Dry Abrasion Wear of Windshield Glass and its Effect on Night Driving

A thesis project report submitted in requirements for the

Master of Engineering

in

CAD/CAM Engineering

by

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PATIALA

July 2023

CERTIFICATE

I, **Bhagya Raj Gill** (Roll No: 802184006), hereby declare that this thesis titled **"Dry Abrasion Wear of Windshield Glass and its Effect on Night Driving"** submitted to Mechanical Engineering Department at Thapar Institute of Engineering & Technology, Patiala, Punjab, India is an authentic work of my own research work carried out by me under the supervision of **Dr. Devender Kumar** and **Dr. Anshul Sharma**. The work reported herein does not form any other project report or dissertation based on which a degree or award was conferred on an earlier occasion on this or any other candidate.

Place: Patiala

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This is to certify that the above statement made by the candidate is correct to the best of my/our knowledge.

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Contents

List of Figures

List of Tables

Abstract

Windshield wipers are safety equipment for cars, especially for maintaining clear vision during inclement weather circumstances as rain, snow, or sleet. Windshield glass plays a crucial role in protecting driver visibility and safety, particularly during night-time conditions. Windshield wipers are employed on windshields to clear the windshield of water, snow, grime and other debris so that the driver can see clearly. However, when the glass surface is cleaned with wipers, continuous exposure to various external variables, such as dust, sand, etc., can result in the formation of dry abrasion wear. Motive of present research is to examine; how dry abrasion wear affects windshield glass and its effect on night-time driving. In the past, numerous studies demonstrating windshield wear have been conducted, but none in India, where the amount of dust and debris in the air is more than in other nations. Additionally, no studies have looked into windshield wear under actual environmental conditions.

The wearing of windshield glass and its effect on visibility at night have been examined through a number of tests. A proper setup with a functioning wiper mechanism was designed to abrade the windshield with the dust accumulated in natural environmental conditions. Different wear regions on the windshields were identified and high-resolution night photography was carried out to observe the impact of windshield wear during night-time driving. To assess windshield wear, the roughness of the windshield glass was also tested. Using the EDS method, the constituents of the dust that was deposited on the windshield glass were also assessed.

The findings from the experiments shows that dry abrasion wear has a substantial impact on the windshield glass surface and increases light scattering at night. It is also verified that as the number of wiper cycles on the windshield increases, the wear increases, i.e., the scattering of light is greater in the regions where the wiper cycles are higher. Another important finding reveals that new wiper blade damages the windshield glass more than the old wiper blade, as it has a better area of contact.

Keyword: Windshield wear, Wiper Blade, Wiper damage, Night Driving, Glare

CHAPTER 1

INTRODUCTION

1.1 Windshield and Windshield Wipers

A car's windshield is the front window glass, through which the driver and front-seat passenger can see outside the automobile. Almost every modern automobile has a windshield which is laminated and acts as a safety glass for the vehicle, driver and passengers. A windshield wiper is a mechanical apparatus employed for the purpose of eliminating precipitation such as rain, snow, ice, washer fluid, water and debris from the front window of a vehicle, hence enhancing the visual clarity of the vehicle's operator with regard to the road ahead. The majority of motor vehicles, encompassing automobiles, trucks, buses, locomotives and watercraft as well as certain airplanes are typically outfitted with one or more windshield wipers It is worth noting that the presence of these wipers is often mandated by legal regulations [1]. According to a recent survey (2022) [2], there were approximately 1.45 billion vehicles on the road globally, of which about 1.1 billion are passenger cars, meaning 1.1 billion windshields and thus, 2.2 billion wipers working to keep these windshields clean.

1.2 Dust Deposition

Air quality in India is not as good as compared to other countries, India ranks 8th among the most polluted countries in the world [3]. Air quality degrades as the amount of Carbon Monoxide, Lead, Nitrogen oxide, Ozone, and Particulate Matter increases in the atmosphere. Particle pollution, also called particulate matter (PM), is made up of particles (small pieces) of solids or liquids in the air.

Fig. 1.1 Dust deposition on a car [4]

This pollution is our major concern here as with the increase in particle pollution, the dust and dirt in the atmosphere increases and ultimately, as this dust settles down, it makes a significant layer on the vehicles as shown in Fig. 1.1. These particles may include dust, dirt, soot, etc. This dust is deposited not only in the open but also on vehicles parked in covered places/parking. However, the continuous use of windshield wipers can cause wear and tear on the windshield, leading to scratches, pitting, and other forms of damage. This wear and tear, if not addressed, can impair the driver's vision, leading to unsafe driving conditions.

Fig. 1.2 Dust deposition on the windshield

Fig. 1.3 Dust deposition on the wiper blades

Fig. 1.1 and Fig. 1.2 clearly show the dust deposition on the windshield and the wiper blades. This dust acts as an abrasive material between the wiper blade and the windshield which causes obstruction in clear vision.

According to a recent survey [5], there are 326.3 million vehicles on the road in India, and except two wheelers, windshield is present in almost every other vehicle. Still, no research on windshield wear in India was ever done. In a market as big as India with top car manufacturers and a varied atmosphere, the research on windshields in India was the need of the hour. Road accidents in India are high and 60% happen in night-time [6],[7]. A case study revealed that the visual factor accounts for 47% of the night-time accidents on the road in a particular state of India [7]. The windshield plays a vital role in safe driving during night time and due to its wear, it obstructs the driver from driving the vehicle efficiently on the road at night. Evidence suggests that, as is the case in other countries, night-time driving in India is substantially riskier than daytime driving.[8] It is well documented that vision is the predominant source of information that drivers rely on for safe driving, and that damaged windshields may create obstruction with a driver's vision of the road ahead. Thus, research was necessary on this topic.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Various studies on windshield glass and its wear were done in the past. Present chapter reviews various published literatures of the researchers which puts foundation for the present work. Literature reviews provide a better understanding about the studies that have been done in the same interests and helps in finding new methods, research gaps, formulation of new problems etc. and therefore, works as a guideline for the thesis. This study mainly deals with the wear of windshield glass due to wipers and the effect of this wear during night driving. The effects as the night time driving in India is substantially risker than day time driving as compared to other countries accidents in the night time also toll a high number here [7]-[8]. With the increase in wear of windshield the ability of the driver to see clearly during night driving decreases. Since windshields are present in almost every automobile except two wheelers, research around this topic has been thoroughly done and is being done by researchers in different regions of the world. Following are some research papers that have been highlighted in the thesis

2.2 Research done in past years

Merrill J. Allen (1970) conducted a study on automobile windshield surface deterioration using used windshields of various cars in Melbourne, Australia [9]; they discovered that the damage caused by wiper blades on a windshield is significant, as the greater the distance travelled by the vehicle, the more light is scattered on the windshield at night. It entailed photographing an oncoming vehicle's headlights through the windshield. To measure the extent of light diffraction, translucent layers of polyethylene plastic were layered over a photograph of the scratch pattern until the scratch pattern was no longer discernible.

Merrill J. Allen (1975) did a study to measure the amount of windshield dirt and the prevalence of surface damage in a sample of passenger cars [10]; did a study to evaluate the ability to see through dirt and surface damage in a static and a dynamic driving situation; and did a study to evaluate the practicability of resurfacing automobile windshields. They also urged that there should be an increase in the level of public awareness of the problem. Windshields that sustain damage should either be resurfaced or replaced as soon as possible.

Paul Green William and T. Burgess in 1981 did a study on windshield damage and safety [11] to see the effects of windshield wear on driver's vision. They performed experiments using different individuals by giving them different road conditions that the rivers usually faced. They also did a thorough literature review on how windshield optical quality is measured, general and related problems of driver vision, and studies focusing specifically on windshield d damage.

J. Locke and L.A. Rockett (1985) surface scratches on automobile windshields were their focus of the study [12], which involved doing research on several areas of a windshield to identify the different types of scratches. They discovered that a toughened vehicle windshield, which has a long service life, has substantial scratch marks over the entire area that is swept out by the windshield wiper blades, but very little scratching was detected over the remainder of the screen. This was discovered despite the fact that the windshield had a long service life. Either the interference objective or the specular reflection objective can be used to locate these types of markings on particles the size of casework.

Alwin Timmermann and Gudrun Gehring (1986) described an instrument shown in Fig. 2.1 which permits the measurement of scattered light on windshields in cars in full daylight [13].

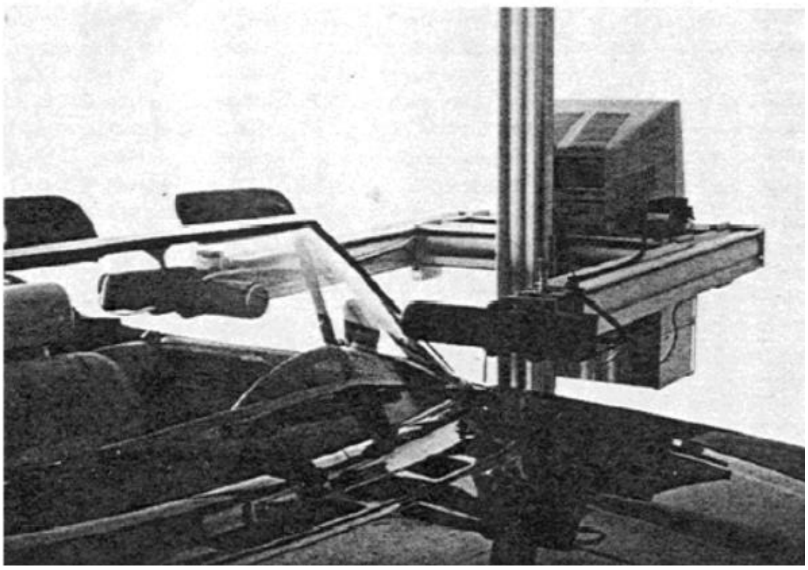


Fig. 2.1 Instrument to Measure SLI Values on Mounted Windshields (Timmermann) [13]

It presents the intensities of the scattered light as a diagram and calculates two indices, which was associated with the most prominent types of wear, i.e. impact of small stones and wiper damage. They started many studies from 1985 to 1986 on this topic.

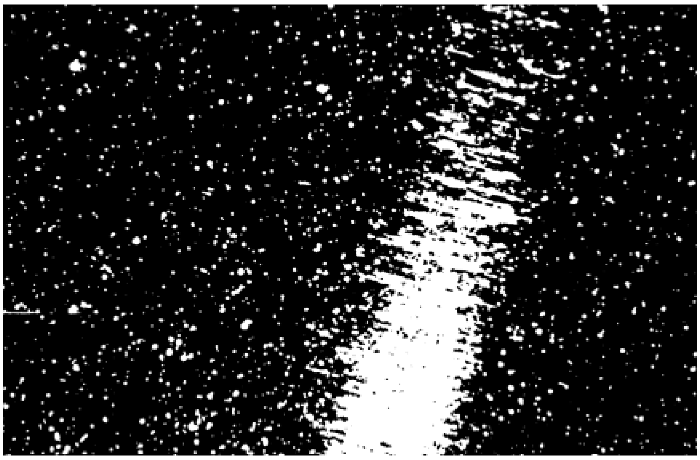


Fig. 2.2 Surface Wear on a Windshield at 80,000 km [13]

Fig. 2.2 shows a damaged windshield evaluated of a vehicle which is driven 80,000 km. They also concluded that the difference in wear was probably due to differences in climatic and road (driving) conditions. They found that cars that were usually parked on the street often had higher light scattering values than those that were garaged.

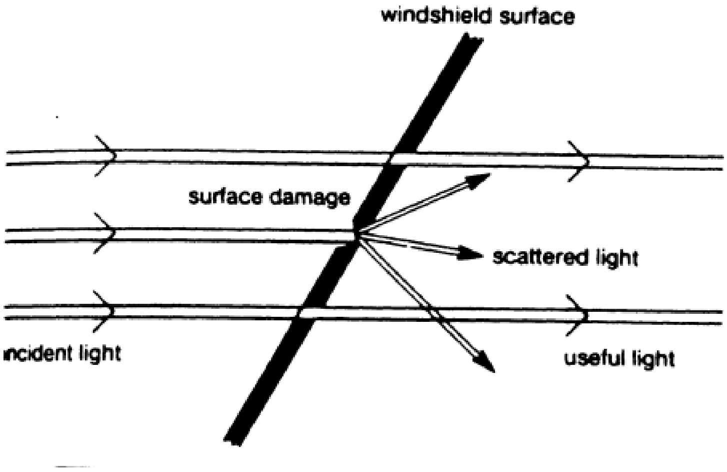


Fig. 2.3 Light Travelling Through a Damaged Windshield [13]

They also defined how the light enters and scatters through a damaged windshield as shown in Fig. 2.3.

Derkum (1991) identified that stray light emanating from different types of windshield damage such as craters, wiper damage, scratches produce different types of distributions [14]. They also suggested that the effects produced by different types of damage could have differing effects on driver perception. Through his studies Derkum also confirmed that the windshield must be in its mounted position when the stray light is measured to acquire the appropriate information about the drivers' perception.

Owens et al. (1992) investigated the effects of various factors on night vision [15]. The factors considered were 1. Rake angle 2. Tinting 3. Light scatter 4. Target contrast 5. Glare 6. Age and 7. Night myopia. They concluded that light scatter due to dirt and wear can dramatically impair night-time visibility

Lundkvist and Helmers (1993) carried out an experiment to measure the detection distances to objects on the road when viewed through windshields in different stages of wear [16]. They found out that the distances to an object on the road when viewed through a very worn windshield can be 15% greater than when viewed through a new windshield.

National Road Transport Commission's "Roadworthiness Guidelines", September 1995 these guidelines were formed for the safe and efficient operation of road transport in Australia [17]. This document divides the windshield into three vision areas, Critical vision area, Primary vision area and Secondary vision area. Critical vision area mentioned in the guideline's states that "For light vehicles this is an area 220mm wide for the depth of the windshield in the wiper arc, but excluding the area above the wiper arc or the top 10% of the windshield, whichever is the greater".

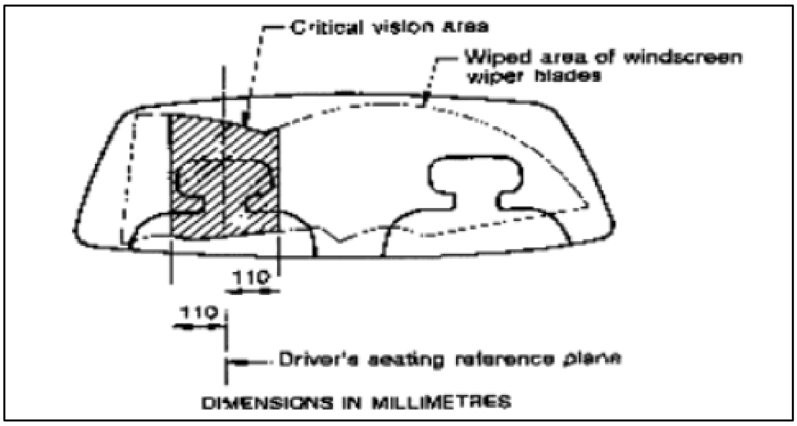


Fig. 2.4 Critical vision area of light vehicle [17]

Fig. 2.4 illustrates the critical vision area described by the" Roadworthiness Guidelines" which should have no scratches or damages whatsoever.

A. Koenen (2003) studied tribological and vibroacoustic behaviour of a contact between rubber and glass [18]. They also studies about the dry and wet friction coefficient between wiper blade and the glass. They concluded to adapt the treatment and coating of wiper blades and glass in order to reduce the tacky friction (Dry friction).

Alexander Toet et al. (2013) investigated how high-power illuminators affect drivers' ability to see through windshields and how they behave behind the wheel [19]. The purpose of this study was to create a test procedure for the certification of high intensity light sources that are meant to be employed as warning devices or to deny the view of the outside world that automobile drivers see through windshields. This study was carried out in order to qualify high intensity light sources. They also investigated the hypothesis that filth and scratches on a windshield create an increase in the veiling luminance (*Lv*) that is produced when a high intensity light source is aimed at a windshield. This obscuring luminance both lessens the contrast of the things in the scene and shortens the distance at which the driver of the car is able to make out individual objects.

Ovidiu Antonescu et al. (2015) investigated the primary types of windshield wiper mechanisms, which were found to be composed of bars and gear linkages [20]. The mechanisms can be broken down into two distinct categories: 1. those with arms of a fixed length, and 2. those with arms of an adjustable length. In this study, the primary advantages and disadvantages related the wiped windshield surface and the constructive structural complexity are highlighted for each type of mechanism utilised for a variable-length wiper. These were discussed in detail for each type of mechanism.

S. Cadirci et al. (2015) performed both numerical and experimental research on the performance of the wiper system at high speeds [21]. The study assisted in gaining a better understanding of the design of the wiper blade, as well as the wiper profile, and the effect of the angle of the windshield on wiper performance.

Oana Dobre (2016) conducted a tribological study on the performance of windshield wipers with the goals of reducing friction and wear, improving wiping quality, and preventing friction-induced vibration [22]. They used a variety of scientific approaches to carry out an in-depth investigation into the behaviour of the wiper on the windshield. In addition, a comprehensive study was conducted on the friction that existed between the wiper blade and the windshield. The study also determined the influence of dry wiping on the windshield's coefficient of friction, which was another finding of the study.

Piotr SZCZYGLAK et al. (2018) studied how windshields affect safety and what makes windshields and windshield wiper blades wear out faster or slower [23]. Also, it shows a new way to test how the glass wears down on a bench. The method lets tests be done in settings that are close to real-world use. The paper also talks about an automatic bench with an abrasive dispenser and ways to measure the wear on a windshield. The roughness Ra value changed a lot more when quartz sand was used than sea sand and electro-corundum did. It was also shown that the state of the wiper blades changes with different abrasive materials.

CHAPTER 3

PROBLEM FORMULATION

In India, cars are usually parked outside in the open. Specifically, in the metro cities and NCR regions where population density is very high. In these regions due to high per capita income, most of the residents have more than one car and there is no covered space for car parking. Car is parked in the open throughout the year. Over the night, there is a significant dust deposition on the cars as the level of particle pollution is relatively high in India compared to other countries [1]. This dust settles on the windshield and the wiper blades and acts as an abrasive material when the driver cleans the windshield using the wipers. Usually, the cleaning of windshields is done in two ways: by using washer fluid or not using the washer fluid, i.e., dry wiping of the windshield. Usually, water is used as the washer fluid. The damage to the windshield is more severe in dry wiping.

Low and mid-segment cars also observed a lag between the wiper and the washer fluid being sprayed on the windshield. When the steering mounted lever is operated to clean the windshield, there is a time lag between the water jet/stream and wiper movement. The wipers reach quickly to the middle of the windshield and then the water jet/stream is sprayed for the first time on the windshield. This time lag results into dry abrasion of the windshield, which causes its wear. Due to this dry abrasion scratches are formed on the windshield as the dust particles slides between the wiper blade and the windshield, acting as an abrasive material. Also, if the windshield is totally clean the coefficient of friction between the windshield glass and the wiper blade increases during dry wiping and causes squeaky noises and wear of both [19]. With passage of time as this activity is repeated multiple times or every day in most of the cases, the windshield scratches become more severe and impair the driver's vision during night.

3.1 Windshield Wear effect on Night-time Driving

During the day time driving, these scratches seem to be insignificant and looks very minor, however, during night driving, as the headlight from different vehicles fall on the windshield, the light rays get reflected into multiple directions, thus causes glare as shown in Fig. 3.1. The secondary reflection restricts the driver's visibility resulting into unsafe driving conditions.

Fig. 3.1 Glare during night-time driving

Many research studies [9]-[23] have been done around this topic, but there was no research performed on the wear of windshields using natural dust accumulation conditions in India or abroad till now. Since the climate and weather conditions are different in different regions, the results will also be different as the size of dust particles, dust particle constituents and the amount of dust in the atmosphere vary from region to region; therefore, a study in India was required.

3.2 Research Gap

However, after analysing different research papers and studies on this topic, the following research gap was observed-

- Most of the past studies were conducted in laboratory using standard Taber Abrasion instrument [24].
- No study uses natural environmental conditions, i.e., natural dust deposition containing industrial dust particles and silica to test the windshields wear.
- There is no scientific study/research was ever performed in India for windshield wear.
- No detailed study was conducted on the amount of glare produced by scratches on the windshield.
- There was no research conducted to measure the severity of scratches and its relation to the light scattering.

A detailed study was performed in Patiala to bridge this gap. This region is in Punjab (India), and the amount of dirt and dust in the environment here is moderate to high as the city has small scale industries, farms and fields. Also, the AQI here is usually above 75[25].

3.3 Research Objectives

A study using natural environmental conditions was required to evaluate the wear of the windshield as the increase in wear causes unsafe driving conditions during night driving.

The present study aims to:

- Build a setup to perform windshield wear
- Evaluation of the dust particles deposited on windshield
- Light scattering evaluation on abraded windshield
- Roughness measurements on abraded windshield

CHAPTER 4

EXPERIMENTAL SETUP AND PROCEDURES

To perform this study a proper setup using an old chassis of a car was made, with a functional wiper mechanism. Two new windshields were used for this experiment with different sections marked on them to study the wear with respect to the number of wiper cycles. The dust was allowed to deposit on the windshields naturally by keeping the windshields outside in the open. Two studies were carried out simultaneously using an old wiper blade and a new wiper blade to see the effect of the wiper blade's age on the windshield. Night-time photography was done using a high-resolution camera to study the glare and the effects of windshield wear within different windshield.

4.1 Test Vehicle

A movable setup was made using a chassis of an old Alto car. The chassis was welded with three wheels to make it movable, and the front wheel was steerable.

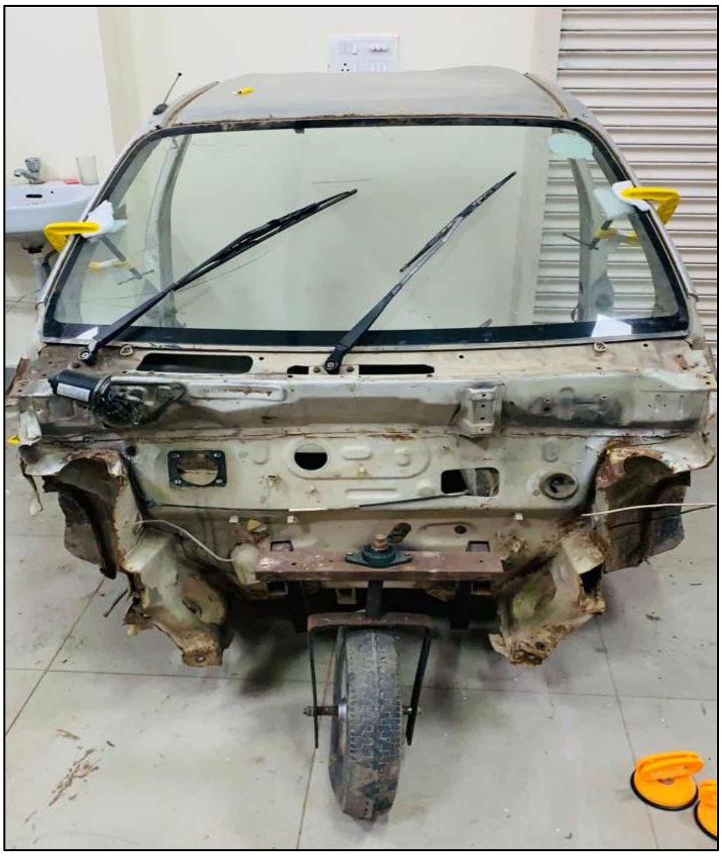


Fig. 4.1 Test Vehicle (Front View)

Fig. 4.1 shows the front view of the test vehicle; a working wiper motor was also installed in the test vehicle and the wiper assembly was made functional. The test vehicle was made such that night-time photography could easily be done by sitting inside it. Everything was removed from the inside so that plenty of space was there to do the photography of light scattering.

Fig. 4.2 Test Vehicle (Side View)

The side view of the test vehicle is shown in Fig. 4.2. The ground clearance of the test vehicle was kept at 190 mm, the average of most low and mid-segment cars today.

4.2 Windshield and Wipers

4.2.1 Wiper specifications

There are three main types of wiper blades: conventional, flat and hybrid. A conventional type wiper blades were used in this experiment. Two set of wiper blades were used to obtain a relationship between the wiper blade's age and the windshield wear: a Wiper Blade 18" (New) and a Wiper Blade 18" (Old) were used which were compatible with the model and type of the car chassis. The old wiper was taken from an old car (mileage of 25,000 Kms and 4 years old).

Fig. 4.3 Conventional type wiper blade [12]

4.2.2 Wiper Motor Specification

As per the vehicle specification a compatible 12V DC wiper motor and mechanism was used for this experiment. The motor was capable of moving the wipers at 40 wiping strokes per minute (Low) to 65 wiping stroke cycles per minute (Fast), 1 wiping stroke here can be understood as one wiper cycle, which is defined as the movement of the wiper from its rest position to its full extent and then coming back to its rest position again.

4.2.3 Windshield specifications

This research study used two new unused laminated windshields of the Maruti Suzuki Alto to study the effect of the wiper blade's age on the windshield. Windshield description- AIS (OEM) Maruti Suzuki Alto windshield glass, LAMISAFE-LT (29.92Wx50.39L inches).

4.2.4 Windshield Segmentation

In order to perform systematic wear on two windshields, the windshields were protected with a thin transparent film from outside to protect it from abrasion to control the number of abrasion cycles over different regions. The swept area of wipers and segments to be studied were marked on inside of the windshield. This swept area was further divided into small segments numbered accordingly, as shown in Fig. 4.4. The idea was to study the wear of windshields with respect to the number of wiper cycles. These marked sections of the laminations were removed after defined number of strokes to perform the experiments.

Fig. 4.4 Segmentation of Windshield

4.2.5 Windshield Frame

A frame was also made to keep the windshield outside safely, as shown below in Fig. 4.5. The setup was made such that it could easily be moved from one place to another. The wheels had stoppers to keep the windshields safe and the frame stationary during different weather conditions. Inclination of the windshield on frame was kept similar to that of car chassis so that dust accumulation would be same.

Fig. 4.5 Windshield Frame

The experimental setup i.e. the test vehicle and the windshield frame were kept in an open environment as shown in Fig. 4.6.

Fig. 4.6 Experimental Setup

4.3 Dry Abrasion of Windshields

The windshields were left outside so that dust accumulates on it. Lamination from the marked sections were removed in a sequence so that just that only the exposed portion of the windshield will be abraded by the wiper blades. The old and new wiper blades were used to dry wipe the corresponding part of the windshields when a sizable coating was evident there. The dust typically took two to three days to accumulate on the wiper blades and windshield. The time it took for the dust to settle on windshields could vary depending on the weather and wind conditions. Sometimes it took longer than five or six days. The 12V battery supplied power to the wiper motor, which was run at a medium speed of 50 wiping strokes per minute. This was picked to be a standard referenced in AIS- 019/2001[26]. A total of 5 wiper cycles were used in one experiment, i.e., cleaning one marked section. The next experiment required removing the adjoining lamination part from both windshields. In this process already abraded section was remain exposed for further abrasion. In this process, number of abrasion cycles on the earlier exposed section will increase as we progress towards the later sections. This will provide abrasion of last section with minimum number of cycles and the first section with highest number of abrasion cycles.

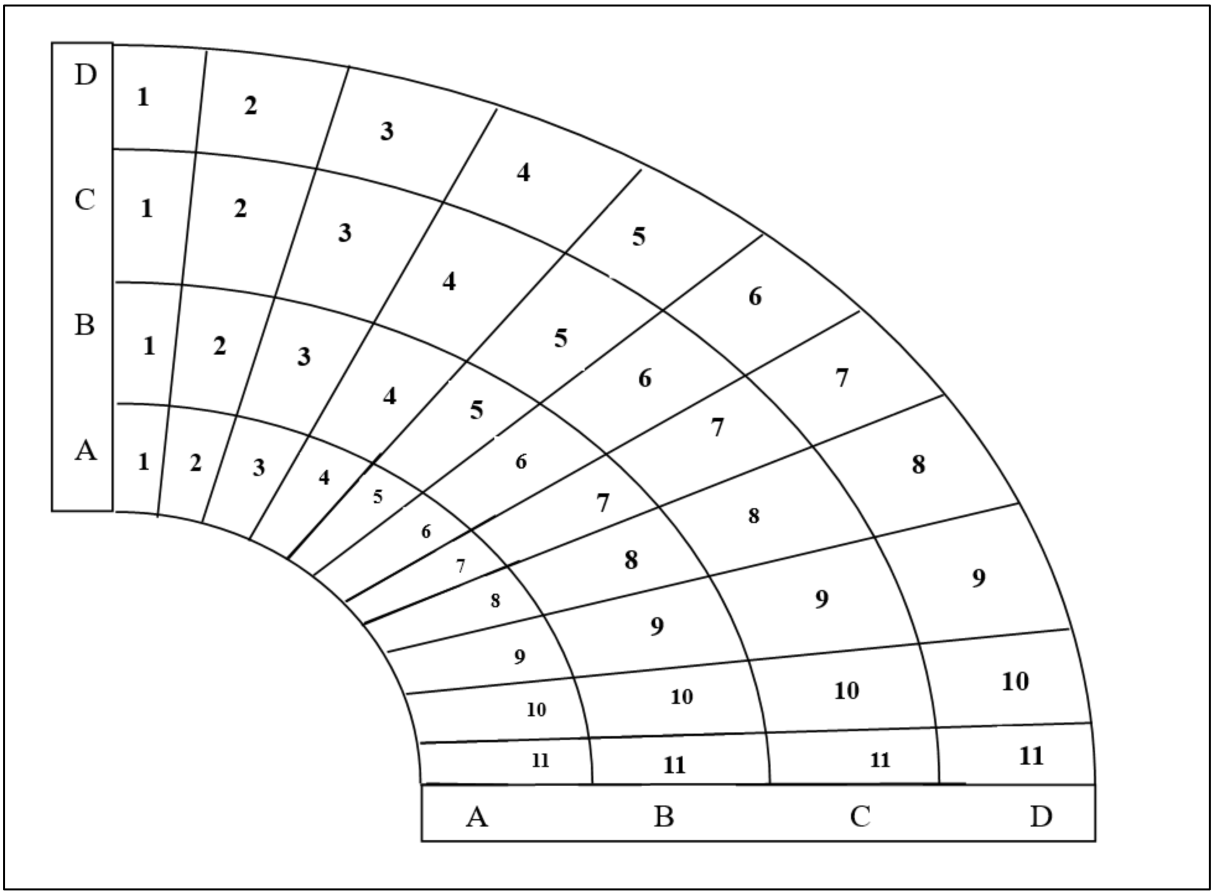


Fig. 4.7 Section-wise Representation of Windshield

Fig. 4.7 depicts the sections indicated on the windshield's lamination. The investigations began in late December 2022 and concluded in early April 2023. The testing area on the windshield was in front of the driver's line of sight and comprised the majority of the wiper's swept area. First, lamination from sections 11D and 1C was removed, while the windshields remained outside. After a substantial dust accumulates, the windshields were cleansed with both old and new wiper blades. Then sections 10D and 2C were removed, and a test was conducted after dust was visible on the sections. The decision of wiping after sufficient dust accumulation was based visual observation as user generally do in real life usage of vehicle. After concluding the D and C series, the B and A series' lamination was removed and tests were conducted.

Table 4.1 Wiper cycles at different sections of both windshields

Section	No. of Wiper Cycles	Section	No. of wiper cycles
1A, 11B	5	1D, 11C	60
2A, 10B	10	2D, 10C	65
3A, 9B	15	3D, 9C	70
4A, 8B	20	4D, 8C	75
5A, 7B	25	5D, 7 C	80
6A, 6B	30	6D, 6C	85
7A, 5B	35	7D, 5C	90
8A, 4B	40	8D, 4C	95
9A, 3B	45	9D, 3C	100
10A, 2B	50	10D, 2C	105
11A, 1B	55	11D, 1C	110

Table 4.1 illustrates the number of wiper strokes on each windshield section, providing 44 wear regions on each windshield.

4.4 Photography Setup

After abrading the windshields to study the effect of windshield wear during night driving, night-time photography was performed using a high-resolution camera with high dynamic range with manual adjustment and without any post processing of image. The imaging was performed in RAW format so that characteristics of the original image will be retained. For this purpose, the test vehicle was parked on a flat road with a light source (headlight of another car) in front at a distance of 25m and photography of each marked section for both windshields was performed. The parking area was selected in such a way that there was total dark area and no stray light coming towards the test setup. Reflection of light coming from the test vehicle headlamps will only be recorded for the measurement of light reflection during imaging.

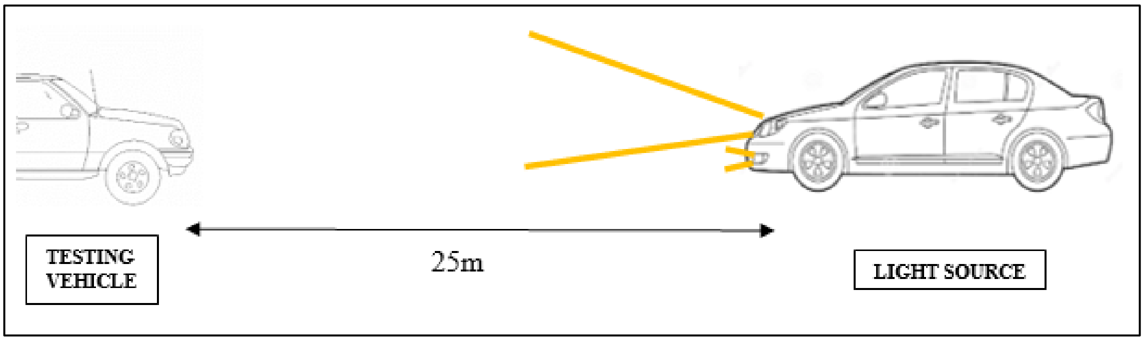


Fig. 4.8 Photography Setup

Fig. 4.8 shows the light source and the test vehicle setup. The photography was performed from the inner side of the test vehicle for each windshield.

4.4.1 Light Source

The light source was an actual Maruti Suzuki Baleno, with white (6500K) LED headlights. The lights were kept on high beam as shown in Fig. 4.9.

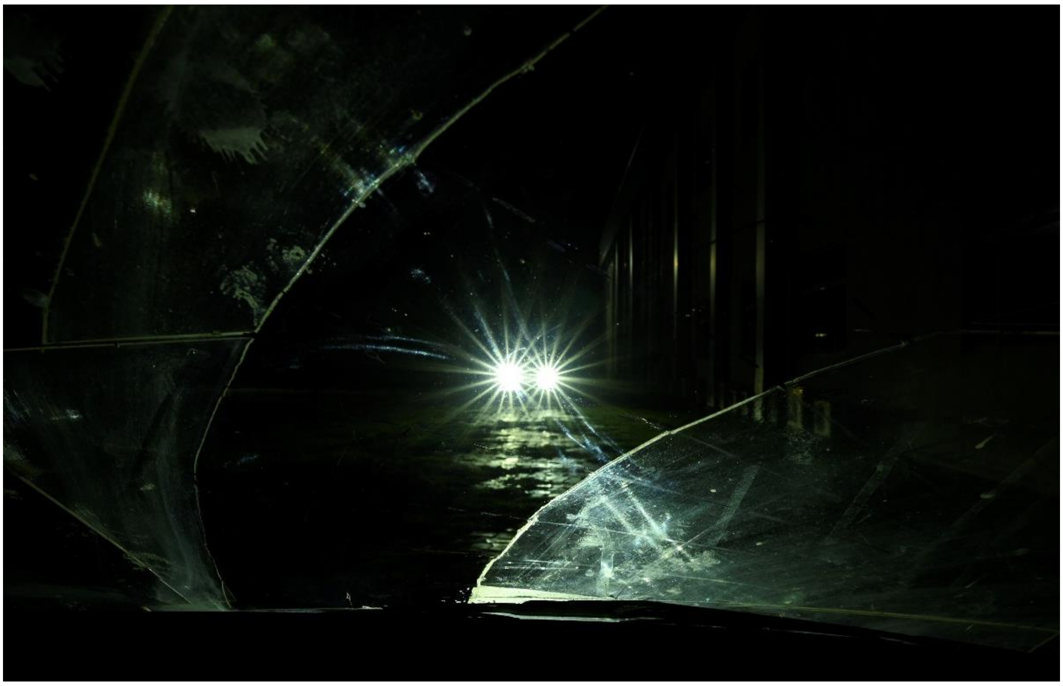


Fig. 4.9 Image taken from the test vehicle

4.4.2 Camera Specification

Nikon Z6 II was used to do the night-time photography. The Nikon Z6 II offers a 24MP full-frame sensor, in-body 5-axis stabilization and high-quality 4K video shooting. Specifications of the camera used for night time photography are listed in Table 4.2.

Table 4.2 Camera Specifications

Make	NIKON CORPORATION
Model	Z 6 II
F-Number	f/4.5
Image sensor type	CMOS
Sensor size	35.9 mm x 23.9 mm
Total pixels	25.28 million
Image size	(L) 6048 x 4024 (24.3 million)
File format	NEF (RAW): 12 or 14 bit (lossless compressed, compressed, or uncompressed);
Frame coverage	Approx. 100% horizontal and 100% vertical
Speed	1/8000 to 30 s
ISO sensitivity	ISO 100 to 51200
Other options	HDR (high dynamic range)
Focus point	273
Frame size (pixels) and frame rate	3840 x 2160 (4K UHD):

Table 4.3 Lens Specification

Type	Nikon Z mount
Format	FX/35mm
Focal length	14 – 24 mm
Maximum aperture	f/ 2.8
Minimum aperture	f/ 22
Lens construction	16 elements
Angle of view	114° to 84°
Focal length scale	Graduated in mm (14,15,16,18,20,24)
Aperture range	f/2.8 to 22

4.4.3 Night-time Photography

The night photography was performed from inside the test vehicle, as shown in Fig. 4.10. Photographs of each section were taken separately to study the effect of wear during night driving. The photography was done in two phases in May 2023 and June 2023 and the weather was all clear when the photography was done. Fig. 4.11 shows an image taken from section 7D of one of the windshields. Brightness of the light source i.e car headlamp was assumed to be unchanged over the time of different experiments. Settings for the camera and the lens were also fixed (ISO speed: ISO 400, F-stop: f/4.5, Exposure time ½ seconds) for all the experiments so as to capture images using same imaging conditions.

Fig. 4.10 Photography in the night-time

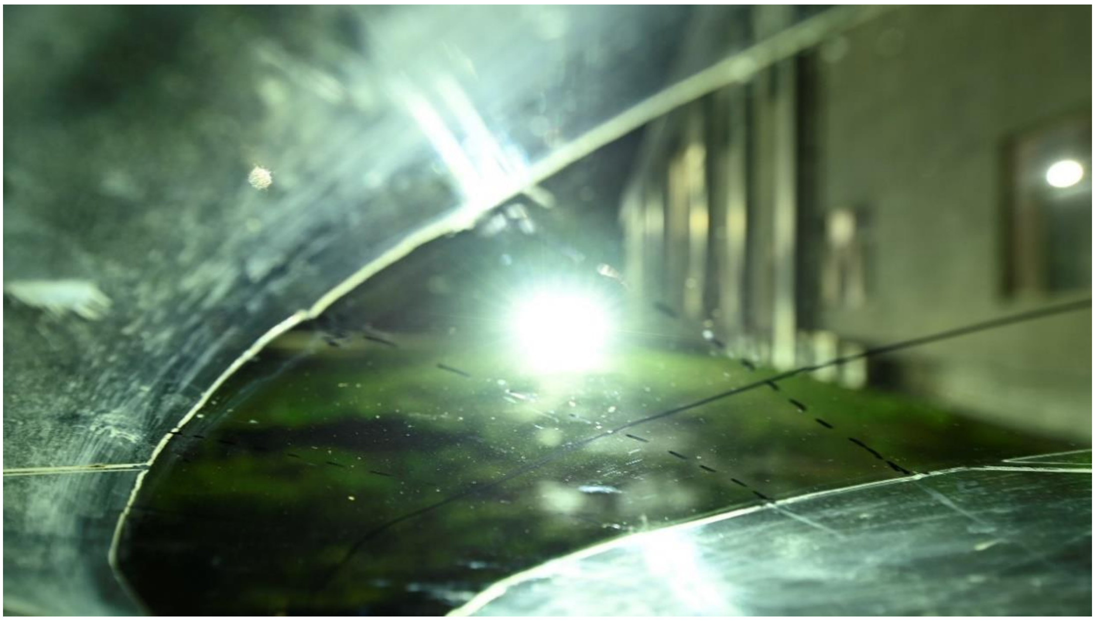


Fig. 4.11 Image taken at section 7D

4.5 Image Processing

It is very difficult to differentiate the amount of light scattering through different sections of the windshields just by naked eyes or looking at the RAW images taken by the camera. In order measure the light scattered from each section, some smaller area of the image processing was required which will represent the abraded surface. For this purpose, a MATLAB software code was created. The RAW images in the NEF format were first processed through 'Faststone' image viewing software and the equal area of interest from all the images were cropped from the RAW images. After this a separate MATLAB code was created to calculate the intensity of light in the cropped images image section. Common size of the cropped image was decided based on the image with largest scattering.

4.5.1 Editing the RAW Images

The area of interest was cropped (800x600 pixels) using 'Faststone' software as shown in Fig. 4.12 and then was imported to MATLAB. This process has no effect on intensity or other characteristics related to image quality.

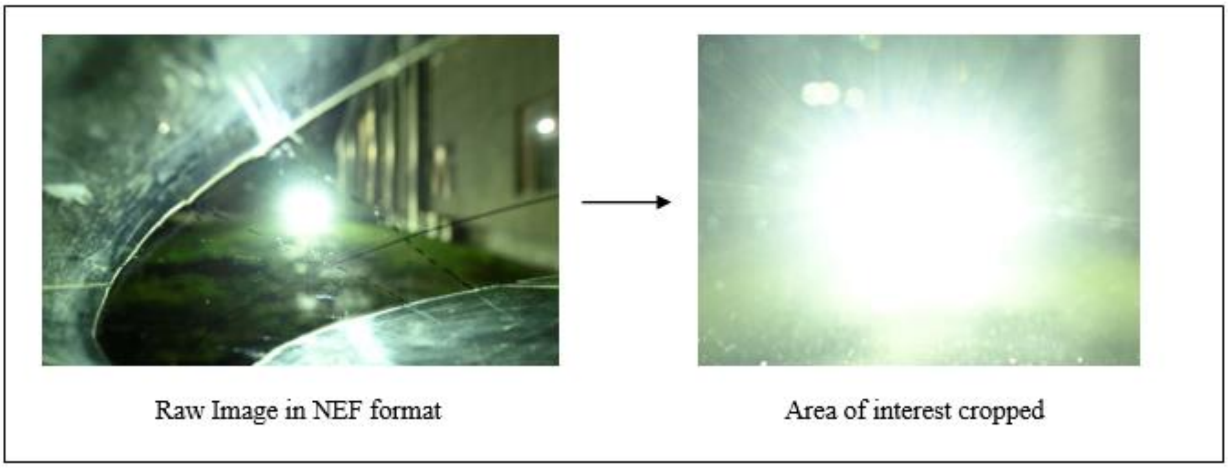


Fig. 4.12 Editing of RAW images

4.5.2 MATLAB Code for intensity calculation

It is difficult to calculate the intensity level of different pixels in an image and their numbers without any post processing method. Thus, a MATLAB code was created to calculate the amount of light scattered through the abraded wear sections. Light scattering spot has the brightest spot in the middle of the image. Brightness of pixels goes on decreasing towards the outer boundary. In order to keep all the calculation on a common platform, there was requirement of fixing the threshold value above which the bright spot was considered for pixel intensity calculations and decided the size of bright spot under consideration

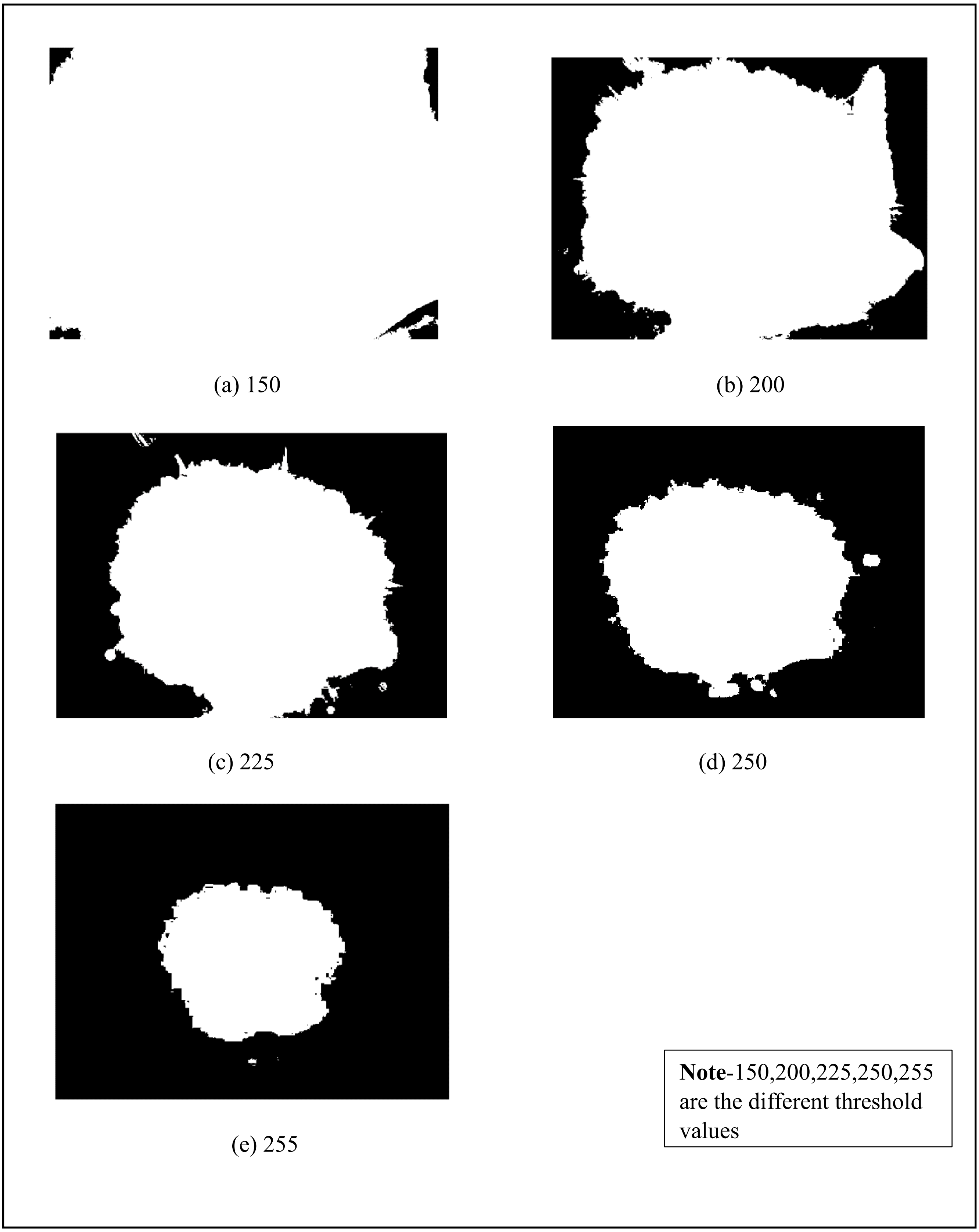


Fig. 4.13 MATLAB result images at different threshold value

In the process, trials were performed to find the appropriate amount of threshold value as shown in Fig. 4.13 of filtering which would remain constant for all the images. The following method was used to do so

Method-

1. The cropped images were imported into MATLAB software
2. The imported images were converted into grayscale
3. Intensity of each pixel was calculated
4. A threshold value of 225 was finalized for the intensity
5. An if/else loop was created to filter out the image
6. Threshold image was converted into a binary image (Black and White)
7. The number of white pixels was calculated
8. The filtered image was saved.

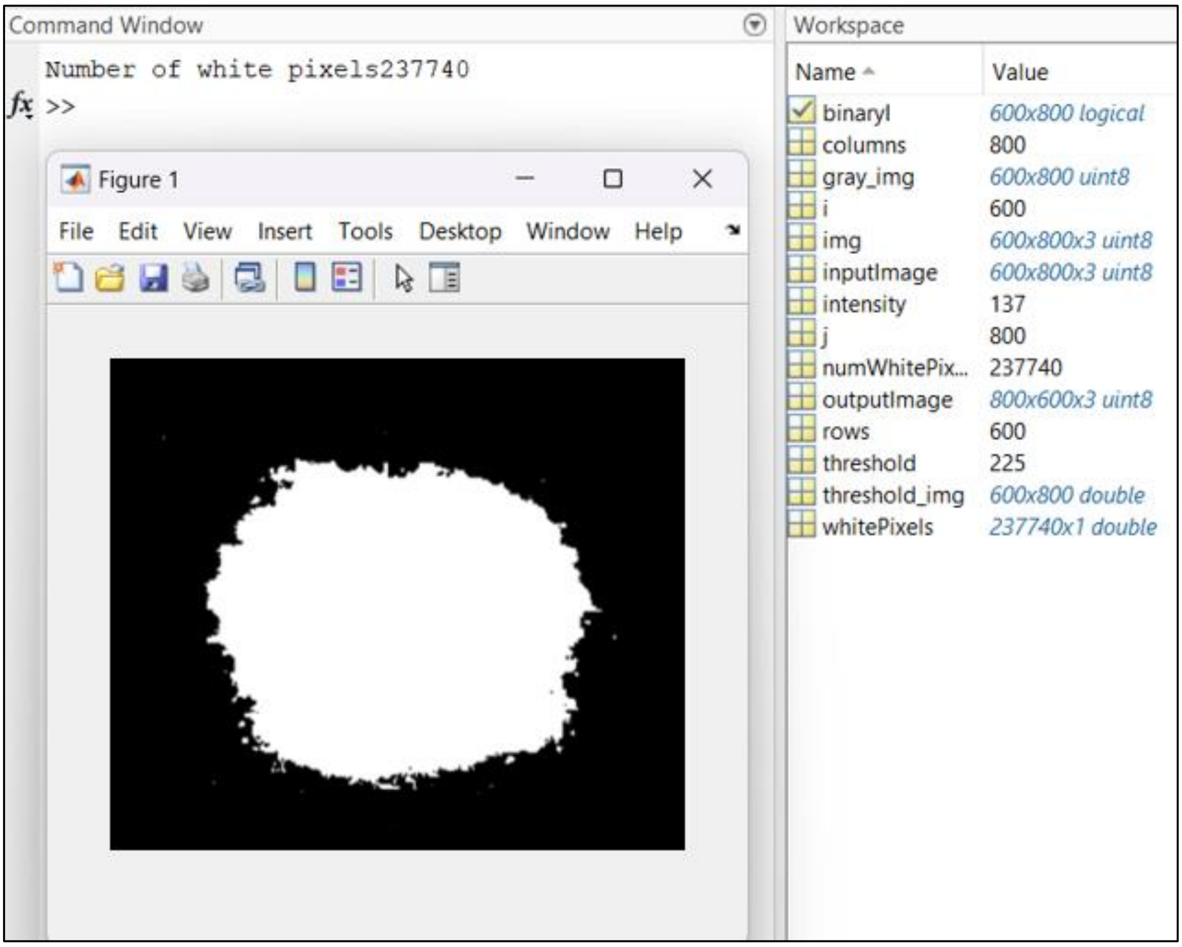


Fig. 4.14 MATLAB Code results

A binary image was obtained as shown in Fig. 4.14 and the number of white pixels was calculated for the section 1D of the windshield abraded through old wiper blade.

4.6 EDS of the Dust Deposited on Windshield

Energy dispersive X-ray spectroscopy (EDS) is a process that analytically identifies the elements (elemental composition) present in any given material. So, to study the wear on the windshield, it was required to know the constituents of the dust deposited on it. The dust from the windshield was collected and analysed using EDS. The drop cast technique was used to hold the dust sample for analysis on Bruker, QUANTX 200 machine.

4.7 Roughness Testing

4.7.1 Cutting of windshield

It was not possible to do the roughness testing of the whole windshield as it was curved and also, there are certain limitations of the roughness testing machine related to sample size. Mitutoyo surface roughness tester cannot accommodate large size samples. The windshield was cut into different pieces suitable for roughness testing. Using a diamond cutter as shown in Fig. 4.16, the windshield was cut from above and beneath along the marked sections. A gas flame was used to melt the thin transparent UPVC film between the windshield.

Fig. 4.15 Diamond Glass Cutter

4.7.2 Surface Roughness Testing

Each section's roughness (*Ra* value) was measured, as shown in Fig. 4.17. A graph was also plotted to analyse the scratch pattern on the windshields. Table 4.3 shows the specification of the roughness testing machine.

Table 4.4 Roughness test specification

Operator	Mitutoyo
Measuring Tool	SurfTest SJ-400
Standard	JIS 2001
N	5
Profile	R
Cut-Off	0.8mm
Filter	GAUSS

CHAPTER 5

RESULTS AND DISCUSSION

The results obtained from various techniques were evaluated and corelated in order to get a clear understanding of the quantum of abrasion and its effect on the scattering of light during night driving. As the experiments were conducted in the open environment at a fixed location, hence the present study was not able to evaluate the effect of various dust composition on the abrasion properties depending on the highly populated industrial regions. The environment of Patiala city is moderate in terms of air quality, with presence of small-scale industries and a good amount of vehicular traffic. The dust accumulated on the windshield was collected and tested for the presence of various possible elements which affects the wear phenomenon.

5.1 EDS of Dust Particles

The EDS of the sand deposited on the windshield was performed and the results obtained are mentioned in Fig. 5.1, 5.2 and Table 5.1.

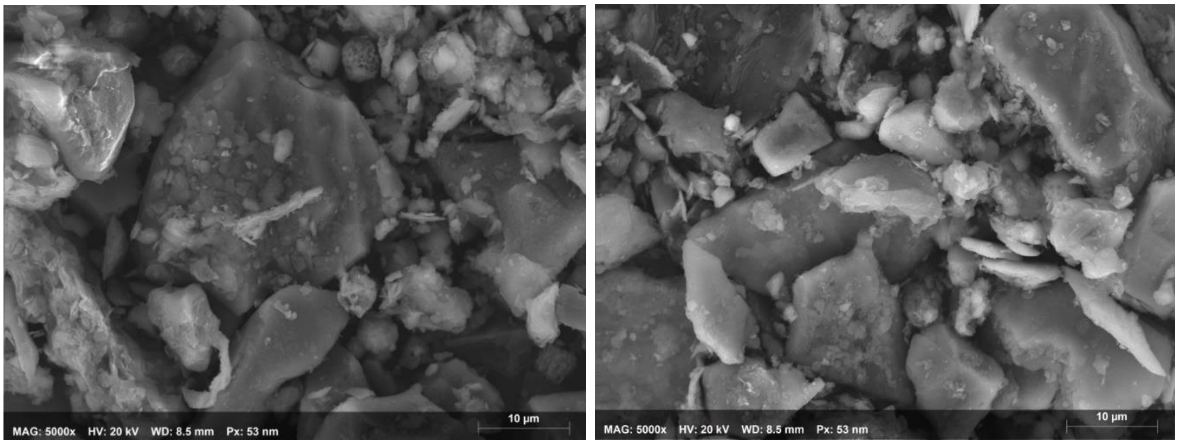


Fig. 5.1 Microscopic image of the dust sample

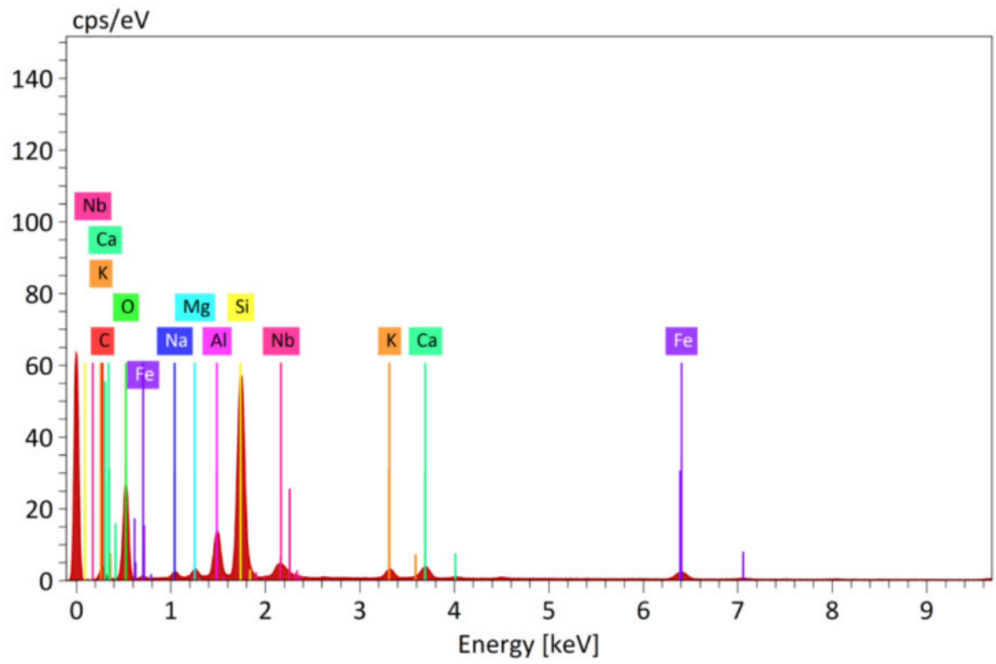


Fig. 5.2 Energy levels of elements found in dust

Table 5.1 Mass concentration of the elements

Element	At. No.	Netto	Mass Norm [%]	Atom [%]	Abs. error [%] (1 sigma)	rel. error [%] (1 sigma)
C	6	11747	14.78	23.40	0.69	5.53
O	8	102430	44.88	53.34	1.90	5.04
Na	11	6997	1.04	0.86	0.06	6.45
Mg	12	9591	0.95	0.74	0.04	5.19
Al	13	64186	5.15	3.63	0.16	3.79
Si	14	314584	20.04	13.57	0.55	3.24
K	19	18511	1.83	0.89	0.04	2.48
Ca	20	25407	2.84	1.35	0.05	2.27
Fe	26	20360	3.53	1.20	0.06	2.19
Nb	41	35190	4.94	1.01	0.12	2.88
		Sum	**100.0**	**100.0**		

It can be observed from the Fig. 5.1, that all dust particles are not round in shape. Very small particles of in the size less than 5 μm bears less sharp edges, whereas larger particles of more than 10 μm are having irregular size with sharp edges. Few particles of larger aspect ratio can also be seen which causes abrasion during dry sliding. Presence of Al_2O_3 i.e., alumina in the environments pollutants is very common. Alumina is harder than soda lime glass of which windshield is made. Presence of Fe_2O_3 is also possible due to rusting of iron, the industries and household items. Wear and tear of brake discs and brake drums of the vehicles is a huge source of iron oxide in the environmental dust. Iron oxide is also harder than glass and causes wear when present in the dust particles. The composition of abrasive test material used as standard procedure for testing the windshield wiper mechanism (in Annexure III) (System and Windshield –washer tests) of AIS - 019/2001 [26] is given in Table 5.2. This standard test AIS 019 is for the testing of wiper blades. The mass percentage of various constituents is given but particle sizes of each composition is nowhere mentioned in the standard. The composition mentioned in Table 5.2 is very similar to the composition of dust samples obtained from the windshield.

Table 5.2 Standard testing dust mixture [26]

Constitute	% mass
SiO_2	67 to 69
Fe_2O_3	3 to 5
Al_2O_3	15 to 17
CaO	2 to 4
MgO	0.5 to 1.5
Alkalis	3 to 5
Ignition loss	2 to 3

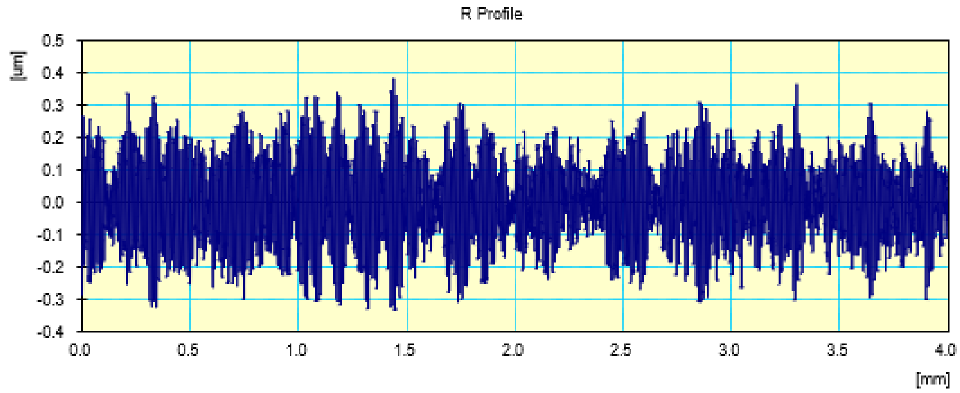
5.2 Relationship of Surface Roughness with Wiper Test Cycles

The surface roughness measurement technique is very helpful in finding the fine worn-out surface irregularities on the windshield surface. Surface roughness testing of the windshield sections after dry abrasion was performed using Mitutoyo Surface Roughness tester (SJ-400) as per JIS 2001 standard. The roughness of a new unused windshield glass was also measured. It was found that unused new glass has roughness value *Ra* to be 0.03. The graphs of the measured values of test surface were drawn within the measurement machine setup as shown in Fig. 5.3. (Sample 9A) of the windshield abraded through old wiper blade. The test results of both the windshields were analysed using old and new wiper blade.

Mitutoyo

21- Jun -2023

CERTIFICATE OF INSPECTION



Work Name	Sample	Operator	Mitutoyo
Measuring Tool	SurfTest SJ-400	Comment	Ver4.00

Standard	JIS 2001	N	5
Profile	R	Cut-Off	0.8mm
Range	800um	Filter	GAUSS

Ra	0.10um	
Rz	0.7um	
Rq	0.12um	

Fig. 5.3 Certificate of inspection of 9A section

5.2.1 Windshield abraded using old wiper blade

A new unused windshield was abraded as per the process mentioned in chapter 4, with an old wiper which was four years old and vehicle was used for approximately 25000 kms. Abrasion on the surface can be testified with its roughness values. Table 5.3 to Table 5.6 depicts the data of wiper cycles at different sections and their corresponding roughness values.

Table 5.3 Relation of Wiper cycles with *Ra* and *Rz* value on A-Region

S No.	Section	No. of Wiper Cycles	*Ra*	*Rz*
1.	1A	5	0.03	0.3
2.	2A	10	0.05	0.2
3.	3A	15	0.04	0.3
4.	4A	20	0.05	0.3
5.	5A	25	0.07	0.5
6.	6A	30	0.04	0.3
7.	7A	35	0.08	0.6
8.	8A	40	0.07	0.4
9.	9A	45	0.10	0.7
10.	10A	50	0.14	0.7
11.	11A	55	0.05	0.4

As described in chapter 4, the wipe area of the wiper blade was divided into 4 peripheral section and then each peripheral section is divided into 11 equal radial sections. Section 'A' was the innermost section and 'D' being outermost. As the sections 1A to 11A were exposed for abrasion, the number of wiper cycles faced by the section increases for 1A to 11A as we go on exposing next section after each 5 test cycles. Section 11A being highly abraded and 1A being least abraded. It can be clearly observed from the roughness values of the sections in Table 5.3 that as the number of wiper cycles increases, there is increase in surface roughness. Although the section 11A is at the bottom of the arc and it is the innermost section of all. It was abraded for 55 test cycles; however, its roughness value is not reflecting the same increasing pattern. The reason behind the less abrasion might be due to the reduced pressure of the wiper blade at the bottom tip. Section 11A is the bottom most section, from where wiper stroke just starts and accelerates towards 1A. This variation can also be due to misalignment of the wiper blade at the rest position. Similarly, the section B is parallelly being abraded in the same manner as section A, however, the increasing sequence of the subsections is just in the opposite order in order to study the effect of abrasion of the windshield in the forward stroke and reverse stroke of the wiper. The increasing order of roughness values with increase in test cycles, in section B is also evident from the Table 5.4.

Table 5.4 Relation of Wiper cycles with *Ra* and *Rz* value on B-Region

S No.	Section	No. of Wiper Cycles	*Ra*	*Rz*
1.	11B	5	0.04	0.3
2.	10B	10	0.04	0.3
3.	9B	15	0.05	0.6
4.	8B	20	0.06	0.5
5.	7B	25	0.06	0.8
6.	6B	30	0.08	0.6
7.	5B	35	0.07	0.5
8.	4B	40	0.07	0.8
9.	3B	45	0.10	0.7
10.	2B	50	0.15	0.8
11.	1B	55	0.14	0.9

Table 5.5 Relation of Wiper cycles with *Ra* and *Rz* value on C-Region

S No.	Section	No. of Wiper Cycles	*Ra*	*Rz*
1.	11C	60	0.05	0.3
2.	10C	65	0.05	0.3
3.	9C	70	0.06	0.5
4.	8C	75	0.04	0.3
5.	7C	80	0.03	0.3
6.	6C	85	0.06	0.4
7.	5C	90	0.08	0.6
8.	4C	95	0.08	0.7
9.	3C	100	0.14	0.7
10.	2C	105	0.14	0.9
11.	1C	110	0.20	1.2

Table 5.6 Relation of Wiper cycles with *Ra* and *Rz* value on D-Region

S No.	Section	No. of Wiper Cycles	*Ra*	*Rz*
1.	1D	60	0.05	0.3
s2.	2D	65	0.04	0.4
3.	3D	70	0.04	0.4
4.	4D	75	0.08	0.6
5.	5D	80	0.06	0.5
6.	6D	85	0.06	0.5
7.	7D	90	0.09	0.6
8.	8D	95	0.10	0.7
9.	9D	100	0.10	0.7
10.	10D	105	0.13	1.0
11.	11D	110	0.18	1.3

The section C is second from the outer and Section D is on the outermost periphery. It can be observed from the Tables 5.5 and 5.6 that abrasion cycles are increasing from subsections 11C to 1C and 1D to 11D. Sections C and D were subjected to double the number of abrasion cycles as compared to section A and B as the experimentation of abrasion starts for the outer section first and then the inner sections were exposed for abrasion so that an increasing order of wear pattern can be obtained. During the abrasion of sections, A and B, all the surfaces of sections C and D are also involved in the abrasion process, hence the number of increments in A and B, automatically gave increments in C and D. In other words, abrasion starts first from C and D, then it comes to A and B. It is evident from Tables 5.5 and 5.6 that surface roughness values follows an increment order with respect to the increasing order of test cycles in a similar fashion as in A and B. However, the roughness values are different depending on the number of test cycles.

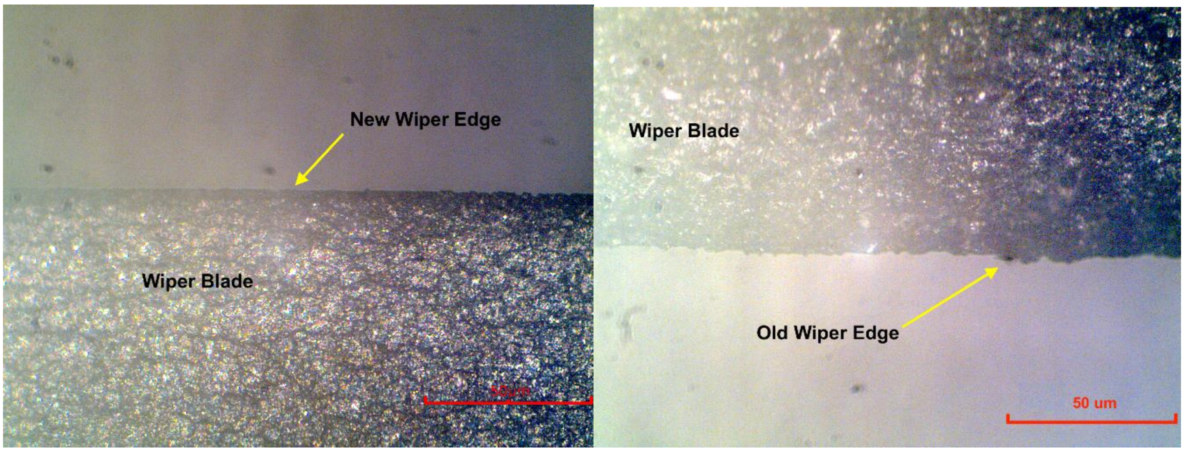


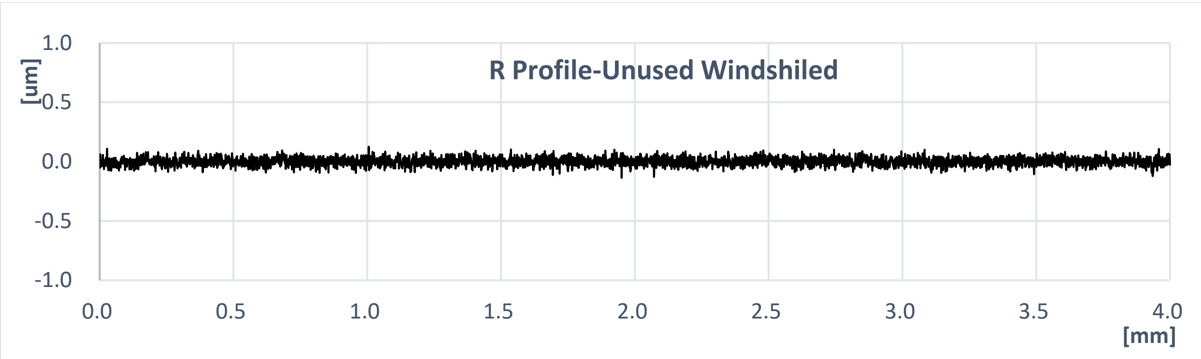
Fig. 5.4 Wiping edge of unused and used wiper blade

The above discussion in section 5.2.1 is the abrasion caused due to usage of old wiper blade. In general, it is presumed that old wiper rubber becomes harder over the time and harm the windshield to more extent than the new wiper blades. However, in the present study it was found that as the wiper blade becomes older, its cleaning/wiping quality decreases more instead of its damaging effect. Regular usage of wiper, (either with liquid or dry) the sharp wiping edges gets deteriorated with each wiping stroke. Over the passage of time cleaning quality of wiper decreases, however the abrasion probability due to fine particles decreases. It is clearly visible in the Fig. 5.4 that wiping edge of new wiper is smooth and the edge of old wiper possesses more irregularities which gives way to fine particles to stay on their location without moving along the wiping edge of the blade i.e., the poor cleaning effect is caused by the existence of fine particles which were not removed and did not participate in the abrasion. The abrasion due to larger dust particles increases due to their rolling effect between wiper blade and glass surface. This is evident from the surface roughness graphs obtained during the measurement. As compared to the new glass surface, the depth of damage is very high on the glass surface abraded using old wiper blade with more number of test cycles. Since the R_a value is indicates the average of roughness values over the span of measured test surface and did not represent the extent of damage. The value of Rz (the measure of the absolute distance between the highest peak and the lowest valley) is the maximum variation in the roughness values and represents the maximum depth of damaged location.

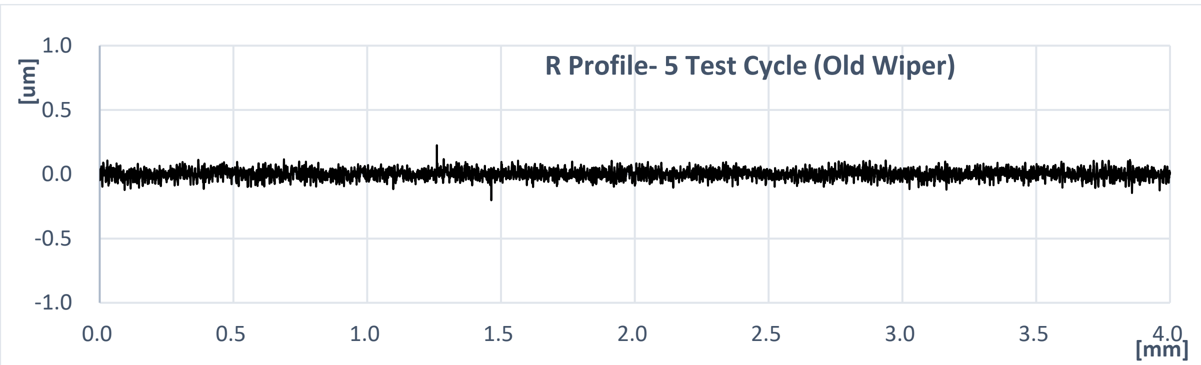
As the present research was carried out with the dust particles on the actual parked car like situation, hence it involves the variations in the dust particle sizes. It can be clearly observed from the Table 5.7 and Fig. 5.5 that the variations of R_a value after 5 test cycles and 110 test cycles is not too high but the value of R_z has increased to a larger extent i.e., larger dust particles (although less in number) has damaged the surface to a greater extent.

Table 5.7 Comparison of surface abrasion severity after unused, 5 test cycle and 110 test cycle

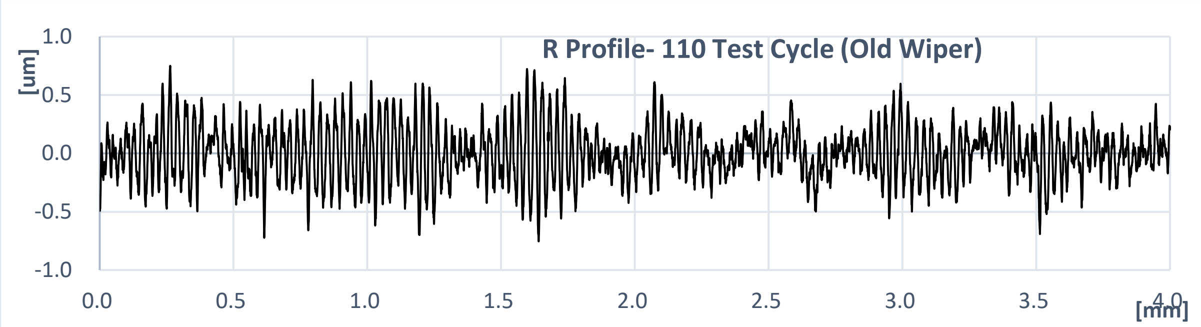
Parameter	Unused Windshield	After 5 test cycle	After 110 test cycles
	Value μm		
Ra	0.03	0.03	0.18
Rz	0.2	0.3	1.3



(a)



(b)



(c)

Fig. 5.5 Roughness profile of windshield **(a)** Roughness profile of unused windshield, **(b)** Roughness profile of windshield after 5 test cycles using old wiper, **(c)** Roughness profile of windshield after 110 test cycles using old wiper

5.2.2 Windshield abraded using new wiper blade

In the second set of experiment, a set of new and unused wiper blades was used on the second new and unused windshield in parallel with the experiment described in section 5.1 above. Other experimental conditions remain the same. Table 5.8 to Table 5.11 depicts the data of wiper cycles at different sections and their corresponding roughness values R_a and R_z. Few measurements of the section 3A - 8A cannot be performed due to damages in some portion of the windshield by external factors as the whole setup was lying outside in open environment.

Table 5.8 Relation of Wiper cycles with *Ra* and *Rz* value on A-Region

S No.	Section	No. of Wiper Cycles	*Ra* (µm)	*Rz* (µm)
1.	1A	5	0.04	0.3
2.	2A	10	0.07	0.5
3.	3A	15	-	-
4.	4A	20	-	-
5.	5A	25	-	-
6.	6A	30	-	-
7.	7A	35	-	-
8.	8A	40	-	-
9.	9A	45	0.11	0.8
10.	10A	50	0.11	0.9
11.	11A	55	0.16	1.6

There is no possibility of recreating the already performed wear test cycles as the two experiments with same environmental conditions are running simultaneously. It can be observed from the Table 5.8 that *Ra* and *Rz* values are increasing with increase in test cycles.

Table 5.9 Relation of Wiper cycles with *Ra* and *Rz* value on B-Region

S No.	Section	No. of Wiper Cycles	*Ra* (µm)	*Rz* (µm)
1.	11B	5	0.05	0.4
2.	10B	10	0.05	0.2
3.	9B	15	0.05	0.3
4.	8B	20	0.06	0.4
5.	7B	25	0.1	0.10
6.	6B	30	0.14	1.4
7.	5B	35	0.19	0.9
8.	4B	40	0.18	1.0
9.	3B	45	0.2	1.3
10.	2B	50	0.2	1.3
11.	1B	55	0.21	1.6

Table 5.10 Relation of Wiper cycles with *Ra* value on C-Region

S No.	Section	No. of Wiper Cycles	*Ra* (µm)	*Rz* (µm)
1.	11C	60	0.03	0.2
2.	10C	65	0.05	0.3
3.	9C	70	0.06	0.4
4.	8C	75	0.04	0.3
5.	7C	80	0.03	0.4
6.	6C	85	0.06	0.4
7.	5C	90	0.08	0.7
8.	4C	95	0.08	0.6
9.	3C	100	0.14	1.4
10.	2C	105	0.21	1.8
11.	1C	110	0.18	1.2

Table 5.11 Relation of Wiper cycles with *Ra* value on D-Region

S No.	Section	No. of Wiper Cycles	*Ra* (µm)	*Rz* (µm)
1.	1D	60	0.06	0.4
2.	2D	65	0.08	0.6
3.	3D	70	0.10	0.7
4.	4D	75	0.18	1.3
5.	5D	80	0.08	0.6
6.	6D	85	0.14	0.9
7.	7D	90	0.16	1.1
8.	8D	95	0.18	1.3
9.	9D	100	0.20	1.6
10.	10D	105	0.29	2.3
11.	11D	110	0.26	2.4

Similar to the results obtained by the abrasion of old wiper blades, the wear pattern created by the new wiper blade is also in the same trend with increased wear. It is clear from above data that with the increase in the number of wiper cycles the roughness of the windshield glass also increases but it can also be seen that the *Ra* values of windshield abraded trough new wiper blade are more than the windshield abraded through old wiper blade. From the table 5.11, it can be observed that there is sharp increase in *Ra* value of section 4D. This sharp increment in wear is due to the rubbing of the second wiper (left side) on the wiping envelop of the right-side wiper under consideration. This region, 4D is an overlapping region which was abraded by the two wiper blades. This overlapping region can be different in different category of vehicle based in windshield shape, rake angle and area.

It can be clearly observed from the Table 5.12 and Fig. 5.6 -5.7 that the variations of R_a value after 5 test cycles and 110 test cycles is significant but the value of R_z has increased to a larger extent.

Table 5.12 Comparison of surface abrasion severity after unused, 5 test cycle and 110 test cycle

Parameter	**After 5 test cycle**	**After 110 test cycles**
	Value μm	
Ra	0.04	0.26
Rz	0.3	2.4

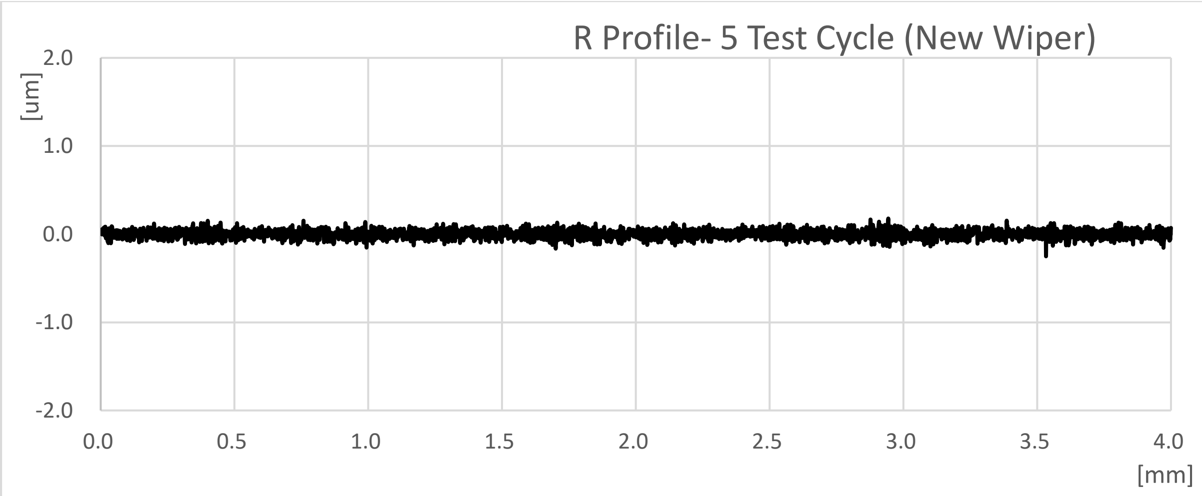


Fig. 5.6 Roughness profile of windshield after 5 test cycles using new wiper

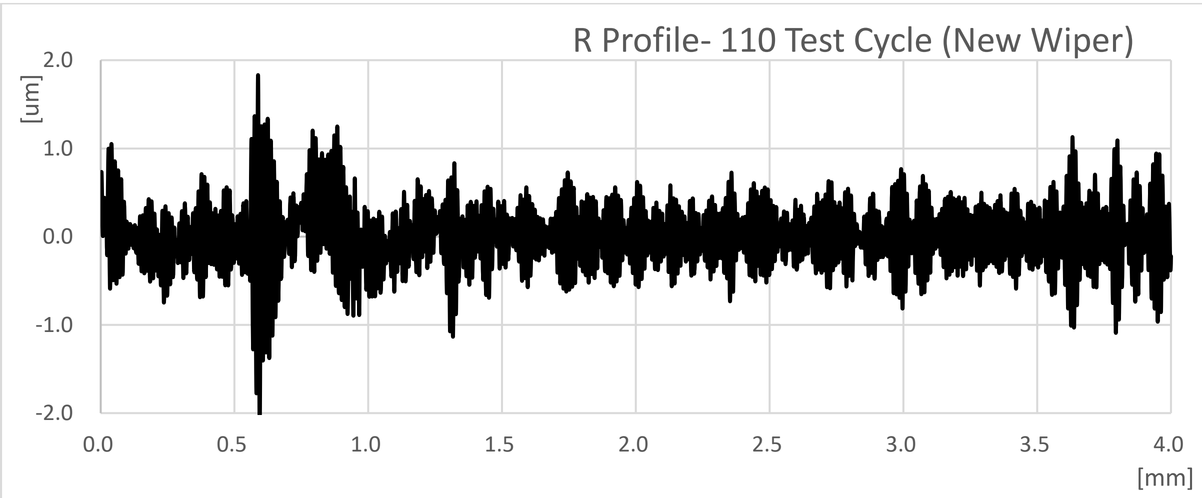


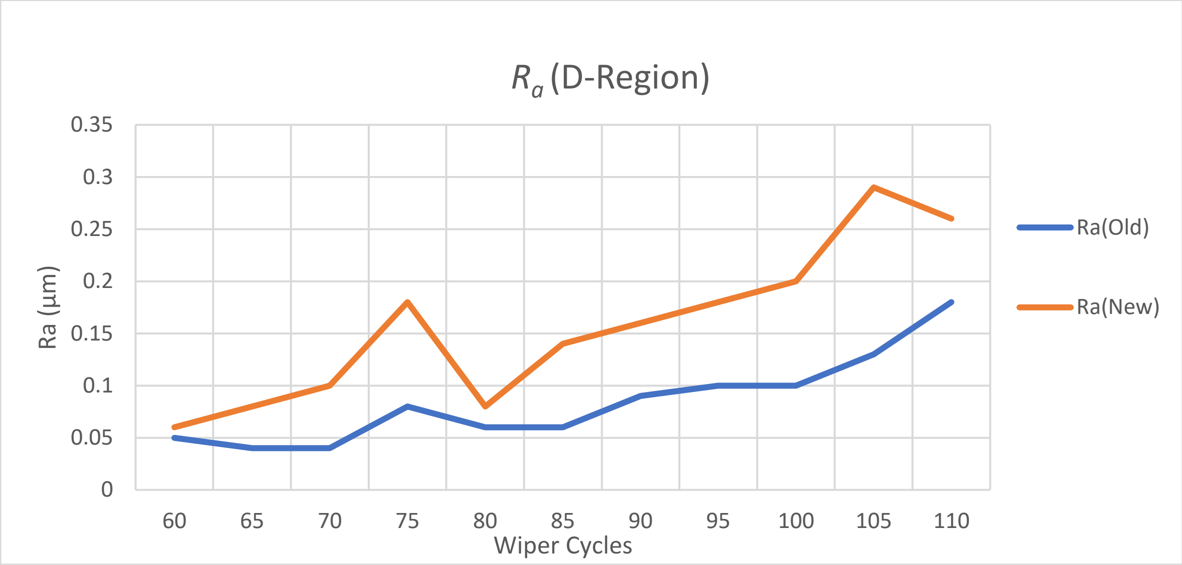
Fig. 5.7 Roughness profile of windshield after 110 test cycles using new wiper

5.3 Effect of Wiper Blade’s Age on the Windshield

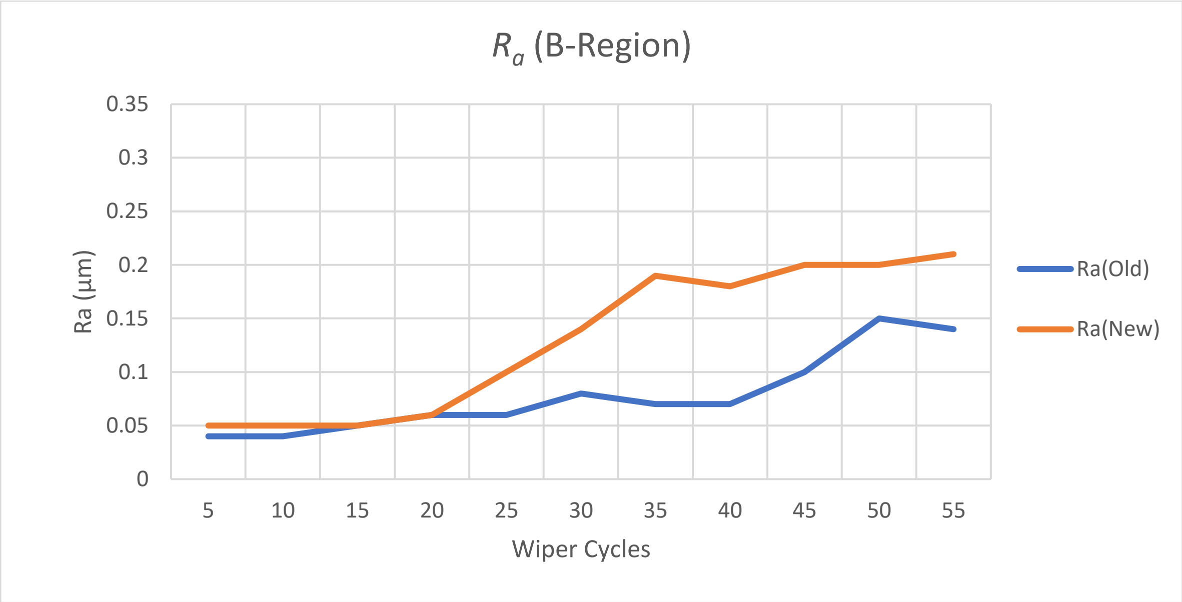
Significant scratches were visible on both the windshields. It was discovered that the age of the wiper blade has a substantial impact on the rate at which the windshield wears. In contrast to the expected phenomenon of wear, the windshield was damaged more by the new wiper blade than by the old wipers. In general, it was expected that as the wiper blade gets harder over the time, it leads to abrade the windshield more. However, the scientific phenomenon is different and true as per the results obtained. One important fact is very well established from the Tables 5.3 to 5.10 that abrasion of glass surface is more in C and D regions due to high number of rubbing test cycles. Another reason of high abrasion in C and D region is the higher value of peripheral velocity on the outer regions of the wiping area. For the present study we have not measured the peripheral velocity and not considered its effect on the abrasion effect.

5.3.1 Comparison of surface wear due new and old wiper blade

New wiper blades had a more severe effect on the windshield as the pressure of the new wiper blade on the surface of the windshield is more than the old wiper blade. Since the rubber of the wiper is blade is new it cleans the windshield more efficiently as the coefficient of friction is higher between the new wiper blade and the glass windshield and the area of contact between the wiper blade and the windshield is also more. This can also be understood by higher roughness (*Ra* value) of windshield abraded through new wiper blade. As seen in the Fig. 5.8, the roughness values *Ra* obtained due to wear using old wiper is less than the wear created due to new wiper blade. Although, the rubber of the new wiper blade is soft, however, softness of the wiper blade makes it more capable to clean better as it rubs the glass surface very closely/effectively. Due to the better grip of soft rubber, more dust particles are carried along the wiper blade and rubbed under the wiper. This can also be understood from the Fig. 5.9. The bending of wiper edge is common in both old and new wiper blades, but as discussed earlier in section 5.2.1, the hard and old wiper's edge give more space to the dust particles to escape out from the contact point. It is also very evident from the common practice that old wiper do not wipe properly and leave most of the dust as it is on the glass. The present study scientifically proved the phenomenon of windshield wear.



(a)



(b)

Fig. 5.8 (a), (b) Comparison of wear due to old and new wiper blades

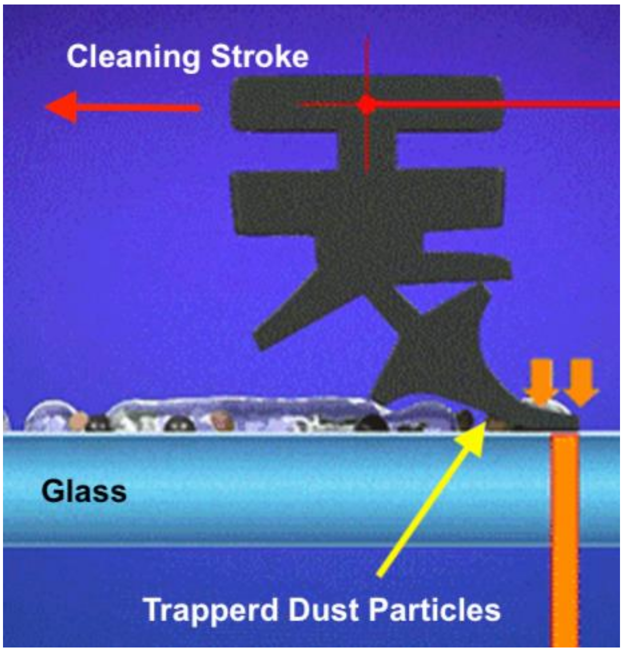


Fig. 5.9 Wiper sliding action on Windshield [27]

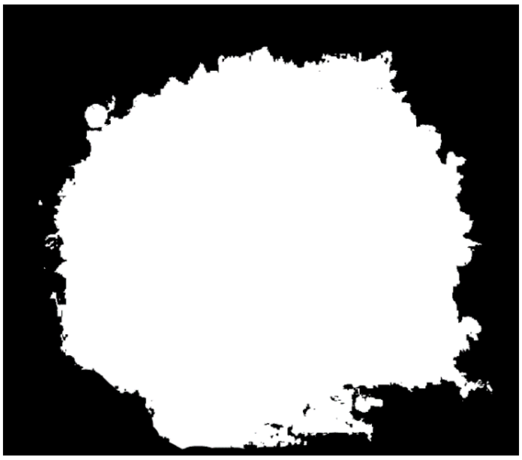
5.4 Effect of Wiper Test Cycles on Light Scattering

Section 5.3 presented above has corelated the variation of windshield abrasion with respect to the number of wear test cycles. The aim of the present research is to highlight the problem of visibility due to scattering of headlights of the oncoming vehicles. In order to establish a relationship among the wear factors and scattering of light, present work formulated a novel method of calculating the extent of light scattering through regions of different surface roughness. The novel process utilizes a software code for the processing of images captured at different sections (i.e., A, B, C, D) of the windscreen, as mentioned in the previous section 5.3.

The processed images are then again analysed through MATLAB image processing software module to get the amount of light scattering at various locations. The effect of windshield wear can be clearly seen during night driving in the form of light scattered after passing through worn out regions. When light rays strike on the outer surface of the inclined windshield, it gets scattered into different directions and generates a cloud effect hampering the visibility of driver through that location. The scattering of light and reduced visibility was the reason reported after lot of accidents during night driving [7]. Fig. 5.10 (a), (b), (c), (d) represents the analysed image through processing code and then intensity representation using suitable threshold value, of different sections.

(a) 4A

(b) 7B



(c) 5C

Fig. 5.10 (a), (b), (c) Image generated by MATLAB for different sections

The angle of secondary reflection and its amount depends on the smoothness of the striking surface. Scratches present on the outer surface provide multiple reflection points to the incident light rays. More is the roughness, more the light will scatter when entering through the windshield thus creating a glare which causes obstruction in proper vision of the driver. The scattering of light was calculated by using the MATLAB Code, in the form of white pixels present in the image. More number of white pixels represents high value of glare.

5.4.1 Light Scattered due to old wiper blade abrasion

As seen in the section 5.3, dry abrasion of the windshield surface is dependent of the number of wiper wear cycles and the rubber of wiper. Table 5.13 to Table 5.16 shows the total number of white pixels present at each section of the windshields abraded through old wiper blade.

Table 5.13 Relation of Wiper cycles with White Pixels in A-Region

S No.	Section	No. of Wiper Cycles	No. of White Pixels
1.	1A	5	231502
2.	2A	10	250901
3.	3A	15	278597
4.	4A	20	284077
5.	5A	25	296270
6.	6A	30	302100
7.	7A	35	300661
8.	8A	40	310129
9.	9A	45	314116
10.	10A	50	313383
11.	11A	55	266299

Table 5.14 Relation of Wiper cycles with White Pixels on B-Region

S No.	Section	No. of Wiper Cycles	No. of White Pixels
1.	11B	5	243170
2.	10B	10	263102
3.	9B	15	284933
4.	8B	20	289705
5.	7B	25	289006
6.	6B	30	282089
7.	5B	35	280217
8.	4B	40	288753
9.	3B	45	297505
10.	2B	50	299003
11.	1B	55	305119

Table 5.15 Relation of Wiper cycles with White Pixels on C-Region

S No.	Section	No. of Wiper Cycles	No. of White Pixels
1.	11C	60	240028
2.	10C	65	281020
3.	9C	70	280031
4.	8C	75	260005
5.	7C	80	279957
6.	6C	85	286046
7.	5C	90	279013
8.	4C	95	288252
9.	3C	100	287419
10.	2C	105	289755
11.	1C	110	295433

Table 5.16 Relation of Wiper cycles with White Pixels on D-Region

S No.	Section	No. of Wiper Cycles	No. of White Pixels
1.	1D	60	237740
2.	2D	65	257342
3.	3D	70	265089
4.	4D	75	287527
5.	5D	80	285436
6.	6D	85	286836
7.	7D	90	292548
8.	8D	95	297330
9.	9D	100	299715
10.	10D	105	317897
11.	11D	110	328227

The following graphs from Fig. 5.9 to Fig. 5.12 show the relation between light scattering and the number of wiper cycles for the windshield abraded through an old wiper blade. All these graph shows an increasing trend as the number of wiper cycles is increased. The x-axis represents the number of wiper cycles, and the y-axis represents the number of white pixels.

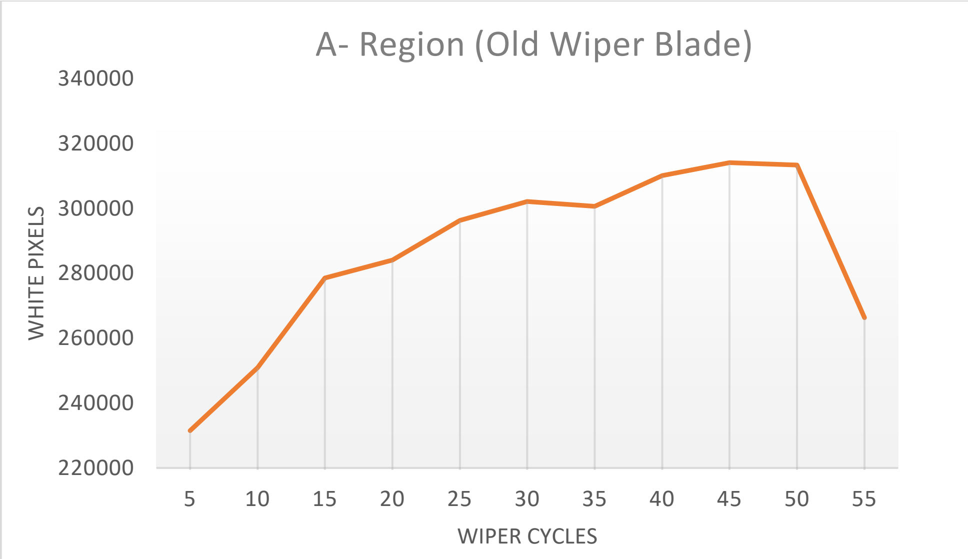


Fig. 5.11 Effect of number of wiper cycles at A- Region

From Table 5.13 to Table 5.16, it can be observed that as the number of wiper cycles increases, the number of white pixels also increases, which means that the light is scattered more in regions where wiper cycles are more.

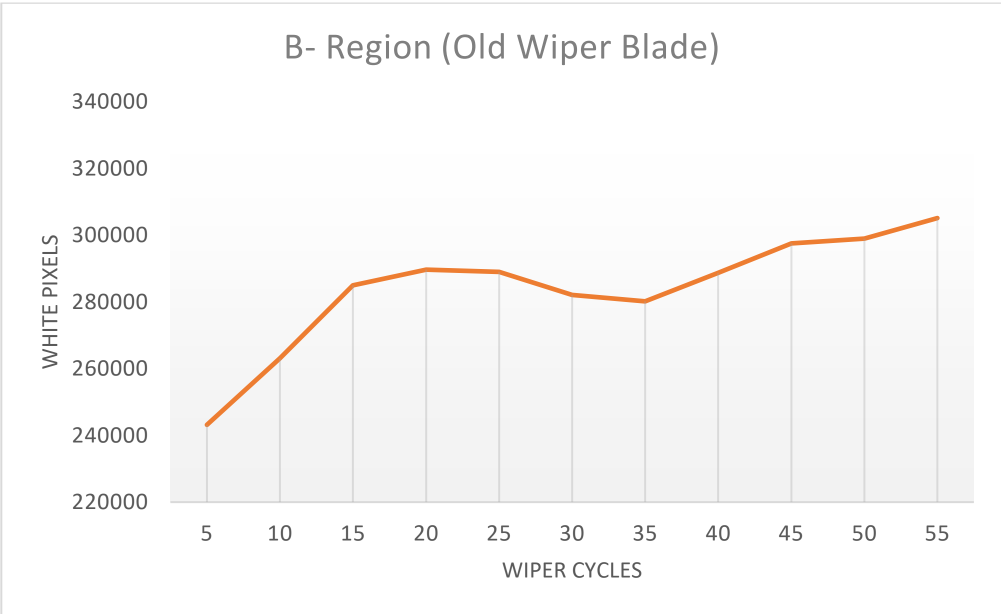


Fig. 5.12 Effect of number of wiper cycles at B- Region

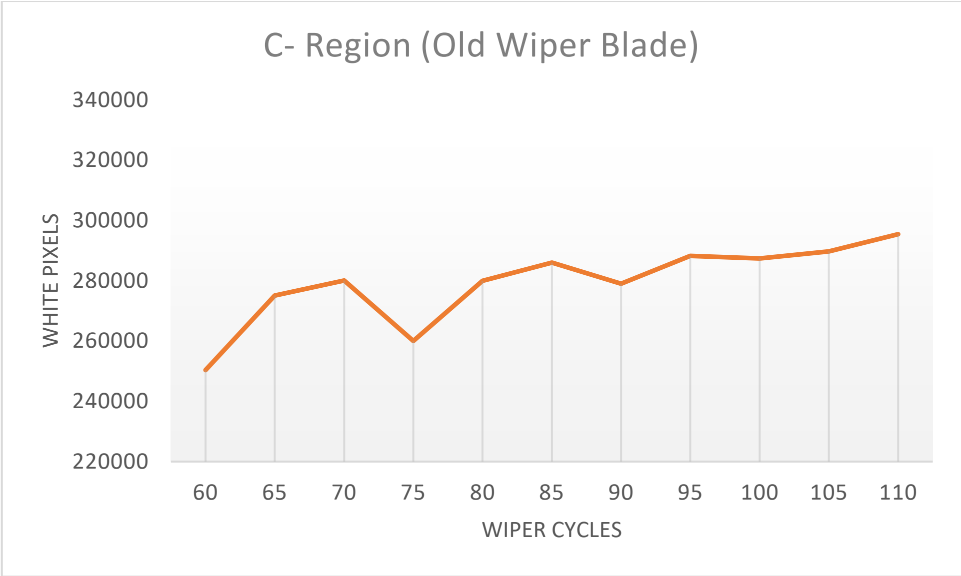


Fig. 5.13 Effect of number of wiper cycles at C- Region

Since the wiper is old, thus it was unable to make proper contact with the windshield at different regions (7C, 8C and 11A) which can also be corelated with the roughness values in these sections. This results into sudden decline in the number of white pixels in the sections after 75 wiper cycles. Similarly, Fig. 5.13 illustrates the increasing trend of the glare as the number of wiper cycles increases.

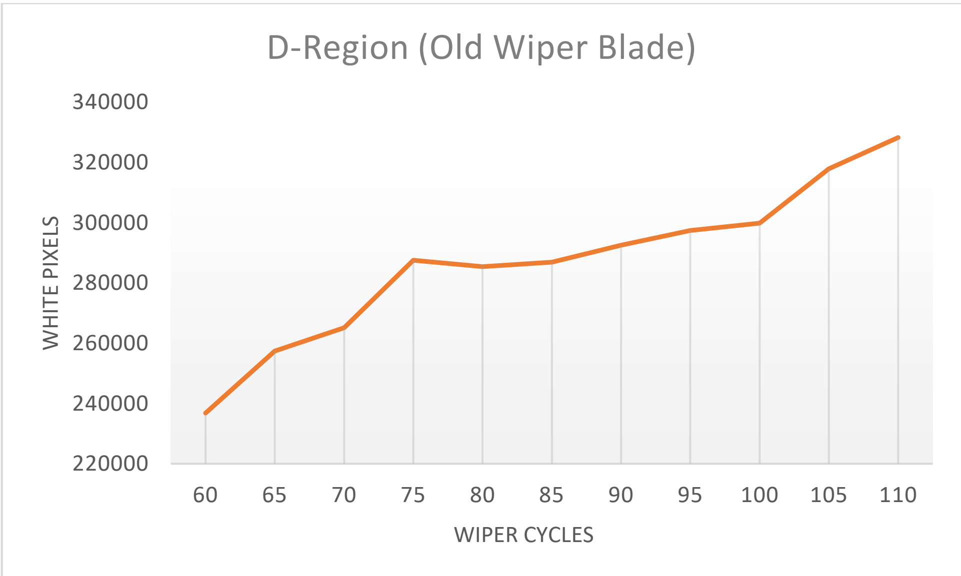


Fig. 5.14 Effect of number of wiper cycles at D- Region

The sudden spike at 75 wiper cycles in the Fig. 5.14 is due to the overlapping region. This overlapping region is due to the left side wiper wiping into the wiping area of the right-side wiper as shown in the Fig. 5.15. Over lapping region is the common region which gets cleaned/wiped by both the wipers. It is in the middle of the windshield. The spike in the graph shows high wear in the over lapped region.

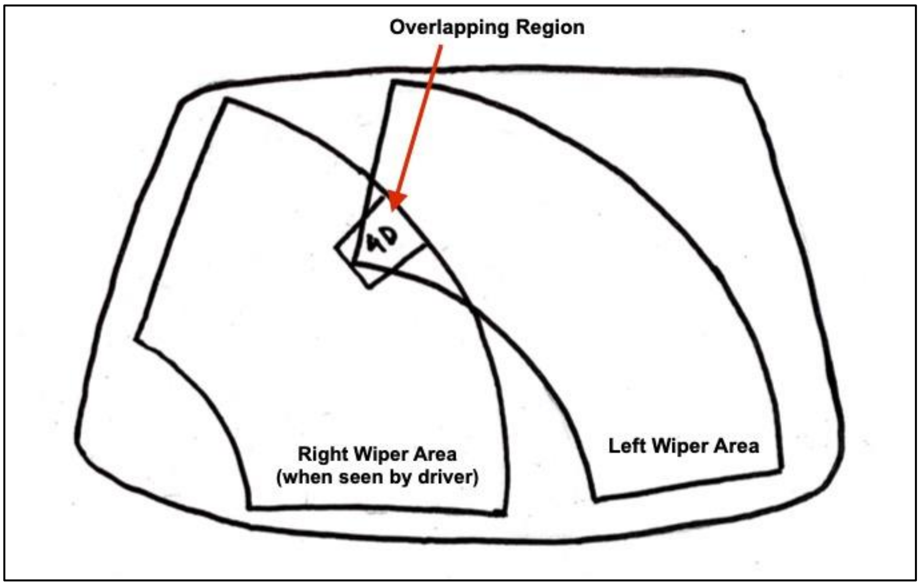


Fig 5.15 Overlapping Region

5.4.2 Light Scattered due to new wiper blade abrasion

Following are the numbers of white pixels at different sections of windshield abraded with new wiper blade.

Table 5.17 Relation of Wiper cycles with White Pixels on A-Region

S No.	Section	No. of wiper cycles	No. of White Pixels
1.	1A	5	278761
2.	2A	10	271451
3.	3A	15	-
4.	4A	20	-
5.	5A	25	-
6.	6A	30	278768
7.	7A	35	297451
8.	8A	40	295371
9.	9A	45	301960
10.	10A	50	316570
11.	11A	55	313886

the A-region were damaged during an outside damages and cracks were developed on these sections. Thus, accurate photography was not possible for these sections. Also, it can be observed that with the increase in number of wiper cycles the number of pixels also increase i.e., the scattering of light is more where the wiper cycles are more.

Table 5.18 Relation of Wiper cycles with Pixels on B-Region

S No.	Section	No. of wiper cycles	No. of White Pixels
1.	11B	5	270024
2.	10B	10	274662
3.	9B	15	285604
4.	8B	20	295969
5.	7B	25	297339
6.	6B	30	306439
7.	5B	35	304804
8.	4B	40	309761
9.	3B	45	313121
10.	2B	50	317223
11.	1B	55	318032

Table 5.19 Relation of Wiper cycles with Pixels on C-Region

S No.	Section	No. of wiper cycles	No. of White Pixels
1.	11C	60	279170
2.	10C	65	280279
3.	9C	70	290850
4.	8C	75	297612
5.	7C	80	306265
6.	6C	85	303669
7.	5C	90	308787
8.	4C	95	309368
9.	3C	100	311650
10.	2C	105	321930
11.	1C	110	320638

Table 5.20 Relation of Wiper cycles with White Pixels on D-Region

S No.	Section	No. of wiper cycles	No. of White Pixels
1.	1D	60	272839
2.	2D	65	280759
3.	3D	70	279663
4.	4D	75	305893
5.	5D	80	298356
6.	6D	85	290225
7.	7D	90	295310
8.	8D	95	313498
9.	9D	100	314269
10.	10D	105	332392
11.	11D	110	326832

Table 5.17 to Table 5.20 illustrates the total number of white pixels at different sections of the windshield abraded by the new wiper blade. The following graphs from Fig. 5.16 to Fig. 5.19 show the relation between light scattering and the number of wiper cycles for the windshield abraded through a new wiper blade. All these graphs show an increasing trend as the number of wiper cycles are increased. The x-axis represents the number of wiper cycles, and the y-axis represents the number of white pixels.

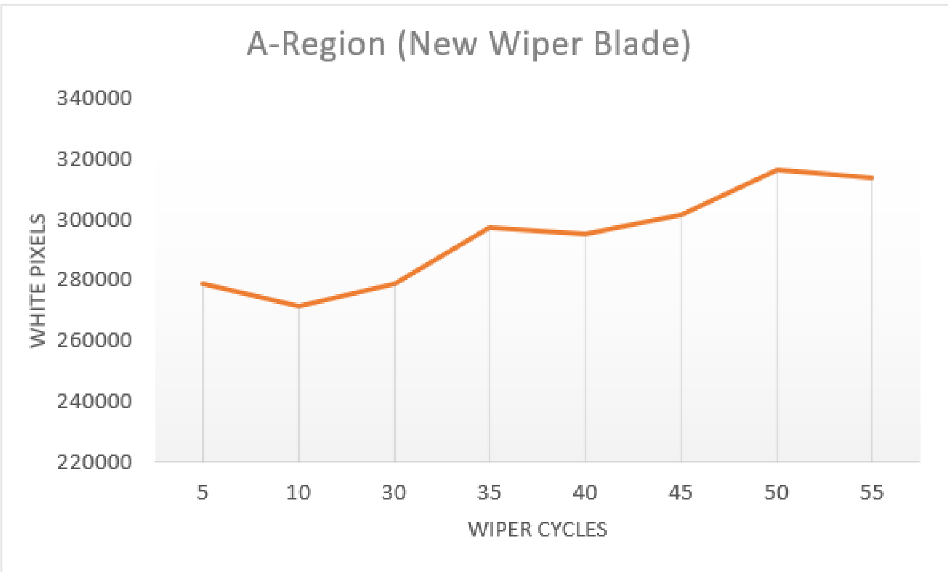


Fig. 5.16 Effect of number of wiper cycles at A-Region

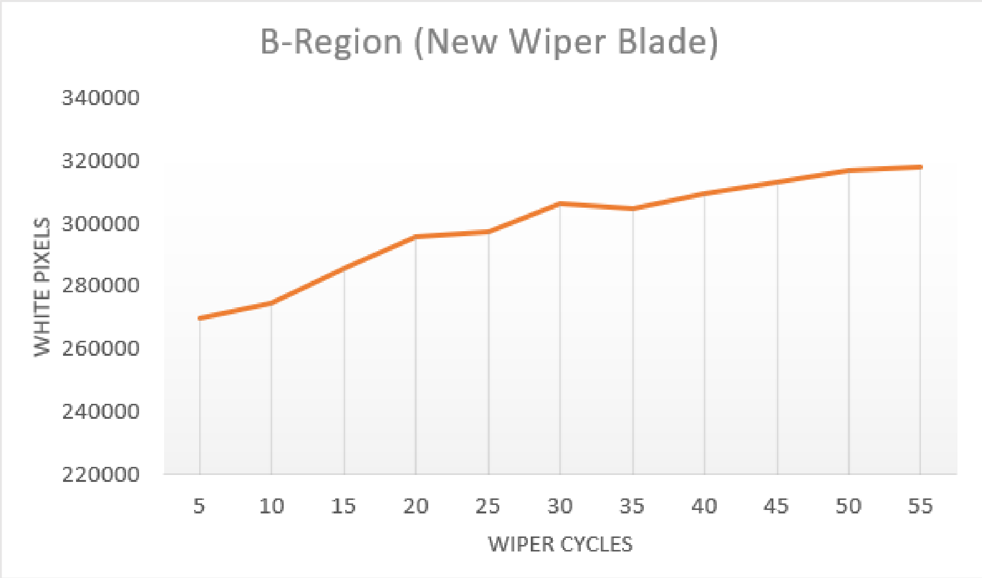


Fig. 5.17 Effect of number of wiper cycles at B- Region

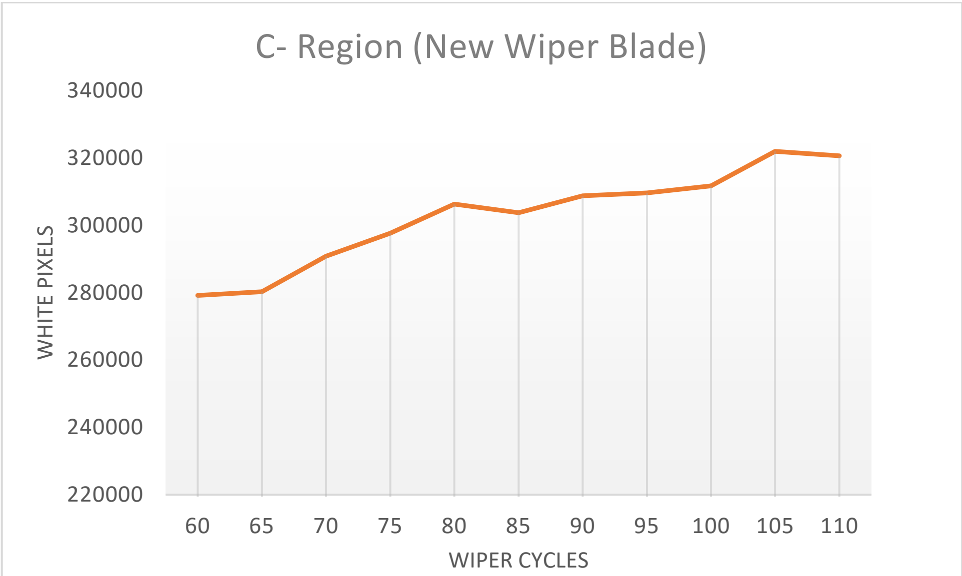


Fig. 5.18 Effect of number of wiper cycles at C-Region

In the C-region, as shown in Fig. 5.18, the amount of light scattering through the windshield increases as the number of wiper cycles increase. We can observe an increasing trend as the number of wiper cycles increases, the white pixels or the wear of windshield is increased.

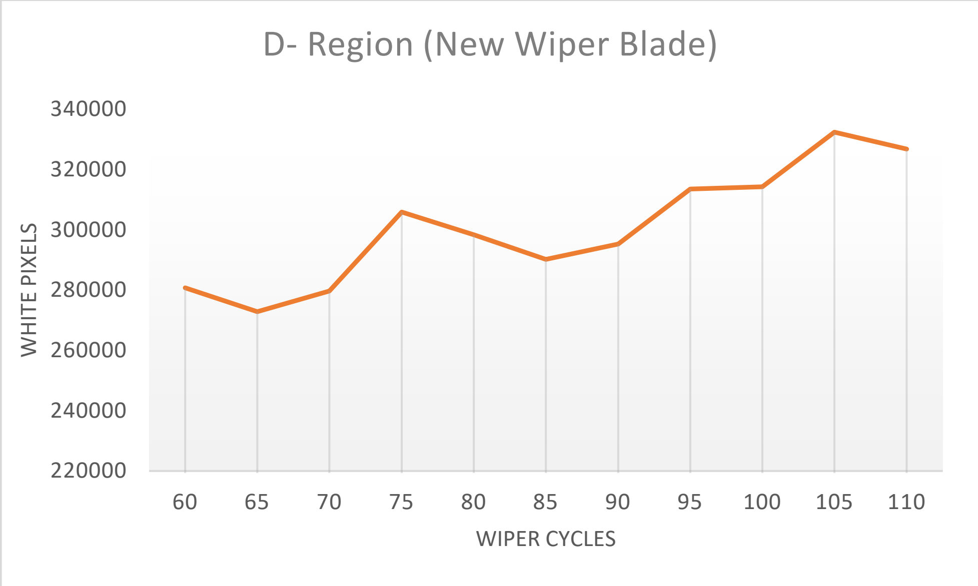


Fig. 5.19 Effect of number of wiper cycles at D-Region

In Fig. 5.19, the spike at 75 wiper cycles is at the 4D section. This section is over lapping region as discussed earlier, where the effect of both wipers is observed and thus, more wear has happened.

The increasing trend of scattering of light in regions A and B is also observed in C and D regions, as shown in Fig. 5.16 to Fig. 5.19. During comparison of old and new wiper effect, it is observed thar the number of white pixels in A and B regions abraded by new wiper blade are more than that in A and B region of the windshield abraded through the old wiper.

5.5 Validation of Wiper cycles, Light Scattering and *Ra*

From the above represented data, it is quite evident that the dry wiping has a severe effect on the windshield glass. With the increase in the number of wiper cycles, both *Ra* value and the number of white pixels has increased. The following Tables 5.21-5.28 compare the *Ra* value and the number of white pixels in each section with the number of wiper cycles.

5.5.1 Windshield abraded through old wiper blade

Table 5.21 to Table 5.24 compares the *Ra* value and the number of white pixels in each section with the number of wiper cycles of the windshield abraded through the old wiper blade. Scattering of light has shown the increment with the increase in number of wiper test cycles. As per the data represented in Table 5.21, there is increment in the number of white pixels when test cycles increased from 5 to 50. In the 11A section, where the wiper blade covered 55 cycles, the white pixel count decreases for 313383 to 266299. The reduced contact pressure of wiper blade at the lowest point (rest position) might be low and it abraded the windshield to a lower value. The corresponding value of Ra at 11A (0.05) also justifies the reduced abrasion.

Table 5.21 Relation of Wiper cycles with White Pixels and Ra on A-Region

S No.	Section	Wiper Cycles	White Pixels	*Ra*
1.	1A	5	231502	0.03
2.	2A	10	250901	0.05
3.	3A	15	278597	0.04
4.	4A	20	284077	0.05
5.	5A	25	296270	0.07
6.	6A	30	302100	0.04
7.	7A	35	300661	0.08
8.	8A	40	310129	0.07
9.	9A	45	314116	0.10
10.	10A	50	313383	0.14
11.	11A	55	266299	0.05

Table 5.22 Relation of Wiper cycles with White Pixels and Ra on B-Region

S No.	Section	Wiper Cycles	White Pixels	*Ra*
1.	11B	5	243170	0.04
2.	10B	10	263102	0.04
3.	9B	15	284933	0.05
4.	8B	20	289705	0.06
5.	7B	25	289006	0.06
6.	6B	30	282089	0.08
7.	5B	35	280217	0.07
8.	4B	40	288753	0.07
9.	3B	45	297505	0.1
10.	2B	50	299003	0.15
11.	1B	55	305119	0.14

Table 5.23 Relation of Wiper cycles with White Pixels and Ra on C-Region

S No.	Section	Wiper Cycles	White Pixels	*Ra*
1.	11C	60	240028	0.05
2.	10C	65	281020	0.05
3.	9C	70	280031	0.06
4.	8C	75	260005	0.04
5.	7C	80	279957	0.03
6.	6C	85	286046	0.06
7.	5C	90	279013	0.08
8.	4C	95	288252	0.08
9.	3C	100	287419	0.14
10.	2C	105	289755	0.14
11.	1C	110	295433	0.20

Table 5.24 Relation of Wiper cycles with White Pixels and *Ra* on D-Region

S No.	Section	Wiper Cycles	White Pixels	*Ra*
1.	1D	60	237740	0.05
2.	2D	65	257342	0.04
3.	3D	70	265089	0.04
4.	4D	75	287527	0.08
5.	5D	80	285436	0.06
6.	6D	85	286836	0.06
7.	7D	90	292548	0.09
8.	8D	95	297330	0.10
9.	9D	100	299715	0.10
10.	10D	105	317897	0.13
11.	11D	110	328227	0.18

Data points in the Tables 5.21-24 reflects increment in the white pixel count with increasing number of wiper test cycles. There is no abnormality or sudden variation noticed in these sections.

5.5.2 Windshield abraded through new wiper blade

Table 5.25 to Tabe 5.28 compares the *Ra* value and the number of white pixels in each section with the number of wiper cycles of the windshield abraded through the new wiper blade. Missing values in Table 5.25 are due to the external damage on the windscreen and the roughness measurements cannot be performed.

Table 5.25 Relation of Wiper cycles with White Pixels and Ra on A-Region

S No.	Section	Wiper Cycles	White Pixels	*Ra*
1.	1A	5	278761	0.04
2.	2A	10	271451	0.07
3.	3A	15	-	-
4.	4A	20	-	-
5.	5A	25	-	-
6.	6A	30	278768	-
7.	7A	35	297451	-
8.	8A	40	295371	-
9.	9A	45	301960	0.11
10.	10A	50	316570	0.11
11.	11A	55	313886	0.16

On the basis of the trend shown by similar experiments with the old wiper blade, the intermediate values can be interpolated by taking the average values of the 2A and 6A sections so that a graphical representation can be made. From sections 6A till 11A, the increasing trend of the white pixel count can be observed.

Table 5.26 Relation of Wiper cycles with White Pixels and Ra on B-Region

S No.	Section	Wiper Cycles	White Pixels	*Ra*
1.	11B	5	270024	0.05
2.	10B	10	274662	0.05
3.	9B	15	285604	0.05
4.	8B	20	295969	0.06
5.	7B	25	297339	0.1
6.	6B	30	306439	0.14
7.	5B	35	304804	0.19
8.	4B	40	309761	0.18
9.	3B	45	313121	0.2
10.	2B	50	317223	0.2
11.	1B	55	318032	0.21

Table 5.27 Relation of Wiper cycles with White Pixels and Ra on D-Region

S No.	Section	Wiper Cycles	White Pixels	*Ra*
1.	11C	60	279170	0.03
2.	10C	65	280279	0.05
3.	9C	70	290850	0.06
4.	8C	75	297612	0.04
5.	7C	80	306265	0.03
6.	6C	85	303669	0.06
7.	5C	90	308787	0.08
8.	4C	95	309368	0.08
9.	3C	100	311650	0.14
10.	2C	105	321930	0.21
11.	1C	110	320638	0.18

Table 5.28 Relation of Wiper cycles with White Pixels and Ra on D-Region

S No.	Section	Wiper Cycles	White Pixels	*Ra*
1.	1D	60	272839	0.06
2.	2D	65	280759	0.08
3.	3D	70	279663	0.1
4.	4D	75	305893	0.18
5.	5D	80	298356	0.08
6.	6D	85	290225	0.14
7.	7D	90	295310	0.16
8.	8D	95	313498	0.18
9.	9D	100	314269	0.2
10.	10D	105	332392	0.29
11.	11D	110	326832	0.26

From the values of D region, it is evident that outermost region with highest number of wiper test cycles was damaged more than the lower regions. Comparing the tables 5.21-5.28, it can be concluded that new wiper with softer rubber generates more abrasion. As the wiper blade gets older, it becomes hard and over the time its regular usage also affects its wiping edge quality.

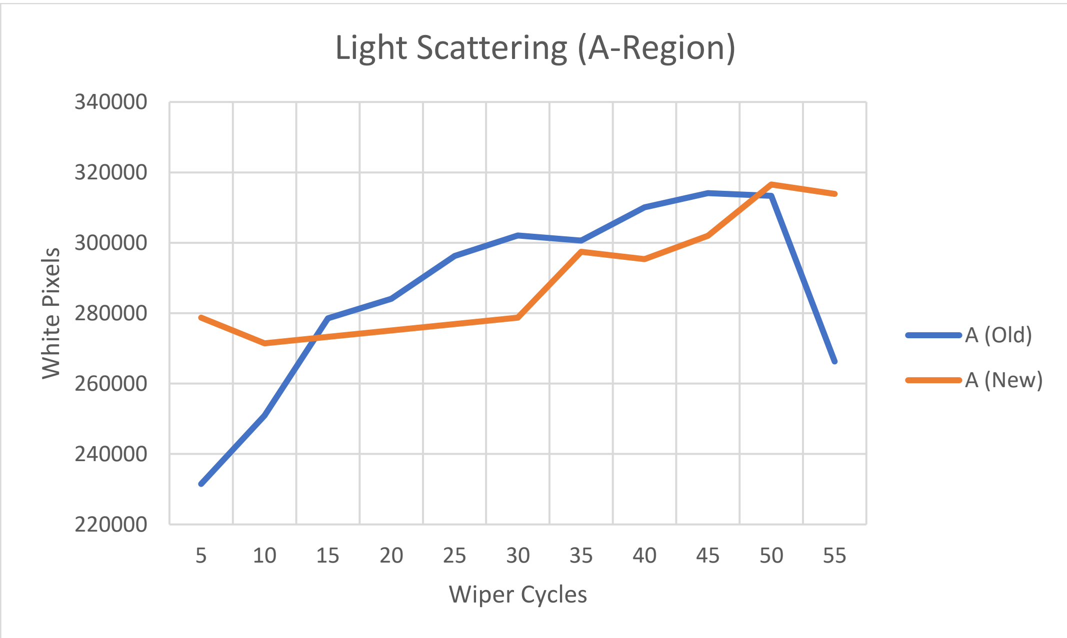


Fig. 5.20 Light Scattering comparison due to old and new wiper blades in A-region

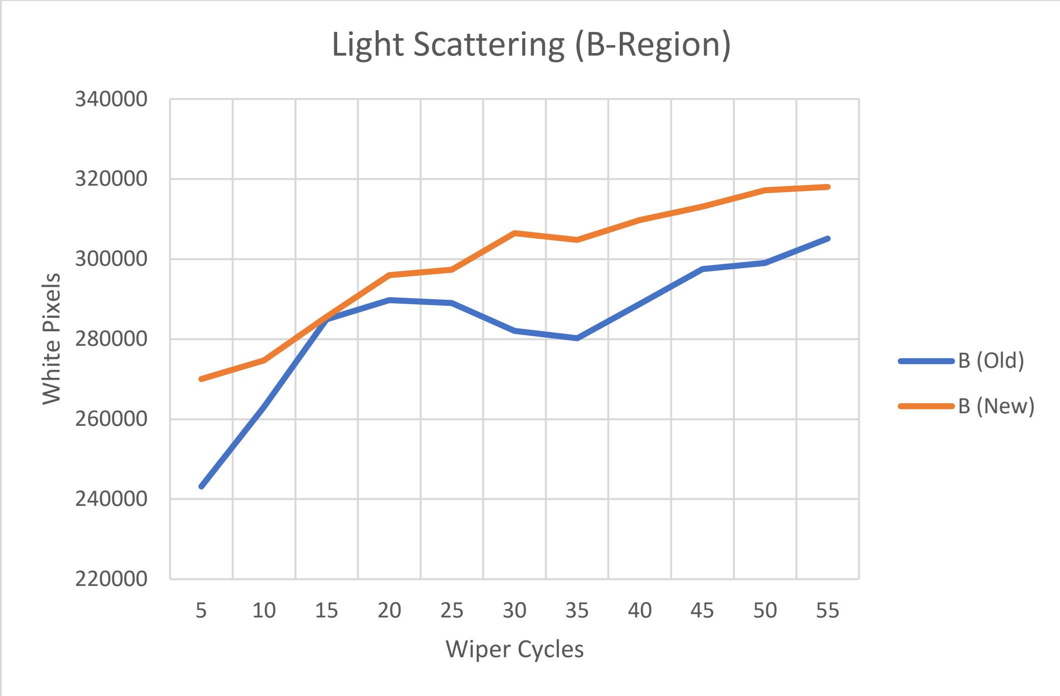


Fig. 5.21 Light Scattering comparison due to old and new wiper blades in B-region

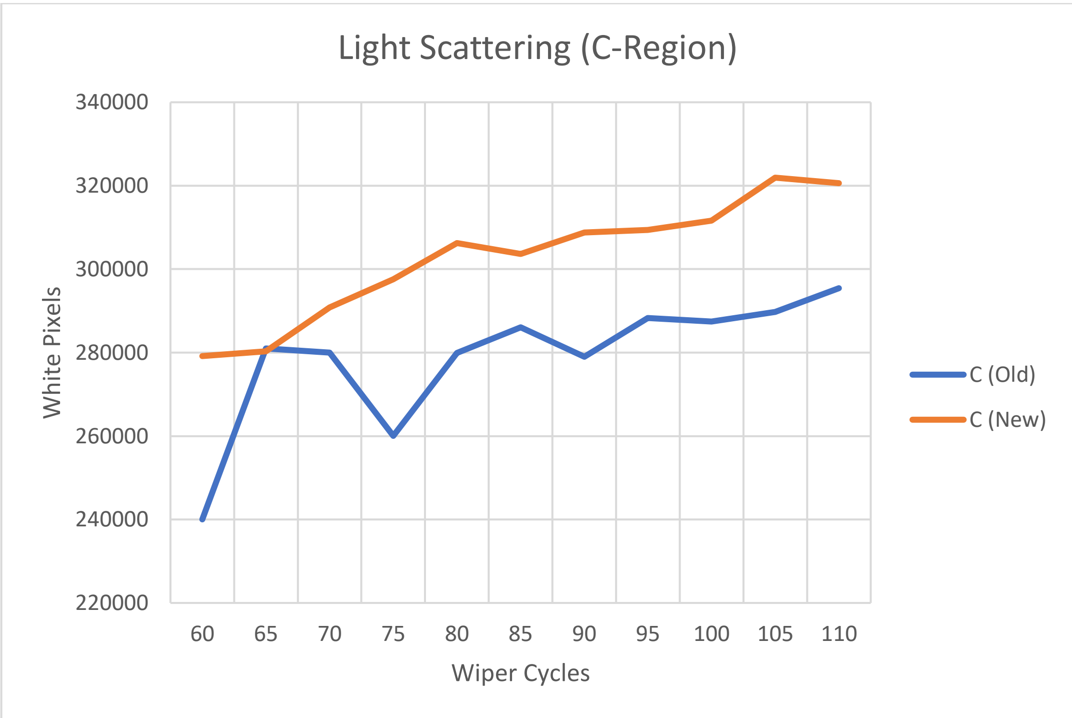


Fig. 5.22 Light Scattering comparison due to old and new wiper blades in C-region

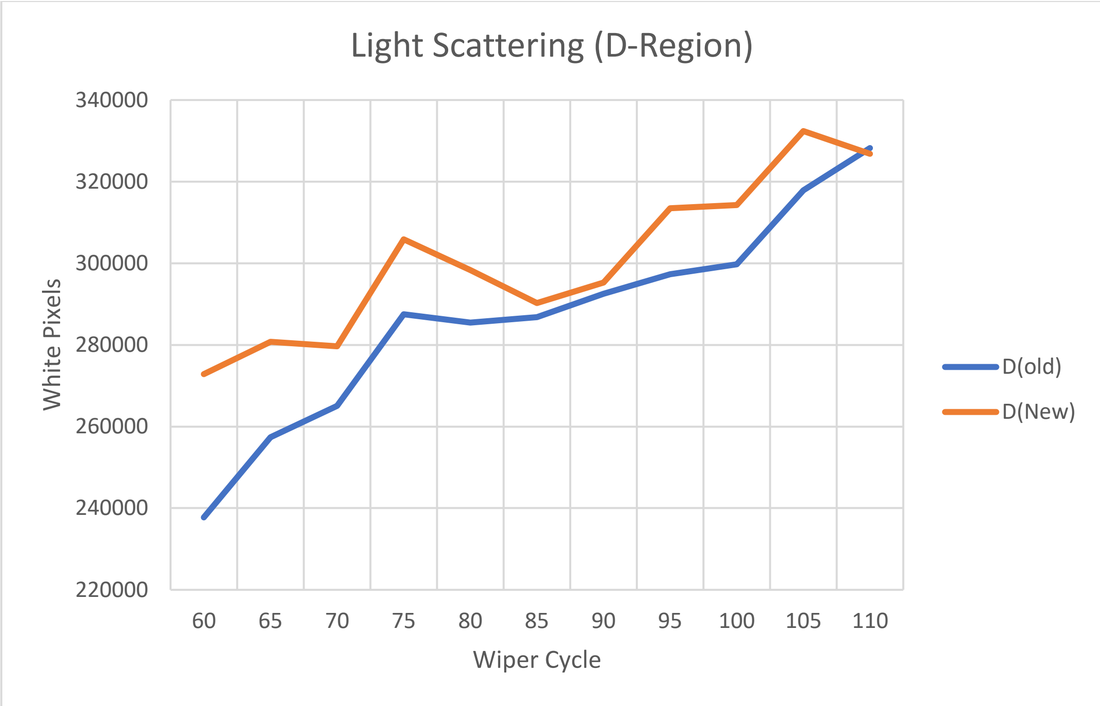


Fig. 5.23 Light Scattering comparison due to old and new wiper blades in D-region

The comparison of scattering of light after abrasion using old and new wiper is shown in Fig. 5.20 to Fig. 5.23. Values of white pixel present and hence the scattering of light is more when new wiper blade is used for dry abrasion. The values of white pixel from the new wiper abrasion in region A are lesser than that of the old wiper due to the limitation of testing in that region after external damage. Regions B, C, and D clearly reflects that scattering of light is more in case of abrasion caused by new wiper blade.

CHAPTER 6

CONCLUSIONS AND FUTURE SCOPE

Results from the systematic experiments performed on fresh and unused windshields using two sets of wiper blades (new and old) with the dust accumulated on the windscreens in a similar way to the near actual usage of car, are carefully studied and corelated to get the important results. Present research concludes that:

- The dry abrasion with the dust deposited on the windshields and wiper blades is a major reason of windshield wear. The regular dry wiping of the windshield will result in serious windshield damage.
- Increase in the number of wiper cycles illustrates there is increase in glare. Even dry wiping of 10 times can abrade the windshield and provide critical abrasion sites for further wear. The windshield wear creates difficult driving conditions during night-time.
- Rubbing of new soft wiper creates more damage than old hard wiper blade.
- Windshield area near to the wiper's rest position is more prone to dry abrasion and hence more damage due to the reason that first stroke of every wiper is halfway dry as water jet takes some time to imping on the glass and make it wet.
- The overlapping region has high roughness and scatters more light than the adjacent non-overlapping regions. Overlapping region must be kept minimum in the design of windshield wiping mechanism.
- The method introduced in the present research, to evaluate the glare is novel and efficient. It can be used to testify results of instruments used to calculate glare.

Future Scope-

In this world, automobiles are everywhere. This method of testing can be used anywhere in the world to provide accurate data on the amount of windshield wear caused by dry wiping. It is possible to do research on a variety of dust samples from other areas where high industrial dust is present. Future studies with more number of test cycles can be explored. The method to evaluate the amount of light entering through a windshield can be used to do further research on windshield glare in different environmental conditions.

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