Conveyor Chain Links – A Review

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Abstract

Industries such as mills, paper mill, food processing, fertilizer industry, pharmaceutical industry, cement industry, foundry industry, heat treatment units, coal mines etc have roller conveyor chains as one of the important components such that its failure ceases production. As chain links are critical components of many industrial companies, reviewing literature on the progress of research made on it is very crucial in providing an understanding of the subject area. This paper delves into the various literatures pertaining to conveyor chain links under categories of failure analysis, modeling and simulation as well as wear. The various methods used for analyses, results and conclusions deduced in addition to the limitations of the various literature are discussed in this paper.

Keywords: Conveyor Chain links, Inclusions, Finite Element Analysis, Fatigue Life, Failure, Necking

1 Introduction

Conveyor system is a mechanical system used in moving materials from one place to another and finds application in most processing and manufacturing industries such as; chemical, mechanical, automotive, mineral, pharmaceutical electronics etc. It is an easier, safer, faster, durable, reliable, more efficient and cheaper means of transporting materials from one processing stage to another compared to manual handling. Material handling is an important factor in manufacturing and therefore the efficiency of material handling equipment adds to the performance level of a firm (Daniyan *et al*., 2014).

They can be installed almost anywhere, and are much safer than using a forklift or other machine to move materials. Chains are made up of several rigid links which are hinged together by pin joints to provide the necessary flexibility for wrapping around the driving and the driven sprocket as shown in Fig. 1. These sprockets have projection teeth of special profile and fit into the corresponding recess in the link of the chain. Based on its history and development, the chain is simply a mechanical belt running over sprockets that can be used to transmit power or convey materials.

Chain strips are machine elements that are subjected to extreme service conditions, such as high tensile loads, friction, and sometimes aggressive operating environment which includes presence of humidity, seawater and chemicals, among others. Apart from tensile overload fracture, double shear is also a common failure mechanism which occurs under lower applied loads (Jagtap *et al*., 2014). As these chains operate under various forces, failure of chain assembly is the major problem. The causes of these failures may include improper material selection, uncertainties in manufacturing and faulty manufacturing processes. The chain link is made up of an inner and an outer link which are press fitted to form a continuous chain. Chains are used in a variety of applications in engineering practice. In general, there are three basic types of system; hoisting and securing chains, conveying and elevating chains and power transmission chains.

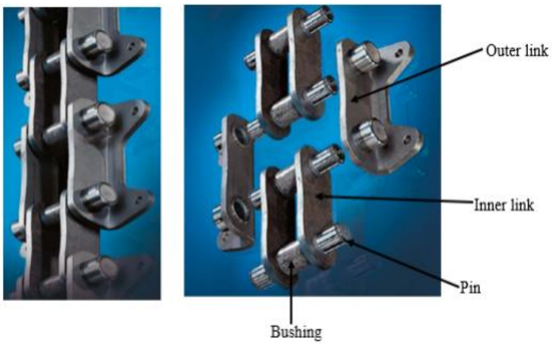

Fig. 1 Typical Chain Link Assembly

2 Review of Literature on Modelling and Simulation of Conveyor Chain Links

Noguchi *et al.* (2009) proposed some methods of weight saving for roller chains. These methods were based on finite element method (FEM) analysis of the stress and deformation in a link plate of a roller chain. Weight reduction was achieved by designing a model with a centrally located hole of diameters 3, 4, 5 and 6 mm in the inner link plate and analyzed for stress. Chamfering edges of link plate circumference as well as reducing the thickness of the chain link were also considered. Stresses were 3 % higher in the proposed design, but the weight reduced by 10 %. Tensile tests were performed on link plates made of resin, and the effectiveness of the proposed model was confirmed.

Jagtap *et al.* (2014) studied analytically, experimentally and numerically the behavior of a roller conveyor chain strip under tensile loading. Comparison was made between the three methods and the results showed that they are within +/- 10 percent of the calculated working stress. It was deduced that, the fatigue cracks initially nucleated at the external cracks of the link, and later propagated to the inside of the links until sudden fracture occurred. It was concluded that a roller chain drive may be subjected to tensile loads, thus it must have high tensile strength to withstand the wide range of tensile loads that may be imposed on it. Comparison between the results obtained from experimental, analytical and numerical showed a deviation for which the reasons behind the deviation was not stated.

Ravindra *et al.* (2014) researched into various application aspects and manufacturing aspects to formulate an idea of the system. In addition, Finite Element Analysis (FEA) was used to conduct shape optimization. Since lot of work has already been done on other components, the focus was narrowed down to specific component of chain which is the outer link. Different parameter of outer link was changed and subsequently, stress analysis was performed using ANSYS simulation software to establish whether material saving is possible or not. A conveyor chain with reduced weight was obtained by changing optimal radius and thickness of link plate, providing central hole in link plate as well as champhering the circumference of link plate edge. Based on the outcome of the simulation, an optimal radius was obtained thereby reducing the weight of the chain link which in turn reduced the cost of operation.

Kulkarni and Patil (2015) carried out failure analysis and weight optimization on conveyor chain numerically using ANSYS simulation software. The aim of the study was to reduce the weight of conveyor chain link through material changes by proposing materials which have a reduced weight but the same strength as conventional steel. E-glass epoxy and carbon epoxy were the proposed material. For E-glass epoxy, as the thickness was increased from 5 mm to 15 mm, the equivalent stress generated varied from 386.01 MPa to 128.3 MPa which were below the ultimate tensile strength (1500 MPa) of the material considered (Bhandari, 2010). The deformation was found to be decreasing steadily from 0.23217 mm to 0.073205 mm. For Carbon epoxy, as the thickness was increased from 5 mm to 15 mm, the equivalent stress generated in the link varied from 786.26 MPa to 250.08 MPa which were also below the ultimate tensile strength (1600 MPa) of the material considered whereas deformation was found to be decreasing steadily from 0.11295 mm to 0.036593 mm. The weight obtained from 15 mm equivalent thickness of steel, E-glass epoxy and Carbon Epoxy were 98 kg, 75.11 kg and 59.78 kg respectively. A 23.71 % weight reduction was obtained for E-glass epoxy whereas for Carbon Epoxy, 39 % weight reduction was achieved. Hence it was concluded that E-glass epoxy was the best alternative to the steel link as it was safe, generated lower stress levels and at the same time resulted in 23.71 % weight saving.

Barge and Gaikwad (2016) employed Finite Element Analysis (FEA) to conduct shape and weight optimization of roller chain outer link plate by changing the shape of outer link plate. The work was validated by carrying out experiments on the optimized outer link of the conveyor chain link using shape finder plot, Von Mises stress plot and displacement plot to obtain an optimized shape for the outer chain link. The failure of the outer link was predicted to occur around the hole as there was a maximum stress concentration around the hole. The maximum stress obtained at a maximum load of 269.3 kN was 820 N/mm^2. A maximum displacement of 0.1226 mm was also obtained around the hole emphasizing the fact that failure was likely to occur around the hole. Experimental results showed that the maximum stress was 821.87 occurring at a maximum load of 282.96 kN. The failure occurred around the hole as predicted by the numerical results. Based on the FEA and Experimental results, it was observed that the optimal value of radius, thickness and height were 44.5 to 45 mm, 9.5 mm and 68.30 mm respectively. It was concluded at the end of their research that the newly designed outer link of the conveyor chain saves 72 gm of weight per link plate and 1.2 kg per meter length of chain.

Sutar and Kondhalkar (2016) carried out a research which focused on weight optimization of roller chain link inner plate by using shape optimization module in ANSYS workbench. By using the Von Mises stress plot and shape finder plot, materials at the corners of the plate and a neck of optimal radius of value between 44.5 and 45 mm were removed as it was the least stressed regions of the chain link. The results obtained from the finite element analysis were within the +/- 10 % of the calculated working stress and therefore the design was safe under the 25 tons maximum working load. Experimentally, the chain links failed at a load of 29.5 tons and beyond.

Kamble *et al.* (2016) in their paper used topological approach to reduce the weight of chain link plate. Industrial factories like sugar factories employ chain conveyors for many applications and due to the bulky nature of stacker chain, power consumption is more. Topology optimization was therefore done using ANSYS software to reduce the power consumption rate. EN19 material was used for chain link plate for better strength. Area where stresses were low for applied loading were reduced by using software topology optimization. The weight of link plate after optimization reduced from 0.504 kg to 0.431 kg, which resulted in 15% weight. Structural analysis was performed on the final design using ANSYS to find out maximum stresses in chain link plate. A computerized universal testing machine was used to obtain the breaking load of the newly designed chain link plate. The breaking load was in the range of +/- 10 % of initial working load and hence new design was safe.

Shahane and Umbrajkaar (2016) in their paper delved into various application aspects and manufacturing aspects to formulate an idea of the system. Finite Element Analysis (FEA) was used to conduct shape optimization. Since lot of work had already been done on other components, in this paper the focus has been narrowed down to specific component of outer link. A composite material was used for the outer chain link in order to reduce its weight. Weight of link after optimization reduced from 0.3135 kg to 0.2407 kg. By using glass fiber material for the outer link, there was a reduction in weight. The reduction in weight and maximum stress is obtained by using glass fiber as compared to original outer chain link.

Bhosale and Patil (2018) in their study proposed glass fiber reinforced polymer (GFRP) as an alternative material in the manufacturing of conveyor chain links to reduce the weight of the chain link thereby reducing power consumption. Theoretical, finite element analysis (FEA) and experimental analysis were performed on the chain links. It was concluded that approximately 30.77 % weight can be saved using GFRP material for the conveyor chain link instead of conventional steel material. Also, the frequency of vibration was improved up to 1.2 times by replacing the current steel design with the GFRP material.

3 Review of Literature on Failure Analysis of Conveyor Chain Links

Sujata *et al.* (2006) in their study using visual examination found a shallow crack on the surface of the chain link as shown in Figure 2.4. Under stereo-binocular microscope, the authors found that the fracture surface showed coarse crystalline features. The sample containing the crack was cut, mounted, metallographically prepared and observed under an optical microscope. Visual examination revealed a crack-like surface defect and the optical micrograph showed oxide entrapment in the material near the surface. The crack-like defect was not perpendicular to the surface. In between the crack surfaces, the authors used Energy Dispersive X-Ray (EDX) analysis in SEM for investigation and found that the non-metallic inclusions were mainly iron oxide. The authors concluded that the conveyor chain links had failed due to presence of manufacturing-in defects. The defects were identified as forging laps or folds and can be summarized as inherent defects. The investigation also showed that surface defects were present in the billet itself. They then recommended that the billet be properly dressed and the surface defects be removed prior to the forging operations. The significance of the coarse crystalline features and the iron oxide inclusions were not stated in this paper.

Bošnjak *et al*. (2011) carried out failure analysis on a Stacker Crawler Chain Link. The goal of the study was to diagnose the cause of chain link breakdown. Working stresses in the chain link were calculated by applying FEM. Experimental investigations were also carried out including; chemical composition analysis, tensile properties, impact toughness and macro and micro-hardness. Metallographic examinations were conducted additionally. Based on the results of the numerical-experimental analysis, it was concluded that chain link breakdown is predominantly caused by (a) substantial deviation of the mechanical properties of the material with respect to those prescribed by the standard and (b) the existence of macro and micro cracks in the material structure. It was therefore concluded that the failure of the chain link was caused by 'manufacturing-in defects. The origination of the macro and micro cracks was not stated; whether they were inherited, whether they originated from grain boundary or inclusions and therefore the root cause of failure could not be established.

Momcilovic *et al.* (2011) investigated a failed bracket of a conveyor using Scanning Electron Microscopy analysis and established the presence of oxide on the crack surface. The authors observed that the contact zone between chain link and bracket was one of the most stressed zones and fracture always occurred in that zone. Based on their research, they concluded that the origin of cracks in chain brackets in this case was due to the production process, because the wrinkling of the material app eared during hot b ending. The implications of the oxide found on the crack surface were not stated and also the relationship between the wrinkling of the material and the crack were not established.

Bosnjaka and Arsic (2011) investigated the cause of the chain link breakdown on a hydraulic excavator. Its superstructure leans on three crawlers of the same length, width and the height. During the stackers travel from the erection site to the open pit mine, three crawler chain links fractured. The working stresses in the chain link were evaluated by finite element analysis (FEM). Experimental techniques were used to investigate the chemical composition, tensile properties, impact toughness, and macro and micro hardness. Based on the numerical-experimental analysis, the authors concluded that substantial deviation of the mechanical properties of the material with respect to those prescribed by the standard occurred and the presented failure of the chain link was caused by 'manufacturing-in' defects.

Haris (2013) investigated the causes of failure of a chain system through characterization of the failed component. The analysis revealed that the weld defects such as craters lead to crack propagation and a cyclic loading causes the fatigue failure. The fatigue failure occurred due to this inherited crack at the outer circumference of the weld within chain attachment and outer chain link plate. This type of defect can also be categorised as designing-in defect. Fatigue crack propagation was evident by progressive beach marks and the scanning electron microscopy (SEM) analysis revealed the types of microstructure that resulted at the heat affected zone (HAZ). Hardness testing by using Rockwell Tester found the different hardness profiles at the three areas, i.e., weld metal, base metal and heat affected zone. The maximum hardness values were found at the heat affected zone and the weld metal. Cracks generated at the outer circumference of the weld within chain attachment and outer chain links plate within the material led to fatigue failure. Haris proposed that the thickness of the outer link be increased but didn't relate it to how this increase will impact on the weld strength or weld defects (craters) within the chain link.

Singh *et al.* (2013) studied the failure of bridle chain used for hoisting in the mines. Laboratory examination proved that the defect is a mechanically induced one. Visual and stereo-binocular observations revealed surface defects in samples. It was observed that it was not safe to strain the chain to beyond the elastic limit of the material. It was concluded that the cause of failure was as a result of inherited defects in the material and that the chain can fail mechanically by overloading, fatigue and wear. The type of inherited defects was not stated. The maximum load the investigated chain link can withstand and the maximum load conveyed by the conveyor chain link were not stated and therefore it cannot be concluded that overloading was the cause of failure.

Bošnjak *et al.* (2013) carried out a failure investigation of the bucket wheel excavator crawler chain link to diagnose the cause of the damage. In order to identify the reasons behind chain link failures, stress state calculations were performed as well as experimental investigations which included visual and metallographic examinations, chemical composition analysis and tests of mechanical properties. The sulphur content obtained from the chemical analysis of both samples was higher compared with specifications. This resulted in decreased impact toughness, particularly under impact conditions. The significant decrease of elongation compared with specified values confirmed the presumptions based on the results of the chemical composition. The obtained low values of elongation and contraction meant that the samples had very low resistance to crack initiation and crack propagation. Based on the results of the numerical–experimental analyses, it was concluded that the chain link breakdowns are caused by 'manufacturing-in' defects. The carbon content obtained from the chemical analysis was lower than that of the required standard but the paper never took into account this observation.

Yin *et al.* (2019) carried out failure analysis on bucket elevator conveyor chain links using visual examination, chemical analysis and metallographic analysis. These processes were performed on both failed and un - failed conveyor chain link samples. Visual examination carried out revealed that the type of failure was brittle fracture in that there was no necking. In addition, the researchers observed an offset between the sprockets evidenced by indentations on the outer link of the chain link as well as vibrations within the bucket elevator system. Chemical analysis performed on 5 samples established that Silicon (Si), Phosphorus (P), Sulphur (S), Manganese (Mn), Chromium (Cr) and Molybdenum (Mo) all met the British standard EN 10293 requirements for steel casting for engineering use but Carbon (C) did not. It was concluded that the type of failure was brittle fracture induced by inclusions which were the root cause of failure of the conveyor chain links

4 Review on Wear of Conveyor Chain Links

Conwell and Johnson (1996) investigated experimentally, the dynamic behavior of roller chain drives. A strain gauge mounted on a link side plate was used to determine chain tension during normal operation over a wide range of linear chain speeds and preloads. The test machine also included specially instrumented idler sprocket that allowed the measurement of the horizontal and vertical components of the bearing reaction force. The roller-sprocket impact force was then computed by an experimental transfer function approach facilitated by a Bruel Kjaer 2032 dual channel spectrum analyzer. It was observed that the tension in a chain link increases rapidly as the link exited the driven sprocket. The increase in tension occured over less than two sprocket teeth from loose side to tight side. The tension in the chain link then decreased very rapidly as the link entered the drive sprocket. The decrease from tight side to average loose side tension occured over less than two sprocket teeth. The impact force tended to increase as chain tension and speed increased. In this research, it confirms the observation that chain links are subject to high levels of fatigue loading in the findings of this study and therefore the new chain link has to be designed taking into consideration fatigue loading.

Sadagopan *et al.* (2007) studied the wear reduction of existing chain used in 100cc motorcycles. Elongation of chain was calculated and compared with the experimental results. In an alternate design developed, theoretical evaluation for elongation was made by applying the same conditions used for evaluating the existing chain. Fatigue properties of existing standard chain components were evaluated using mathematical modeling as well as by using ANSYS software. This research intends to use ANSYS software to evaluate the fatigue properties of the chain links.

Kerremans *et al.* (2011) focused on the wear of conveyor chain with polymer rollers. In his research the different components of conveyor chains and the loading conditions were described. In addition, the applications and disadvantages of chains with polymer rollers were discussed. From the contact mechanics of the chain and pressure-velocity limit of the roller materials, the design constraints for the laboratory test-rig were derived. He observed that experiments performed on this test-rig gave better correspondence with the wear mechanisms occurring in conveyor chain applications. The capabilities and working principles of the developed test-rig are explained in this thesis. He concluded that for conveyor chains with polymer rollers, the expected wear mechanisms are adhesive wear, abrasive wear, impact with sprocket and softening of the polymer due to heat generation.

5 Conclusion

While studying available literatures it was found that, FEA can be very effective tool for analyzing the system of chain link, time required by FEA for determination of stresses is very less, cost involve is low. Effective analysis methodology can save lots of efforts of industries using roller chain as it will improve working life cycle of the whole unit involving chain conveyor. Also, studying the defects of the chain link at micro-structural level using SEM/EDAX, microscopes, mechanical testing, chemical analysis helps in determining the cause(s) of failure of the chain links. The failure of these chain links were primarily caused by manufacturing defects. Much work has not been done on wear of conveyor chain link and this is an area wealth looking into.

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