and r is radius)

$$F = \frac{T \times 2}{PCD}$$

$$F = \frac{192\,696 \times 2}{0.57475}$$

F = 703.912kN

6 teeth are engaged – 3 teeth per sprocket

Force per tooth is 117.32kN

The reason behind the values chosen was according to the material specification.

4.2.2 Load and constraints

The FEA analysis environment requires insertion of the following on the model:

- Load magnitude: - this can be force, torque or pressure.
- Contacts: - these vary from fixed contacts to frictionless contacts depending on the application of the model.

Figure 11 below shows the contacts that were placed on the chain model. The yellow arrows show the forces and where they are applied on the chain model. The blue ones show the contacts placed on the chain. However, the simulation is based on a condition of a jammed chain and the forces are continuously applied on the chain link. The chain links have been assigned with frictionless contacts for them to freely rotate but not to shift from the allotted position. This will cause the results to be inaccurate, as a physical chain metal cannot go past another metal. In this case, the blue arrows represent a fixed constraint.

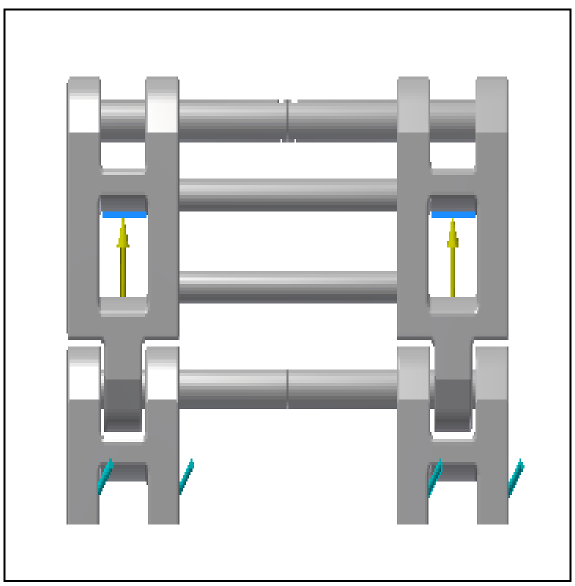

Figure 11: Constraints around the FEA chain model

4.2.3 FEA results on the chain

The model ran on the FEA environment. Several iterations were running to refine the results. The outcome of the FEA is shown in the figures 12 below. The first iteration was done with the force perpendicular to the chain and the second iteration was done with the force at an offset of 5 degrees from the perpendicular force. This offset force is to represent the effects of misaligned sprocket to the chain and can withstand the chain stresses caused due to the offset.

4.2.4 Strain Results on the chain

The two figures (12 and 13 respectively) below show the strain distribution on the Z-axis as well as the Y-axis. The maximum strain on the Z and Y-axis amounted to 0.00138ul and 0.001ul respectively. These are small insignificant values to be concerned about. The chain will be able to withstand the strain induced by the forces applied to it.

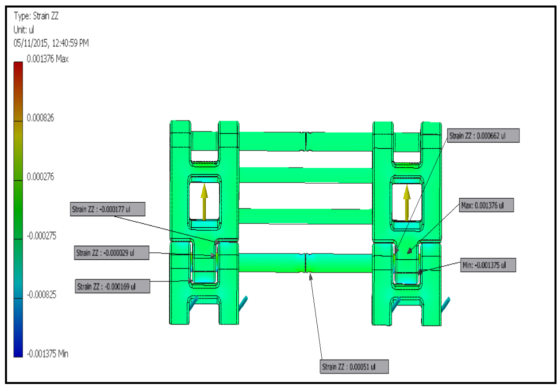

Figure 12: Z-axis strains on the chain

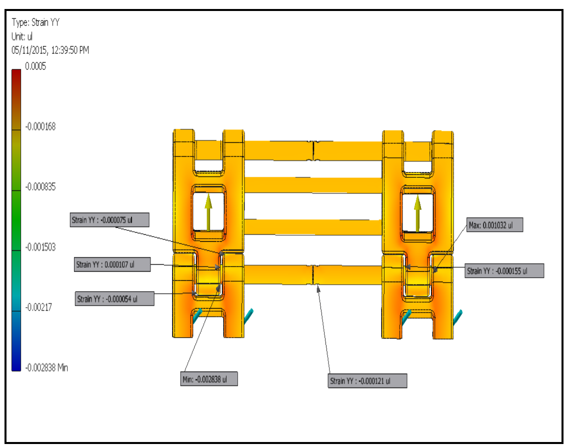

Figure 13: Y-axis strains on the chain.

4.2.5 Displacement on the chain

The FEA Figure 14 shown below explained that the displacement would be more on the connecting chain rod. A maximum deflection of 1.545mm will be experienced on the hole of the chain link where the connecting rod is slotted in. Various points around the chain link were taken to show the pattern of the displacement around the chain link.

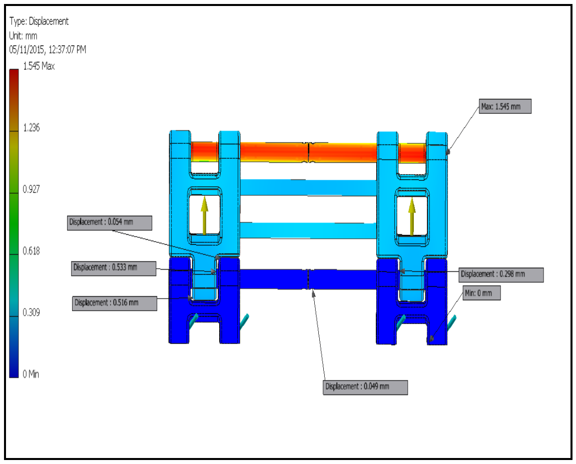

Figure 14: Displacement distribution on the chain link.

4.2.6 FEA results of the force at an angle

In the aim of predicting the possible premature failures that can happen to the chain, the force was placed at 5^0 from the perpendicular plane. This is to simulate a misaligned jammed chain.

a) Z-axis strain results due to the forces at angle.

The strain distribution on the chain shows that the maximum strain will be on the connecting pin and the chain link slot. The maximum value predicted is 0.0024 units. This value has doubled from the first iteration where the force was applied perpendicular to the chain link. The figure below shows the distribution of the strain across the chain on the Z-axis.

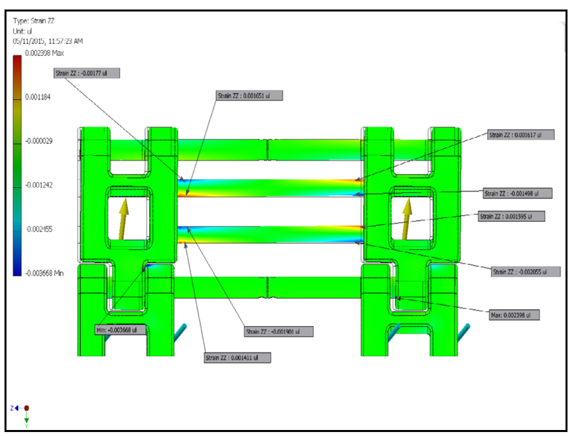

Figure 15: Z-axis strain for forces at an angle

b) Y axis strain on due to the forces at an angle

The strain increased on the edges of the chain where the two links meet, this avenue might cause localized deforming and it might create fatigue cracks. The below figure 16 explains the distribution of the strain on the chain on the Y-axis plane.

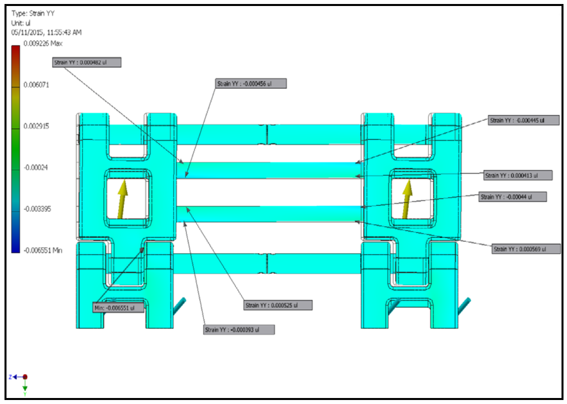

Figure 16: Y-axis strain distribution due to forces at an angle

c) Displacement results due to the forces at an angle

Based on the FEA calculation, the displacement has increased from 1.5mm to 5.5mm. The maximum force can be noted on the link and if that force is being applied on, this will cause the chain to pull out from the connecting pin. The stability pins will also experience some movement due to the forces at an angle. They will experience bending and elongation. This may cause them to fail prematurely. Figure 17 below shows the displacement values across the chain.

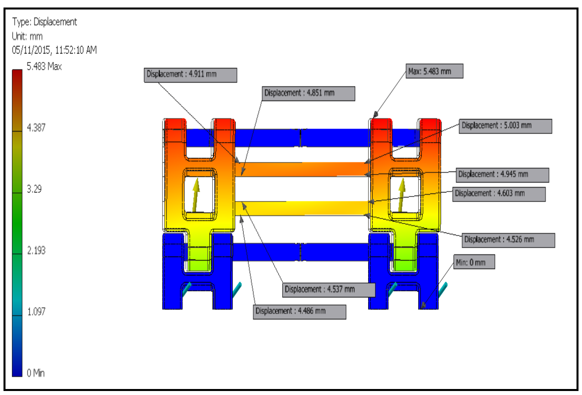

Figure 17: Displacement due to the force at an angle

5. Manufacturing Costs

5.1 Carbon fiber concept cost.

Consultation with Company A was done on the manufacture of composite chain using the carbon fiber material. The concept had to be designed to remove sharp edges, from there, tooling had to be manufactured to shape the mould to be used and then a prototype chain had to be made for quality checks. This meant that the price to manufacture a mould for a once off chain would be too high. However, carbon fiber is out due to the expensive material.

5.2 Steel concept cost

After consultation with Company B, three options were available to manufacture the chain. The chain could be manufactured using investment casting or machined using Weldox 700 (High Strength Low Alloy Steel) or Hardox 400 (Abrasive Resistant steel). The investment casting proved to be the cheapest. Weldox 700 is high strength material that has good impact properties but it has weak abrasion resistance properties. This means it will wear at a faster rate than Hardox 400.

Hardox 400 has well anti abrasion properties but weaker impact properties compared to Weldox 700. This is a good quality for increased wear life on a chain since there is a lot of rubbing of two metals as the sprocket engages with the chain.

According to the quotation obtained, it was obvious that carbon fiber is costly than the two other material and followed by Hardox 400 and the cheapest is Weldox 700. However, based on the quality material, Hardox 400 will be preferably chosen.

6. Conclusion

The chain was designed and it met the anticipated upshot design and the preliminary needs of the project. The chain is 50% lighter than the initial chain mass of 30kg per link. However, the chain is also strong enough to withstand the high torque induced by the gearbox. The cost to manufacture the chain is reasonable enough for a once off production. The present chain design is easy to manufacture and assemble i.e. no complex machining needed to produce the chain. Furthermore, it reduces the issue of too many manpower to dismantle the equipment or moving it from one point to the other since the weight has been reduced drastically according to proposed plan and objectives.

The great achievement in this research is that the working hours wastage during the maintenance activites was reduced and numbers of skilled personnel was also reduced as well.

7. Recommendations

Further refining of the chain could be done in order to reduce the cost of machining. The chain must be trialed on a small scale prototype to see if there will be any unforeseen complications that may arise during the manufacturing process of the typical chain. A resilience test can be done to the chain model to predict the possible areas of failure in future.

References

Bosnjak, S.M., Miodrag, A. (2011) Failure Analysis of the Stalker Crawler Chain link. Available from: www.sciencedirect.com. [Accessed 15th March 2016]

Budynas‒Nisbett (2006) Shigley's Mechanical Engineering Design- Eighth Edition. USA, McGraw‒Hill Companies.

Chandrupatla, T. R., Ashok, D.B. (2002) Introduction to Finite Elements in Engineering-Third Edition. New Jersey, Prentice Hall Publishers.

Hoffmann, K. (Unknown) Applying the Wheatstone Bridge Circuit. Available from: http://www.hbm.com.pl/pdf/w1569.pdf [Accessed 15th March 2016].

Inggs, N. (2014) 12HM37C Gathering Head-FEA Results [Presentation] Joy Global Inc Johannesburg, 3 April 2014

Inggs, N. (2015) Internal load Feasibility Study [Presentation] Joy Global Inc Johannesburg, 20 April 2015

Macsteel, (Unknown) Macsteel-Special Steels Catalogue. Available from: http://www.macsteel.co.za/files/817m40_en24.pdf [Accessed 30 April 2016].

Renold. M (2006) Conveyor chain: Installation, maintenance & designer guide. Available from: http://www.renold.com/media/165388/Conveyor-Ins-Main-REN16-ENG-10-10.pdf [accessed 3rd March 2016]

Slocum, A. (2008) Fundamentals of Design- Topic5: Power Transmission Elements 1. Available from:http://web.mit.edu/2.75/fundamentals/.PDF [Accessed 12th May 2016]

Tsubaki Inc, (1997) The Complete Guide to Chain. Available from: http://tsubaki.ca/pdf/library/the_Complete_guide_to_chain.pdf [Accessed 22nd March 2016].

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