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IDENTIFICATION OF CHRYSOTILE IN BRAKE PADS AND LININGS FROM MALAYSIAN VEHICLES AND HEAVY VEHICLES BY USING POLARIZED LIGHT MICROSCOPE (PLM)

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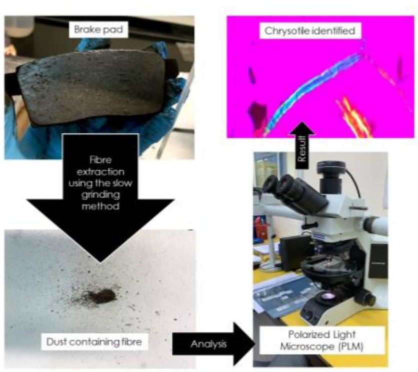
Graphical abstract



Abstract

Exposure to types of asbestos such as chrysotile and crocidolite increases respiratory disease risks such as lung cancer, mesothelioma, and asbestosis. Nevertheless, asbestos products banning in Malaysia is only limited to crocidolite as per stated in OSHA (Prohibition of Use of Substance) Order 1999, though other types are highly suspected to be found in asbestos-containing materials (ACM) like brake pads and linings. This study ascertains the presence of asbestos fibres, particularly chrysotile, in brake pads and linings used in Malaysia's vehicle and heavy vehicle sector. Seven different brake pads; three from vehicle brands, and four from heavy vehicle brands were collected by bulk sampling approaches from the market and field. Dust fibres were extracted using slow grinding method and analysed under Polarized Light Microscope (PLM). The fibre characteristics such as colour, morphology, pleochroism, extinction, and dispersion staining technique were examined, referring the National Institute for Occupational Safety and Health (NIOSH) Manual of Analytical Methods (NMAM) 9002. Additionally, the observed samples also were verified by an accredited lab to support the authenticity of the outcome. From the analysis and lab results, chrysotile fibres were consistently detected in all brake pad samples, fulfilling the fibre characteristics and positive elongation signs.

Keywords: Asbestos, chrysotile, brake pad, brake lining, polarized Light microscope (PLM)

Abstrak

Pendedahan kepada asbestos seperti krisotil dan krosidolit meningkatkan risiko penyakit pada sistem pernafasan seperti barah paru-paru, mesothelioma dan asbestosis. Walau bagaimanapun, larangan penggunaan produk-produk asbestos di Malaysia hanyalah kepada asbestos jenis krosidolit, seperti yang tertulis dalam OSHA 1994 Perintah Keselamatan dan Kesihatan Pekerjaan (Larangan terhadap Penggunaan Bahan) 1999. Walhal, jenis-jenis asbestos lain berkemungkinan besar dijumpai pada bahan-bahan terkandung asbestos sepeti alas dan pelapik brek. Kajian ini menyiasat kewujudan serat asbestos jenis krisotil di alas dan pelapik brek kenderaan sederhana dan kenderaan berat yang digunakan di Malaysia. Sebanyak tujuh lapik brek telah dikumpulkan menggunakan pendekatan persampelan pukal daripada pasaran dan lapangan. Tiga daripadanya adalah untuk kenderaan sederhana, dan empat daripadanya adalah untuk kenderaan berat. Habuk serat telah diestrak menggunakan kaedah kisaran perlahan dan dianalisa dibawah mikroskop polarisasi. Ciri-ciri serat seperti warna, morfologi, pleokroisme, pemadaman dan penyebaran warna telah diperiksa berpandukan Manual Kaedah Analisis Institut Keselamatan dan Kesihatan Pekerjaan Kebangsaan(NIOSH)(NMAM) 9002. Tambahan lagi, sampel-sampel yang dikaji telah dihantar ke makmal akredasi untuk pengesahan bagi mennguatkan hasil kajian. Hasil daripada analisa dan keputusan makmal telah menemukan serat krisotil di semua sampel alas brek dalam kajian ini berdasarkan pemadanan ciri-ciri serat dan signal pemanjangan positif.

Kata kunci: Asbestos, kristotil, alas brek, pelapik brek, mikroskop polarisasi

1.0 INTRODUCTION

Malaysia had never been an asbestos-producing country, but in 1963 Malaysia set up a joint venture with Australian and Japanese companies in operating the first ever asbestos product manufacturing factory, such as pipes, asbestos cement (AC), roofing sheets, friction materials, and gaskets [1]. Asbestos is usually present in buildings or friction materials, which includes the automotive sector where they had been utilised since the 1900s. The reason asbestos is known to be a great friction material in brake pads is especially because of its robust physical, chemical and tribological properties [2]. As for today, Malaysia only managed to partially ban asbestos according to these three main laws: (i) Factories and Machinery Act (Building Operations and Works of Engineering Construction) (Safety) Regulations 1986 [3], (ii) Occupational Safety and Health Act (Classification, Labelling and Safety Data Sheet of Hazardous Chemicals) Regulations 2013 [4], and (iii) Occupational Safety and Health Act (Prohibition of Use of Substance) Order 1999 [5].

Despite all the laws clearly stating the prohibition of crocidolite asbestos, chrysotile asbestos usage prohibition was nowhere to be found due to scarce "uncertainty" over the health risks. Despite numerous sources confirming that chrysotile asbestos is cancer-causing, mechanics have been exposed to brake debris that contains chrysotile [6-19] . For instance, the World Health Organisation [20] had formally published a complete guidance assessing the health risks and making informed decisions about the health risks management concerning both occupational and non-occupational exposure of chrysotile asbestos towards the public. WHO [20] further emphasised that all types of asbestos, including chrysotile are carcinogenic despite its long latency period, and prolonged exposure could lead to respiratory diseases such as lung cancer, mesothelioma, asbestosis, and lung fibrosis. Therefore, this study aims to ascertain the presence of asbestos fibres (chrysotile) in brake lining pads used in the Malaysian market vehicles and heavy vehicles using a Polarized Light Microscope (PLM) as the instrumentation data analysis.

2.0 METHODOLOGY

2.1 Materials

Brake pads used in this study were obtained through two sources, either market sampling or field sampling. As for the sampling method, asbestos containing material (ACM) dust from both used and unused brake pads were obtained through the bulk sampling method. The list of brake pad brands and its sources used in this research are listed in Table 1.

Table 1 List of Brake Pads

Brand	Source	Automotive sector
BWJ	Market sampling	Vehicle
LMT	Field sampling (HV Engineering)	Heavy vehicle
LBP	Field sampling (HV Engineering)	Heavy vehicle
BBX	Field sampling (LV Group)	Vehicle
LBX	Field sampling (HV Engineering)	Heavy vehicle
BLV1	Field sampling (LV1 Group)	Vehicle
BLV	Field sampling (LV Group)	Vehicle

2.2 Sample Preparation of Brake Dust

The overall methodology process, starting from sample preparation to the qualitative assessment of the samples used in this research were mainly based on the standardised NMAM 9002 techniques by NIOSH (1994) [21], but with some modifications. A total of seven different brands of brake pads, which were collected from either market sampling or field sampling via the bulk sampling method were all manually ground using the slow grinding method in order to extract the brake dust samples under a ventilated fume hood. Each of the brake dust samples were properly stored in a 25mL falcon tube and labelled according to the stated brands using a permanent marker. All of the sample containers were taped neatly in order to prevent any spillage occurring along the transit process. Additionally, the samples were stored in a sturdy container with sufficient packaging material to prevent potential sample loss or damage. A disclaimer shall be made whereby throughout the methodology process, complete personal protective equipment was worn at all times, such as dust-free nitrile gloves and N95 masks. This is due to the fact that asbestos-containing materials have high carcinogenicity effect towards human and these fibres can enter the human body through inhalation or ingestion [20].

The samples were later brought to the laboratory under a fume hood for naked eye visual examination using stereomicroscope, and NIOSH general drawing guidelines to confirm the presence of emergent fibre edges. Only the positively confirmed samples which contain the edges of emergent fibres were brought in to be observed under PLM. The seven different samples of brake pads were further triplicated each, according to the respective brake pad brands or sources. Later, a small representative portion of the sample was removed from the container and placed on the glass slides by a tweezer. Meanwhile, the slightly inhomogeneous sample were mixed and crushed in the container using a spatula or tweezer before being taken out for analysis. Subsequently, a few drops of Refractive Index 1.550 High Dispersion liquid were placed on the brake dust sample on the glass slide. The brake dust and liquid on the glass slide were mixed as homogeneously as possible, and finally a cover slip was mounted carefully on to the sample before it was observed under the PLM.

2.3 Identification of Chrysotile Asbestos Fibres

As stated above, three slides with the same types of samples were prepared which resulted to a total of 21 slides to be observed. The glass slide examination approach was done by following one type of sample per examination session, then proceeded with the next type of sample accordingly. All of these mentioned procedures were applied to all 21 slide samples. Firstly, a slide containing sample was mounted cautiously on the microscope stage, with partially crossed polars and the lowest magnification available on the microscope was applied. The polariser and the analyser used throughout the research was fixed at a 0° angle, the only manipulated angle was the stage rotation. The presence of fibre was scanned and examined meticulously. When the suspected fibres had been located in the glass slide sample, the polariser was fully crossed to confirm it exhibits the anisotropic properties.

Next, the microscope stage was rotated slowly for determination of extinction angle and the angle data was recorded. Besides that, other optical properties such as fibre morphology and shapes viewed under PLM were recorded too. For the identification step in confirming that the fibres present were chrysotile asbestos, the same sample were viewed under fully crossed polars (with the inserted analyser). As stated by National Institute for Occupational Safety and Health [22] in NMAM 9002, chrysotile asbestos fibres will exhibit "blue and blue-magenta" as its dispersion staining colours when paired with RI 1.550 HD liquid. All identified chrysotile asbestos fibres were reported as asbestos-containing samples and sample images were taken. In order to further authenticate the results, another alternative method had been taken whereby all of the same samples observed were send to an accredited lab, ChemVi Laboratory Sdn. Bhd. in Shah Alam, Selangor. This step was necessary to cross check the accuracy of research findings with a registered industrial hygienist who is more experienced and to avoid false reporting.

3.0 RESULTS AND DISCUSSION

3.1 Presence of Chrysotile Asbestos in Brake Dust Samples

Overall, chrysotile asbestos was found to be reported in all of the 21 samples observed under PLM as shown in Table 2 and Table 3. These samples consistently exhibited anisotropic behaviour when rotated at different angles and shared the same form of extinction which is the parallel extinction viewed in a fully crossed plane polarized light. As chrysotile asbestos fibres depicted the exact same optical characteristics in the results obtained, therefore its presence was justified.

Table 2 Results obtained for Morphological Form, Presence of Anisotropic Behaviour, Extinction Form, and Presence of Chrysotile according to different brake brand samples

Brand	Morphological Form	Anisotropic Behaviour	Extinction Form	Presence Of Chrysotile
BWJ				
Sample A	Irregular & Fibers	Present	Parallel Extinction	Yes
Sample B	Fibers	Present	Parallel Extinction	Yes
Sample C	Fibers	Present	Parallel Extinction	Yes
LMT				
Sample A	Irregular	Present	Parallel Extinction	Yes
Sample B	Fiber	Present	Parallel Extinction	Yes
Sample C	Fiber	Present	Parallel Extinction	Yes
LBP				
Sample A	Fiber	Present	Parallel Extinction	Yes
Sample B	Fiber	Present	Parallel Extinction	Yes
Sample C	Irregular	Present	Parallel Extinction	Yes
LBX				
Sample A	Fiber	Present	Parallel Extinction	Yes
Sample B	Fiber & Irregular	Present	Parallel Extinction	Yes
Sample C	Fiber	Present	Parallel Extinction	Yes
BBX				
Sample A	Fiber	Present	Parallel Extinction	Yes
Sample B	Fiber	Present	Parallel Extinction	Yes
Sample C	Fiber	Present	Parallel Extinction	Yes
BLV1				
Sample A	Fiber	Present	Parallel Extinction	Yes
Sample B	Fiber	Present	Parallel Extinction	Yes
Sample C	Fiber	Present	Parallel Extinction	Yes
BLV				
Sample A	Fiber	Present	Parallel Extinction	Yes
Sample B	Irregular	Present	Parallel Extinction	Yes
Sample C	Fiber	Present	Parallel Extinction	Yes

Table 3 Recorded Results of Dispersion Staining Colour observed at different orientations for different brands

	Dispersion Staining Colour (orientation angle)		
Brand	**0°**	**45°**	**90°**
BWJ			
Sample A	Transparent	Blue	Transparent
Sample B	Transparent	Blue-brown	Transparent
Sample C	Transparent	Blue	Transparent
LMT			
Sample A	Transparent	Blue-brown	Transparent
Sample B	Transparent	Blue-brown	Transparent
Sample C	Transparent	Blue brown	Transparent
LBP			
Sample A	Transparent with a hint of light brown	Blue-magenta	Transparent with a hint of light brown
Sample B	Transparent	Blue-magenta	Transparent
Sample C	Transparent with a hint of bluish hue	Blue-brown	Transparent with a hint of bluish hue
LBX			
Sample A	Transparent	Blue-brown	Transparent
Sample B	Transparent	Blue-brown	Transparent
Sample C	Transparent	Blue-brown	Transparent
BBX			
Sample A	Transparent with a hint of bluish hue	Blue-brown (with hint of magenta)	Transparent with a hint of bluish hue
Sample B	Transparent with a hint of bluish hue	Blue-brown	Transparent with a hint of bluish hue
Sample C	Transparent with a hint of bluish hue	Blue	Transparent with a hint of bluish hue
BLV1			
Sample A	Transparent with a hint of bluish hue	Blue-magenta	Transparent with a hint of bluish hue
Sample B	Transparent with a hint of bluish hue	Blue-brown	Transparent with a hint of bluish hue
Sample C	Transparent with a hint of bluish hue	Blue-magenta	Transparent with a hint of bluish hue
BLV			
Sample A	Transparent with a hint of bluish hue	Blue	Transparent with a hint of bluish hue
Sample B	Transparent	Blue-magenta	Transparent
Sample C	Transparent with a hint of bluish hue	Blue	Transparent with a hint of bluish hue

3.2 The Use of Refractive Index 1.550 HD Liquid

According to Delly [23], refractive index (RI) is defined as the ratio of light velocity in a vacuum condition compared to the velocity of light when it passes through another relative substance. The relevance of using an immersion oil having the closest RI towards the wanted observed fibres was to eliminate any possibilities of interference that might limit the viewer's ability in identifying the specified type of asbestos fibres in the study. As for this study, the aim was particularly to identify chrysotile asbestos presence in the brake pad dust samples, hence, NIOSH [21] recommends using RI 1.550 HD liquid as the immersion oil for samples potentially having chrysotile fibres in it.

McCrone [24] once reported that each type of asbestos has its distinctive RI without overlapping with one another; therefore, by using RI 1.550 HD liquid, theoretically the only observable asbestos fibre would be chrysotile. Regardless, there will be some other fibre interference possibilities, but not coming from the asbestos family which will be discussed later. Theoretically, when a mineral or fibre immersed in a medium has dissimilar RI, it will result in visible light reflection and refraction which allow the viewer to see the mineral or fibre distinctly. On the other hand, when a fibre or mineral is immersed in a similar RI, there will be no light reflection or refraction occurring causing the fibre or mineral to appear see-through. Both of these observations must be viewed under a single polarized light, whereby during this particular condition the analyser must be placed out of the microscope.

In Figure 1(a), a sample from BBX brake pad was observed under a similar descriptive above and it shows a precisely identical outcome as mentioned in the stated theory whereby the fibre appeared to be see-through or almost invisible-like at a parallel microscopic view, but when the sample was rotated at the angle of 45° as in Figure 1(b), the colour of the fibre emerged proving that it has an anisotropic property which should be present in chrysotile and all other asbestos.

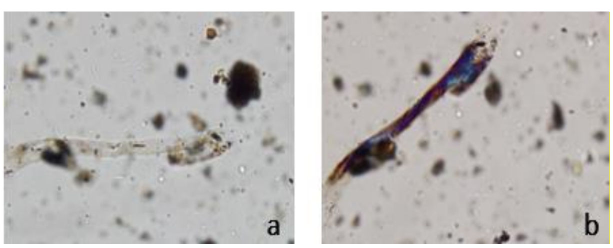


Figure 1 Single polarisation detection image of chrysotile under RI 1.550 BBX B using 20X objective lens. (a) Fibre was aligned at parallel orientation and (b) the fibre was aligned at 45° orientation

As the sample observed was immersed in the RI 1.550 HD liquid, thus the possibilities of other types of asbestos presence were disregarded, except for chrysotile asbestos. In a research conducted by Xu *et al.* [25], they explained that "the single polarized light only uses the incident light to bias with the polariser" which explained why the analyser must be placed out of the microscope. The phenomenon is further described as only allowing parallel light to pass through to the lower polariser direction and passed through the sample to reach the observer eyepiece.

3.3 Colour and Morphology

The term morphology is described in many ways depending on the particular study area, as for this research the term morphology is used to explain the shape, texture, and the physical habit of the fibre (including colour) which can be seen under the plane light microscope. From the results obtained in Figure 2(a) (b) (d), all three images share the same structure which can be described as long, fibrous, crinkled, and damaged wavy hairs that somehow also appear almost similar to snake-like figure. These are the same morphology of chrysotile asbestos mentioned in the study conducted by Reeves [26], and Micro Analytical Laboratories [27]. In addition, the appearance of the fibre is slender, narrow, and a bit bent, which is better known as the knee-folding phenomenon where the fibre resembled human joints or bamboo knots [25].

Moreover, the sample in Figure 2(a) and (b) were colourless. This is because when a sample potentially containing chrysotile fibres is parallelly aligned to a 0° polariser in a single plane polarisation, the fibre will appear to be colourless [25]. Chrysotile fibres also have a high tendency to form bundles attached together or simply described as having broom-like shape with frayed edges. This description fits perfectly for samples indicated in Figure 2(c) [25]. The reason for the sample in Figure 2(c) to appear multicoloured unlike previously mentioned samples is because this particular sample was oriented at a 45° direction away from the 0° polariser. Since chrysotile fibres are categorised as an anisotropic mineral, when the microscope stage is rotated to a different angle, it will show colour changes depending on the wavelength observed at the particular angle, and usually at a 45° angle, chrysotile containing samples will appear the brightest.

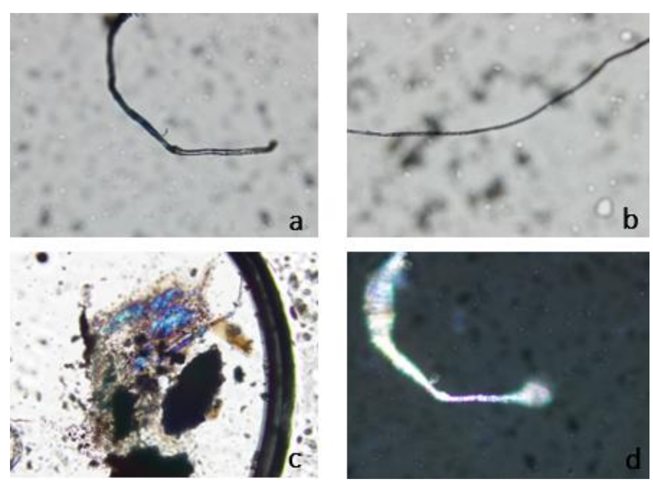


Figure 2 Single polarisation detection image of chrysotile under RI 1.550 using 20X objective lens **(a)** BLV1 A fibre was aligned at parallel orientation, **(b)** BLV C was aligned at parallel orientation and **(c)** BWJ fibre was aligned at 45° orientation. Fully crossed polarisation image of chrysotile detected under RI 1.550 using 20X magnification **(d)** BLV1 A fibre in the darkfield view

A dark view field or central stop image of Figure 2(d) was a bit different compared to the other three samples. This is because a dark view field image can only be seen when the polariser is fully crossed and happens when the analyser is fully inserted into the microscope which is aligned perpendicularly to the polariser. The chrysotile observed in the sample showed colour interferences, which usually enhances the white colour, unlike those seen under single polarisation where the fibres are colourless and transparent. The theory explained that only anisotropic minerals or fibres can produce colour interferences when the polariser is fully crossed because it can exhibit birefringence, a phenomenon termed as the numerical difference between the principal of light travelling between high and low RI [23].

3.4 Pleochroism

Pleochroism is defined as colour changes observed under plane- polarized light in a half or fully crossed polar manner. Normally, pleochroism colours can be vividly seen in a fully crossed polar compared to the half crossed polars. The colours observed in pleochroism can be three and more for a particular sample, depending on the colours observed at different orientations. This occurs due to the fact that chrysotile fibres absorb certain wavelengths of light at a particular angle. According to NIOSH [21], a chrysotile fibre will emit a bright blue or blue-magenta colour when observed under fully crossed polars at a 45° angle when the fibres are experiencing the highest light interference or maximum birefringence.

Figure 3 shows images of chrysotile fibres observed in the studied brake pad, which happened to be in a fully crossed polar where the analyser and polariser were aligned perpendicularly to each other. Pleochroism can be observed in half and fully crossed polars, but preferably in crossed polars. It can be seen in 3(a) that when the sample was aligned parallel to the polariser, the fibre colour was blue with a hint of dark magenta but in 3(b), the colour was being expressed clearer and brighter. The fibre present was definitely chrysotile because it fulfils the colour description in NMAM 9002. Nevertheless, other possible types of fibres may mimic the pleochroism of a chrysotile fibre during the observation process. The most commonly mistaken fibres are cellulose and polyethylene (PE). Cellulose and PE appear as bluish fibres having almost identical morphology with chrysotile fibres when observed under PLM, but this can immediately be distinguished when viewed under fully crossed polars as coloured fibres may not be pleochroic. In fully crossed polars, both cellulose and PE fibres will not change its colour when rotated at different angles because they are categorised as isotropic material.

Hornabrook *et al*. [28] described that the pleochroism in minerals occur due to the adsorption of certain light wavelengths. The selective adsorption of particular light wavelengths resulted in the appearance of colours from the transmitted lights. It is said that "this colour is a function that can represent thickness, particular chemical, and crystallographic nature of the mineral fibres" [28]. When the light wavelength path is adsorbed differently to the optical path, the pleochroism incident occurring within the mineral can be observed. This phenomenon is obviously evident in plane polarized light, and the colour seen via PLM will depend on which angle or optical path was viewed.

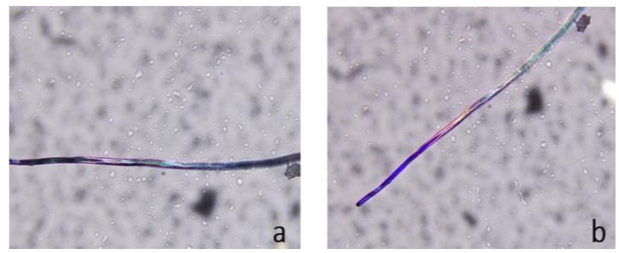


Figure 3 Fully crossed polarisation image of chrysotile detected under RI 1.550 using 20X magnification BLV1 B (a) aligned parallel to 0° angle polariser and (b) aligned at 45° orientation to the polariser

3.5 Extinction Angle

The angle between the orientation of the crystal when it appeared the brightest and extinct is called the extinction angle. This extinction angle can be seen in normal fully crossed plane polarized light, and in centre stop (darkfield view) plane polarized light. Isotropic minerals and substances (like glass) behave differently where they will be completely extinct under fully crossed polars. Therefore, it is an effective approach to be applied when determining chrysotile asbestos fibres in the sample because all asbestos including chrysotile exhibit anisotropic behaviours.

Theoretically according to Powel [29], a chrysotile asbestos fibre is said to have a parallel extinction when viewed under a fully crossed polariser. A parallel extinction phenomenon can be seen when the observed fibres become completely extinct at every 90° angle and appear the brightest at every 45° angle [30]. There is another type of extinction which can potentially occur in asbestos fibres, which is the inclined extinction. Inclined extinction occurs when a mineral goes extinct in an intermediate position, about 20° angle from its initial extinct position [29]. However, this particular extinction only occurs in tremolite-actinolite asbestos [31].

In Figure 4(a), the sample appeared to be slightly different from the theory mentioned where the fibre grains did not fully extinct at 0° angle parallel to the polariser, but instead it illustrates some kind of blotch patchy extinction or known as undulatory extinction. Wavy or undulatory extinction occurs when the fibre grains are potentially being strained along the methodology process and result in a slightly modified crystallographic orientation, whereby "different parts of the grain go into extinction in different orientations" [30,32]. This fibre is said to exhibit a bird's eye extinction, whereby a speckled imperfect extinction was displayed [29]. Regardless, this type of extinction is still considered as a parallel extinction because even though some parts of the fibres extinct at different orientations, each one of them become wholly extinct precisely every 90° as observed in this study. Extinction occurred every time the vibration directions in the mineral grain are parallel to either of the vibration directions coming from two different polarising filters (analyser and polariser) which are set perpendicular to each other [29].

Moreover, Figure 4(b) shows that the fibre is at its brightest when oriented at 45° from the initial extinct position. In this particular condition, it was explained by Powel [29] that fibres with parallel extinction will apparently experience maximum birefringence which results in producing destructive interference colour at every 45° angle [29]. Furthermore, this parallel extinction is claimed to be mostly found in a minerals having hexagonal, tetragonal, and orthorhombic crystalline structure as stated by MicrolabNW [33]. Since chrysolites have an orthorhombic crystalline structure, thus it further proves its relevance for exhibiting a parallel extinction under fully crossed polarized light as in Figure 4.

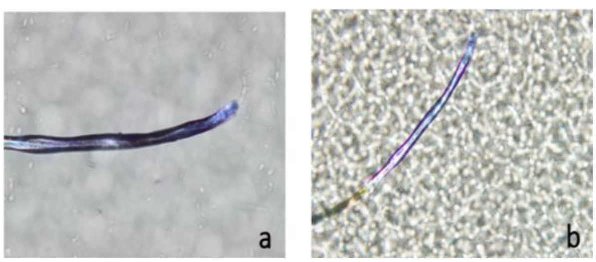


Figure 4 Fully crossed polarisation image of chrysotile detected under RI 1.550 using 20X magnification LMT C (a) aligned parallel to 0° angle polariser and (b) aligned at 45° orientation to the polariser

3.6 Dispersion Staining

In identifying a sample containing chrysotile fibres under PLM via the dispersion staining method, it is best to use the central stop technique or known as darkfield view technique rather than the annular stop or known as the brightfield view technique [34]. These two methods are the aperture stops available to be used in the dispersion staining method. The reason central stop is more preferable when observing the dispersion staining colour is because the grain edges on the fibres emitting white light can easily be observed rather than having an annular stop that will produce a brightfield view. Furthermore, in the brightfield view, the resolution tends to be lower compared to the darkfield view, which will later lead to false account judgement in deciding whether the fibre colour changes or not when the stage is rotated at different angles [34] .

In a central stop aperture, the images formed through the interaction of scattering light with the fibre grains, at the same time low angle incident wavelength are blocked [34]. Figure 5(a) at the tail of the fibre shows a maximum light interference when being oriented at a 45° angle centre stop, which results in emitting the brightest colour seen through the objective lenses. During this particular condition, it is said that the radius of the fibre was inclined between the upper (or known as analyser) and lower polarized light which results in highest light interferences [25]. Meanwhile, when oriented at a 0° angle centre stop, the fibre changes its colour to black, almost blending in with the darkfield background. The reason is that the fibre is parallel to the cross polarized light causing no light to be scattered or reflected back to the observer.

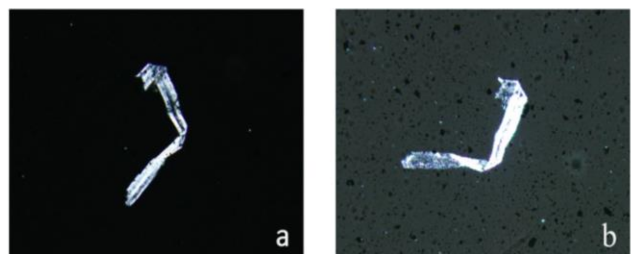


Figure 5 Fully crossed POLARIZED image of BLV1 C at central aperture stop (or known as darkfield view) (a) sample rotated at 45° angle and (b) sample rotated at 0° angle

Additionally, in central stop aperture, the sample colour appeared to be bright white rather than blue or blue-magenta as observed in the normal crossed polarized light. This is because the image formed under centre stop view were composed by deviated light. Referring to Figure 6, the complementary colour of blue and blue-magenta when seen under central stop colour chart range would be white [34].

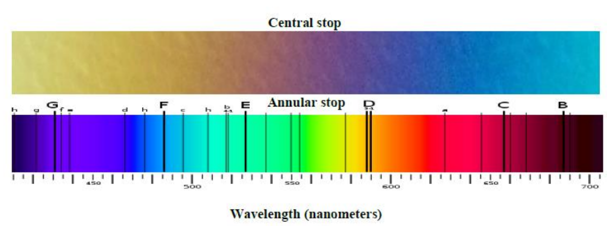


Figure 6 The dispersion staining colour complimentary chart between central stop and annular stop [34]

3.7 Verified Sample Results Obtained from Accredited Lab

Referring to the standard guidance of analysing bulk asbestos via PLM by NIOSH [21], all six types of asbestos have its unique and distinct optical characteristics when detected under polarized light.

The vital step is to determine any presence of asbestos fibres and if any, the types of asbestos that contained in the brake dust samples must be recorded. In Figure 7 are the chrysotile asbestos fibres discovered in the analysed brake dust samples which are taken to the accredited lab at Shah Alam for verification purposes. These verifications were done by a well experienced industrial hygienist who is well versed in using the PLM for asbestos fibre detection. Since, the output of observed samples heavily relied on one's ability and judgement of using PLM, thus a non-biased third party sample verification is needed in justifying the accuracy of the reported results [25].

In the verification results received, the discovery of chrysotile in all the seven types of brake pads were true. All of the received verified result images in Figure 7 were viewed under gypsum plate or known as first order compensator to observe the elongation signs of the fibres. When samples were observed under the gypsum plate, they will produce a pink hue as the background, which further solidifies the elongation signs. Hypothetically, as stated by Ashley *et al*. [31] and NIOSH [22], chrysotile fibres will exhibit a positive sign of elongation where in the NE-SW orientation, it will result in blue colour and in the NW-SE orientation, the fibre will appear yellow [35].

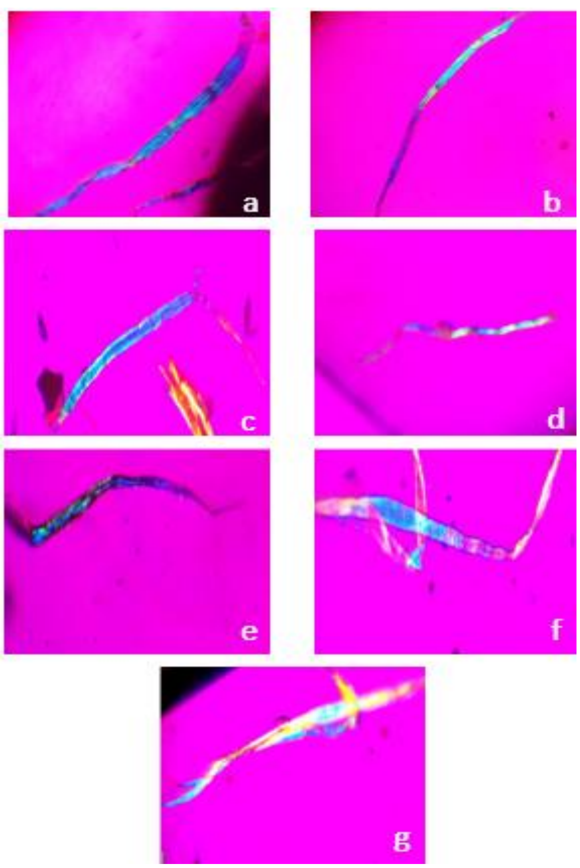


Figure 7 Chrysotile fibre presence was confirmed by the accredited lab in (a) brake pad sample A, (b) brake pad sample B, (c) brake pad sample C, (d) brake pad sample D, (e) brake pad sample E, (f) brake pad sample F, and (g) brake pad sample G

Next, the sample outcomes were all having positive signs of elongation since it showed blue colour fibres at the NE-SW orientation. Meanwhile, the fibres present at the NW-SE orientation in figures 7(c), (f), and (g) appeared in yellow form. Additionally, it was also reported that when viewed under normal fully crossed polarized light, all of these brake pad samples exhibited anisotropic behaviours, which further supported the existence of chrysotile asbestos fibres shown in Table 4.

Table 4 Total of vehicles for each entrance

Sample	Anisotropic Behaviour	Sign of Elongation	Presence of Chrysotile
A	Present	Positive	Present
B	Present	Positive	Present
C	Present	Positive	Present
D	Present	Positive	Present
E	Present	Positive	Present
F	Present	Positive	Present
G	Present	Positive	Present

4.0 CONCLUSION

In conclusion, this research was successfully accomplished to ascertain the presence of asbestos fibres (chrysotile) in seven different selected brake lining and brake pad brands used in the Malaysian market vehicles and heavy vehicle sector, and to identify the characteristics of asbestos fibres (chrysotile) present in the brake pad samples portrayed under PLM. This study has revealed that chrysotile fibres are indeed present in all of the brake pad samples collected. This is largely because Malaysia is not listed in the countries which has completely banned the use of asbestos, and the only banned asbestos in Malaysia is crocidolite according to Occupational Safety and Health (Prohibition of use of substance) Order 1999 [5]. Meanwhile, the observed characteristics of chrysotile asbestos are discussed in five categories: the use of RI 1.550 HD liquid, colour and morphology, pleochroism, extinction, and dispersion staining technique. Chrysotile fibre presence is detected in all of the observed brake pad samples when immersed in RI 1.550 HD liquid, the immersion oil. Besides that, the usual forms of morphology that exists in the samples are either wavy crinkled fibres or irregular shaped fibres. These fibres exhibit anisotropic properties, where the fibres are able to exist or disappear when viewed at different stage angles. Meanwhile, brown or blue-magenta pleochroic colours are observed in a half to fully crossed polarized light. All of the chrysotile samples generally exhibit parallel extinction, where it will appear the brightest when oriented at a 45° angle and disappear at every 90° angle from the 0° polariser. Finally, for the dispersion technique test, all samples emit bright white light resulting from the deviated light produced when the fibres are rotated at different angles in a central stop manner. For the verified samples by the accredited lab, all of the fibres show a positive sign of elongation.

Here are few recommendations and improvements which can be implemented in the future works:

1. Expand the area of study by identifying presence of ACM brake pad in another automotive sector such as motorcycles, aeroplanes, trains, and heavy machineries used in different industries.

2. Since this study focused more on the qualitative part of the fibre analysis in order to justify the existing usage of chrysotile asbestos in present year brake pad market, try to include quantification asbestos fibre analysis such as visual estimation or point counting [36] when using PLM as recommended in NMAM 9002 by NIOSH.
3. The use of PLM for quantification analysis must be accompanied with more precise data-based instrumentation such as X-Ray Diffraction (XRD).

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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