Using the industrial engineering concepts through the reverse engineering approach for improving the sprockets

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Abstract. The sprocket systems have a vital role in the power transmission systems at many applications such as; the tanks, bulldozers, excavators, motorcycles, and bikes etc. Therefore, many investigations have had been carried out in order to improve their performance and increase their lifespan. Consequently, the improvements of the sprocket systems are carried out in the present work through three aspects; material selection processes, material forming processes, and material conditioning processes. The traditional sprocket systems have various defects such as; wear, deflection and chain defects etc. Therefore the present work improves the sprockets by reducing the existing defects through tackling their causes. After analyzing the reasons of the existing defects, the present work initiates the improvements by changing the sprocket material from steel alloy of medium carbon to high carbon, changing the manufacturing processes from common forming processes to laser forming techniques and applying the quenching and partial-annealing heat treatment processes in order to reduce the existing defects. In addition, anti-wear coat of titanium nitride is presently added to the sprocket in order to reduce the wear defect. Eventually, the present improvement is the increasing of the sprocket lifespan from about 15,000 km to about 45,000 km.
Keywords: sprocket-motorcycle-heat-treatment-manufacturing-process-rotational speed.

1. Introduction

The motion and power transfer via many methods such as; pulley-belt, gears, and sprockets. Sprocket systems have advantages such as, positive fit that means no slip on, and they are very efficient at low rotational speeds and high torque. A sprocket is a toothed wheel that is used to transmit motion and torque from one shaft to another through either chain or belt that is called power transmission chain or belt. Unlike gears that have to mesh to transmit motion and torque from drive gear to driven one, sprockets may be positioned far apart. The motion transfers through the sprockets by using pair of sprocket; front one which drives the rear one via a chain connection. They exist in various forms of where, the dimensions, the teeth numbers and the material types depending upon their application requirements. A sprocket is a simple mechanical wheel with teeth or small notches which are designed to rotate and engage with either chain-links or timing belt. To be compatible, though, they both need to have the same thickness and pitch [1]. The basic design of this device has been used all over the world for a long time. Sprockets look very similar to gear, however they aren't designed to be meshed together as in gear systems. Sprocket systems are used for various different applications such as; the bicycles, cars, tanks, motorcycles, tools and other machinery etc. The sprockets are made from different materials either metals or nonmetals regarding to the application requirements. In general, most of the modifications are carried out through the reverse engineering approach. People in rural area generally have used the motorcycles in their transportations also those people have problem in changing their motorcycle torque because their business and life conditions inquire higher torque. Due to increase the torque, changing the sprocket diameter is required therefore there are a lot of researches have been carried out 1970's until today to improve the performances and the characteristics of the sprocket at different geometric dimensions [2]. Recently, a newly design slip-on sprocket has been invented to change the sprocket size quickly, easily and also inexpensive. Items of the sprocket system usually needs to be replaced after approximately from 25,000 to 30,000 kilometers that is called the lifespan of these items. Lifespan of the sprocket systems depends upon several affecting factors such as; the operating conditions, the applying maintenance, and the forming processes [2]. The operating conditions and the applying maintenance can be managed through the lifespan but the forming processes and the design concepts are out of hand during the lifespan [3]. Therefore present work concerns with improving the sprockets by limiting the defects propagation before starting their lifespan.

2. Applying the lean six-sigma methodologies for investigating the sprockets

Interesting people ask about the reasons of the sprocket failure before its half standard lifespan. Therefore, for catching the defects which cause the sprocket failure, the lean six sigma methodologies are presently used. Lean six sigma concepts are define concept D, measuring concept M, analysis concept A, improving concept I, and controlling concept C. The lean six sigma methodologies DMAIC applies Fishbone-diagram and Pareto-Chart as defining and analyzing tools which are presently used as follows [4];

2.1. Define the sprocket and the sprocket defects

The sprocket systems are used to transfer the power/motion transfers through the sprocket system from a drive shaft to a driven shaft through the front sprocket, the chain/belt, and the rear sprocket as shown in Figure 1.

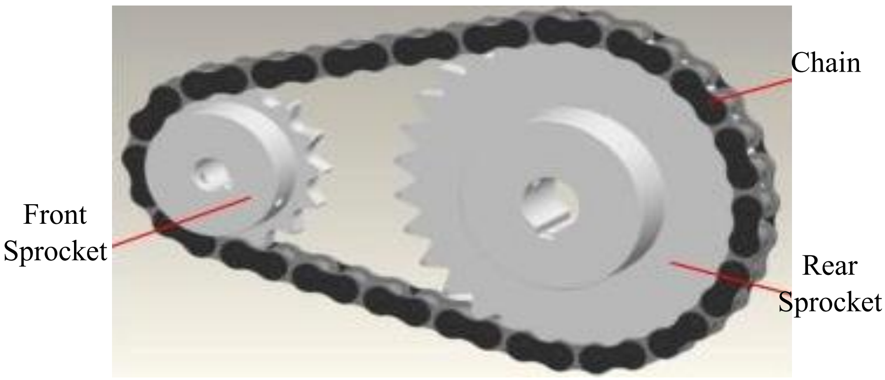

Figure 1. Sprocket system

During the motion transmission process there are various defects such as; wear, deflection, broken, and chain-link problems. These defects are predicted because of different reasons such as the sprocket material properties both mechanical and chemical, sprocket manufacturing processes and sprocket material conditioning of the surface polishing, heat treatment and anti-wear coating. These errors/defects and their causes are investigated in the present work.

2.2. Measuring the sprocket defects

The reasons of the sprocket system breakdown can be measured regarding to different methods such as; the visual examinations, the mechanical conditions, the electronic scanning, the chemical analysis, and the metallographic analysis. A selected sample of ten common sprockets are inspected by monitoring them until their complete failure. The conditions of both sprocket and chain are rusted and wearied as shown in Figure 2. One has to know that the main target of the measuring phase is the counting of the observed sample defects. Sprocket systems start failure when the slip-on phenomena appears which happens at decreasing the sprocket tooth height and at increasing the chain engaging space. These defects happen because of the wear effects.

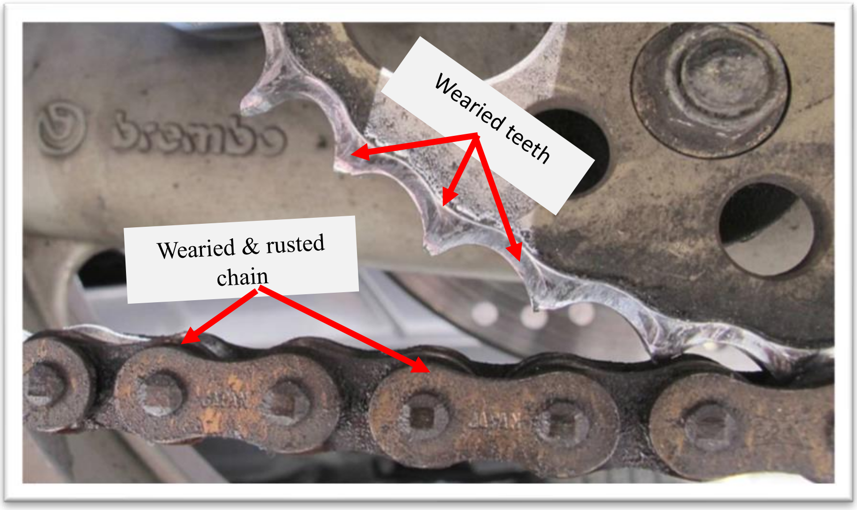

Figure 2. Wear effects on the both sprocket and chain

The average measuring lifespan of the observed sample is about 15,000 km which are considered as lifespan of the monitoring sample. Through the average lifespan period of the sprocket system, the defects are recorded in Table 1 which are measured regarding to the visual, operating conditions, and geometric dimensions. The present measurements can be classified into four categories; sprocket wear, sprocket/chain deflection, chain-link climbs and chain wear. Defect measurements show that the major defects in both sprockets and chain are the wear. In order to investigate the measured defects, all of the measurements are tabulated in Pareto chart form as shown in Table 1. Pareto chart form is performed by estimating the present measurements in an accumulative column.

Table 1. defect type vs. its existing percentage

Defect type	Common	Accumulative
Wear	70%	70%
Deflection	10%	80%
Chain climbs	10%	90%
Chain wear	10%	100%

In addition, Table 1 shows that the wear defect in both sprockets and chains are about 80%. Therefore the wear defect becomes the major defect among all of the other defects which represents about 70% at the sprocket items and about 10% in the chain elements. Consequently the sprocket systems are leaded to breakdown by about 80% because of the wear defect. These data show that the vital improvements will be carried out by decreasing the wear rate propagation in both sprockets and chain [5, 6, 7]. Presently, the wear defect in the sprocket item will be concerned in order to be limited by increasing the wear resistance by improving the used materials and the manufacturing processes.

2.3. Analyzing the sprocket defects

The measured data in Table 1 are analyzed by using Pareto-chart as shown in Figure 3 which represents the present measurement data. Indeed, the wear rate is the major defect among of the sprocket system defects. Therefore the wear rate and its happening reasons become the vital subject in the present investigation. Many investigations have been carried out in order to deduce the reasons of the various wear forms in the elements of the sprocket systems [7]. In addition the present work concerns with either eliminating or limiting the reasons of the sprocket wear as much as possible.

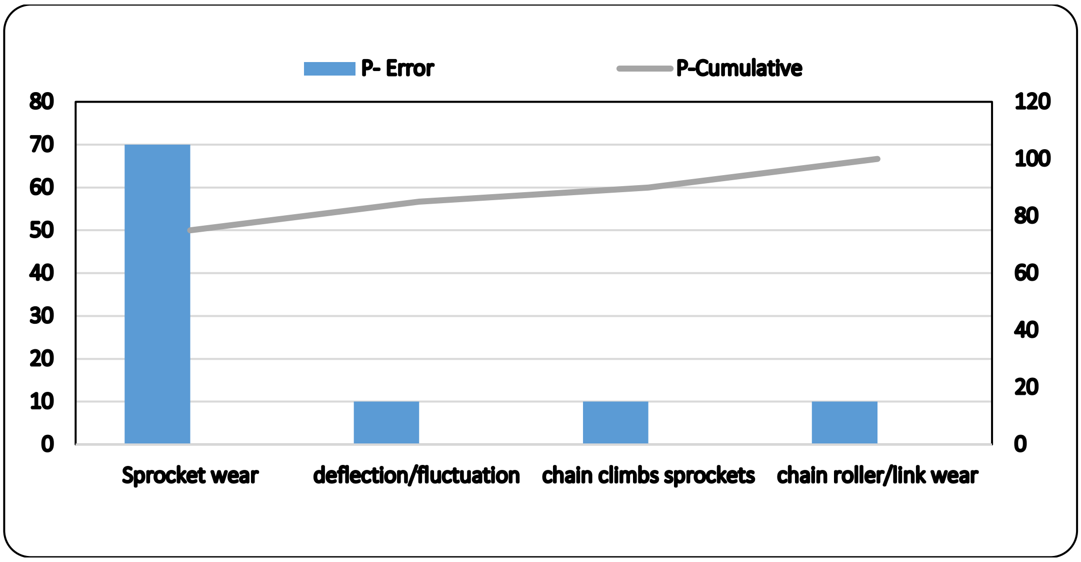

Figure 3. Pareto-Chart of the sprocket-system defects

Figure 4 represents the fishbone diagram for the sprocket system defects and their causes. Wear, deflection, chain-links, and the broken are the common defects of the sprockets which are caused by different reasons as shown in Figure 4.

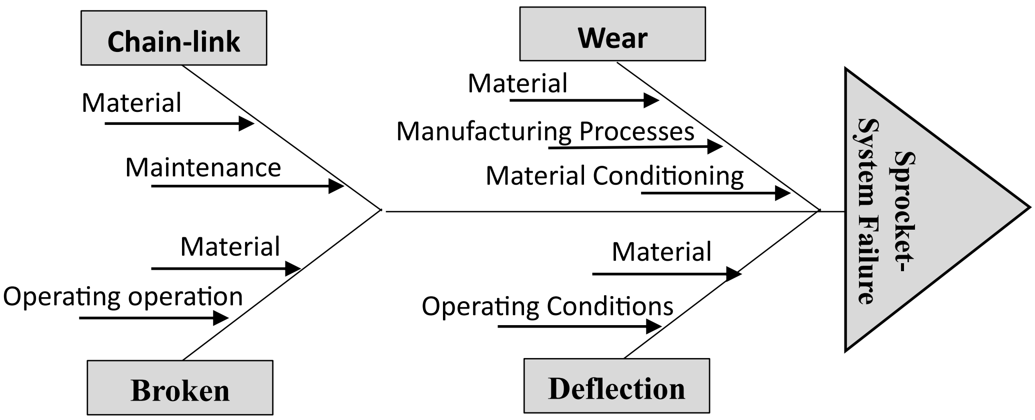

Figure 4. Fishbone-diagram for the failure the sprocket system

Figure 5 shows the fishbone diagram for the wear resistance items as tackling items for the reasons of the sprocket defects. The sprocket defects lead them to the failure in transmission the motion by slipping on between the chain and the sprocket teeth. The defects of the sprocket systems can be noted by either visual examination or noisy operating conditions [5]. Many parameters effect on the sprocket systems performance and their defects intensity such as; the sprocket material, the forming process, and the material conditioning processes such as; surface finishing, heat treatment processes and anti-wear coating. These defects/errors of the sprockets and their causes can be summarized as shown in Figures 4 and 5. These figures as well as the Pareto-chart show the manner of improving which can be defined by the manner of resisting the reasons of defects

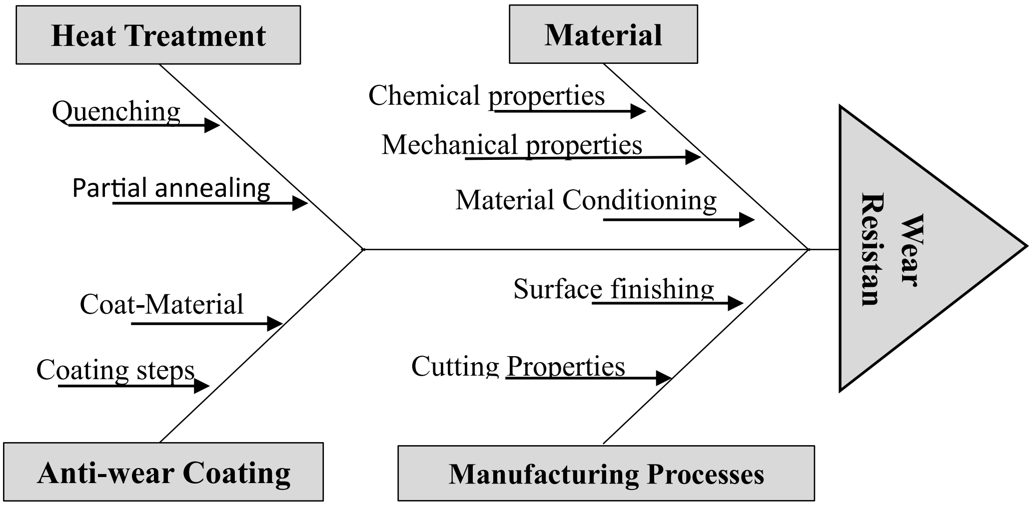

Figure 5. Fishbone-diagram for resisting the material wear

2.4. Improving the sprocket systems.

Following the results of the previous analysis, the improving activities have been carried out. Sprocket improving means improving the sprocket performance and increasing the sprocket lifespan. Whatever, the improving steps are indeed the results of the previous processes of the definition, measuring and analysis. Accordingly, the reasons of the sprocket defects can be summarized in three main reasons, the sprocket material, the sprocket forming processes and the sprocket material conditioning processes. Therefore, the sprocket improving steps have concerned with eliminating its defects by tackling its reasons as follows;

2.4.1 Improving the sprocket material

The most important thing in the manufacturing and production field is the material selection process. Quality, fitness, strength, and lifespan of the manufacturing product depends upon its material properties. Therefore the material selection process becomes the most important process and because of this importance the subjects of the material science are introduced. Therefore the first step of developing of any an industrial item investigates its materials of where their chemical compositions and mechanical properties. Depending on these concepts the observed sample of the common sprockets is chemically analyzed to determine its chemical composition. In order to determine the chemical composition, the non-destructive testing type which is called X-ray fluorescence (XRF) is presently used by the Egyptian Chemical Organization [8]. Egyptian Chemical Organization carries out chemical analysis for the traditional sprocket material that is shown as follows:

Fe	Si	Mn	P	S	Cr	Ni	Al	Cu	C
98.2%,	0.22%	0.61%	0.02%,	0.01%	0.096%	0.05%	0.041%	0.14%	0.45%

The metallurgical analysis shows that the increasing of the carbon amount improves the wear resistance property as well as the other mechanical properties [9]. Asper these concepts, the high carbon steel alloy is preferred for manufacturing the improved sprockets. Therefore the high carbon steel alloy of about 0.8% carbon is used in manufacturing the pieces of the improved sprocket sample. The actual chemical analysis of the improved sprocket material is shown as follows;

Fe	Si	Mn	P	S	Cr	Ni	Al	Cu	C
98%,	0.034%	0.53%	0.002%,	0.01%	0.02%	0.04%	0.041%	0.11%	0.8%

Although the both common and improved sprockets have approximately the same chemical composition except the carbon percentage, they have wide discrepancy in the mechanical properties. The medium carbon steel alloy is less than the high carbon steel alloy in the wear resistance, because of its superiority in the hardness and strength properties.

2.4.2 Improving the sprocket manufacturing processes.

Improving the sprocket systems through their manufacturing processes is carried out by using the reversed engineering approach. Engineering reversed approach means the copping of the piece geometric dimensions and the functions. Only the availability processes through the reversed engineering are the forming processes and the using materials. Forming processes; the blanking cutting process, the punching cutting process and the surface polishing process are in the common sprockets from the traditional cutting processes such as; turning, milling and drilling. In general, one has to know that the steel laser cutting is an essential subtractive manufacturing process in the machining and stressed items forming. In addition, laser cutting technique involves using a high-powered laser beam to cut and polishing through the steel with high accuracy as shown in Figure 6. Forming processes happen by directing the laser beam to the workpiece for melting it to produce a clean, precise and free stress-residual cut. Therefore, in the present work, the traditional forming processes will be replaced by the laser forming process. Presently, the fusion laser technique is considered to form the sprockets from high-carbon steel of 8mm thickness. All of the forming processes for the sprockets such as; blanking cutting, punching cutting, teeth cutting and surface polishing are carried out by laser technique [10, 11].


Sprocket forming by fusion laser

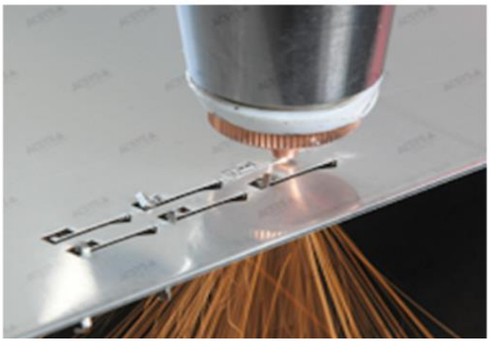
Fusion laser cutting

Figure *6.* Sprocket forming by fusion laser process

2.4.3 Improving the sprocket material conditioning processes.

Material condition processes mean heat treatment and anti-wear coating. Usually, after completing the forming processes, the material conditioning processes are taken place. The heat treatment processes are carried out in two stages quenching heat treatment and partial-annealing heat treatment. The quenching heat treatment increases the hardness and strength of the carbon steel otherwise the partial annealing heat treatment is carried out after the manufacturing processes and the quenching heat treatment in order to moderate the mechanical properties also for treating the brittle phenomena that maybe appears after the quenching process. The quenching heat treatment is carried out by heating until 850ºC then suddenly cooling through brine solution and the partial heat annealing is carried out by heating until about 500ºC then cooling through the ambient temperature at heat transfer coefficient of about $5W/m^2K$ [12, 13]. Beside the heat treatment processes, the anti-wear coating is carried out to improve the surface quality in order to resist the wear rate [14]. In addition, the coating of the sprocket surface is required to keep the sprocket material in safe mode of wear for a longer period at different operating conditions and environment modes. The processes of the chemical vapor deposition CVD are commonly used to create titanium nitride coatings. These processes are carried out by feeding several chemicals ($TiCl_4$, N_2 and H_2) [15] to an evacuated furnace where they react at temperature of about 450ºC to create TiN, which deposits on the sprocket surfaces as an effective coating. Thus the developing through the material conditioning process have been carried out in order to improve the mechanical properties in order to decrease the wear rate.

2.5. Controlling the sprocket improvements

Present study takes real steps for ensuring the improvement of the sprockets such as; preparing the present work for publishing, recording the individual developing activities, and training the concerned technical group. Eventually, the periodic planned inspections and the continuous observation have been followed for the present improvements in order to hold their happening. Anyhow the present improvements exist under deeply observing activities to ensure their existing continuity.

3. Results and Discussion

The common sprocket conditions vs the improving sprocket conditions are shown in Figure 7 which includes both front and rear sprockets. The above sequences of the improvements produce the improved sprockets which have been observed until 45000 km. The measurements of the improved sprocket sample are tabulated vs the measurements of the common sprocket sample in Table 2. Visually, the heat treatment actions and the anti-wear coating are shown in the improved sprocket items while the common sprockets have not any notified about these processes.

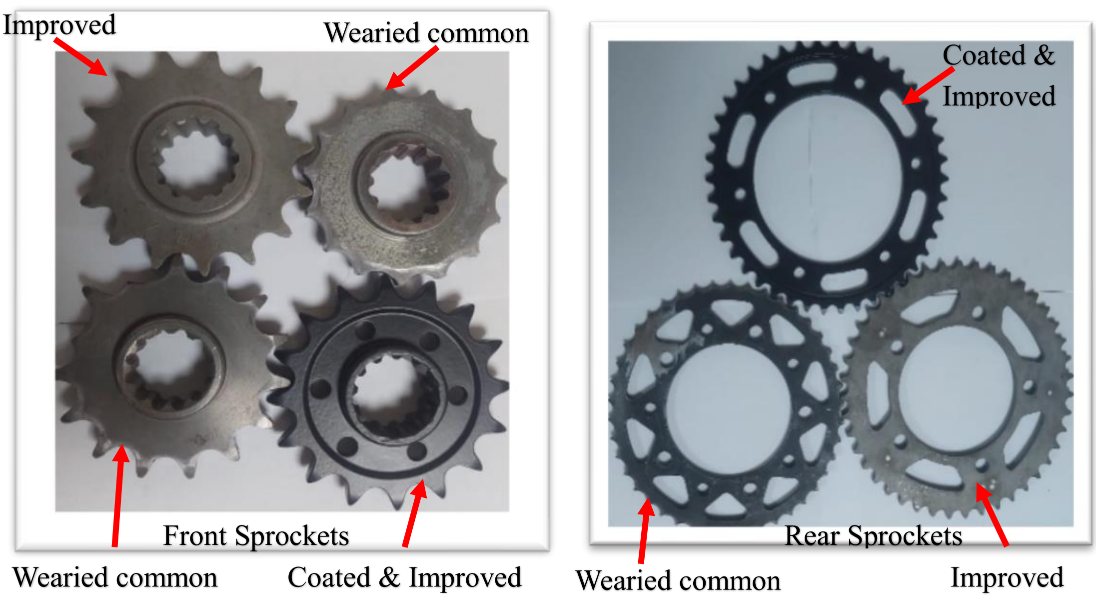

Figure *7.* Common pockets vs the improving sprockets

The actual defect measurements of the present work for both of the common and improved sprockets are presented in the Table 2 which includes all of the present available measurements. Both of the common and the improved sprocket defects are presented in Pareto-chart form at Table 2.

Table 2. Defects of the common and improved sprocket systems

	Common Sprocket		Improved Sprocket	
	@15,000km	Accumulative	@45,000km	Accumulative
Wear	70%	0.70	0%	0.00
Deflection	10%	0.80	10%	0.14
Chain climbs	10%	0.90	30%	0.57
Chain wear	10%	1.00	30%	1.00

The wear defects in both sprockets and chains are the major defects among the sprocket system defects. Otherwise the common sprockets lead to wear defect at 15,000km as shown in Figure 8. Until 45,000km age, the wear defects are completely eliminated in case of the improved sprocket as shown in Figure 8. The lifespan of the improved sprockets are increased from about 15,000 km in case of the common sprockets to about 45,000 km in case of improved sprocket as shown in Figures 8 and 9. The increasing of the lifespan by eliminating the defects means many economic and technical advantages such as; saving the maintenance time, saving the piece price and saving the operating time cost by decreasing the out of order periods.

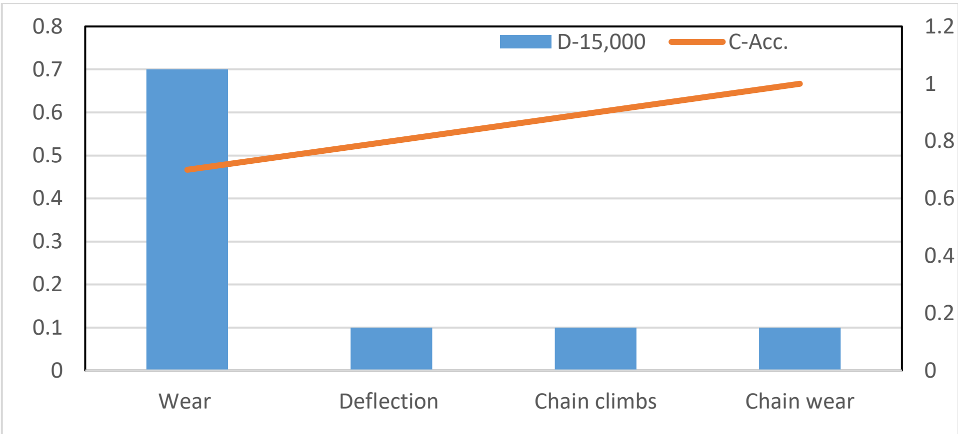

Figure 8. Pareto-Chart for the Common Sprocket System

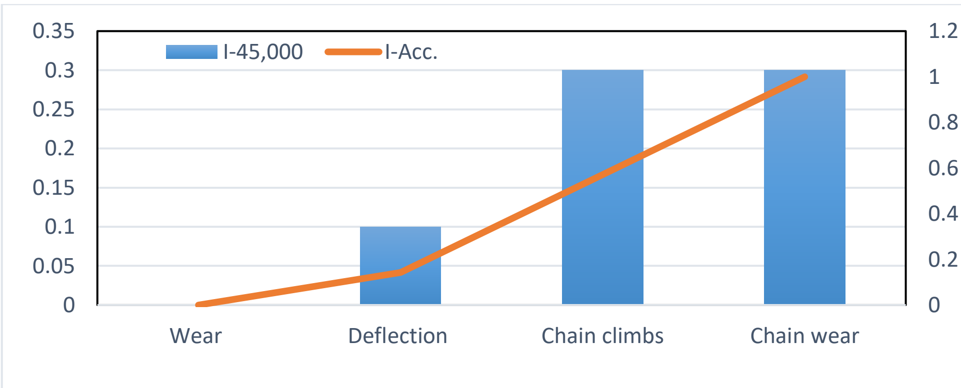

Figure 9. Pareto-Chart for the Improved Sprockets through sprocket systems

4. Conclusions

The present research can be concluded as follows;

1) Presently semi-comprehensive work for the sprocket items is introduced.
2) Sprocket wear defects are about 70% of the sprocket defects.
3) Medium carbon steel 0.48% C is presently replaced by high carbon 0.8% C in producing the sprocket due to increase its sprocket hardness and strength which decrease the wear rate.
4) Accuracy, clean and free residual stresses are presently obtained by replacing the sprocket common forming processes by the fusion laser forming techniques.
5) Heat treatment; quenching and partial annealing are presently carried out due to improve the sprocket mechanical properties which help in decreasing the sprocket wear rate.
6) Anti-wear coat is presently carried out to reduce the sprocket wear rate.
7) Eventually, the average lifespan of the sprocket is increased from about 15,000 km to about 45,000 km because of the present work improvements.

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