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Study of Machining Characteristics of LLPDE/Palmac Palm Oil-Based Wax Blend for Prototype Applications

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Abstract –*Palm oil-based wax is a waste material from palm oil refining process. Recent prototyping activities have used industrial blue wax or synthetic wax to produce prototype parts by machining processes. The new palm oil-based wax blended with LLDPE reduces the use of synthetic wax for engineering applications. This paper studies the machining characteristic of two different composite blends: LLDPE/PALMAC 95 -16 Palm Oil-Based Wax and LLDPE/PALMAC 98-18 Palm Oil-Based Wax. Three machining characteristic results were recorded, namely; surface roughness, temperature and dimensional consistency.*

Keywords: Machinability, Palm Oil, Industrial Wax, LLDPE

1.0 INTRODUCTION

The global increase in environmental awareness in response to waste problems and increased crude oil prices have paved the way for the development of sustainable and renewable resources [1]. Palm oil-based wax is a new material developed for machining industries due to the substantial increase in product prototyping demands following the increase of product development. The research team has seen an opportunity in recycling palm oil-based wax, which is a by-product of palm oil refining industry; by developing a product that will benefit the industry and the country. This research aims to investigate the strength and characterization of a new palm oil-based wax composite that can achieve strength parallel to the existing industrial blue wax [2]. This new material would then substitute the costly petroleum-based industrial blue wax. Machinable wax offers distinct advantages over the other prototype materials for certain applications. It is environmentally friendly and the chips produce no harmful dust, odor or irritants. The material is self-lubricating, easy on tooling and recyclable. The chips and unused pieces of material can be remelted and reformed into useable materials. This attribute of machinable wax can substantially reduce the cost of using other materials. The existing industrial wax is an extremely hard synthetic (microcrystalline) wax that has been formulated to exhibit exceptional machining characteristics. Since it is harder and has higher melting temperature than most waxes, the industrial wax can be machined, cut or shaped using standard metalworking machine. High-quality surface details and dimensional accuracy are possible. Industrial wax is ideal for producing product prototypes and verifying CNC machining programs. The major component in palm oil-based wax is fatty acids, which are chemically derived from basic oleo-chemicals through a few stages of refining process [3, 4]. Oleo-chemicals are derived from renewable resources, as compared to petrochemicals, which are obtained from exhaustible or non-renewable petroleum. Thus, replacing industrial blue wax with palm oil-based wax could have a positive impact on both the environment and economy. As a new material developed for machining industries, research on machinability characteristics of palm oil-based wax is rather scarce. Palm oil wax itself is brittle and has poor tensile strength. Hence, in this study, the Linear Low Density Polyethylene (LLDPE) is used as the matrix, while palm oil wax serves as the reinforcement in this new polymer composite. The objective of this study is to observe the machining characteristics of different compositions of LLDPE and palm oil-based wax blends.

2.0 METHODOLOGY

2.1 Sample Preparation

A commercially available LLDPE in powder form is obtained from Vinodrai Engineers Pte Ltd., India, and used in this experiment. The palm oil waxes are obtained from Acidchem International Sdn. Bhd., Butterworth, Malaysia. Two types of PALMAC fatty acids are used in this study; namely, PALMAC 95 - 16 and PALMAC 98 - 18. The PALMAC 95 - 16 is in the form of solid, which requires crushing while the PALMAC 98 - 18 is already in powder form. Table 1 shows the details of the fatty acids. The composite blends are mixed by using a rod in a mold with a total weight of 100 g for each blend. The blends are then sent to the heat treatment machine to be melted at a temperature of 250ºC for 8 minutes and cooled at room temperature for 30 minutes. A total of 20 samples with 9 major patterns are prepared for both composites. The concentration of Palmac palm oil-based wax is set at a minimum of 40% to a maximum of 60% composition ratios.

Table 1: Fatty Acid Product Detail

Product Name	Fatty Acid	Palmac Fatty Acid
	Stearic Acid 95%	Stearic Acid 98%
Trade Name	Stearic 95 -16	Palmac 98-18
Molar Mass	256.4 $gmol^{-1}$	248.49 $gmol^{-1}$
Chemical Family	Fatty Acids	Fatty Acids
Appearance	White amorphous solid, waxy, flaky crystal, white hard masses -Solid	White amorphous solid, waxy, flaky crystal, white hard masses -Powder

2.2 Design of Experiment

This experimentation employed the design of experiments (DOE) method, which is a

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systematic approach to investigate the significance of different parameters. A two-factor, two-level DOE was constructed. Table 2 shows the detail of the experimental set up.

Table 2: Experimental Runs Parameter

Parameter	Level -1	Level -2
LLDPE (%)	40	60
Palmac Palm oil-based wax (%)	40	60

2.3 Machining Process

End milling was performed on the samples before tested for surface roughness. In the case of milling process, the radial cutting depth, feed rate and spindle speed are some of the most important parameters. It is possible to analyse how the different compositions influence the average surface roughness by keeping these parameters constant and varying the sample compositions. The milling condition was kept constant at the spindle speed of 1100 rpm, feed rate of 200 mm/min and radial cutting depth of 1 mm. A 12 mm diameter four-flute carbide-coated high speed steel end mill was used in the milling operation. Next, drilling operation was conducted on the 9 major pattern compositions of LLDPE /PALMAC 95 - 16 and LLDPE 98 – 18, to test for dimensional consistency. The drilling operation was performed at a constant spindle speed of 960 rpm with a 10 mm drill bit. Three holes were drilled on each sample.

2.4 Surface Roughness Measurement

Surface roughness is an important factor for determining the quality of a product. It is a measurement of the fine irregularities of the surface texture, which in this case, are the feed marks generated by the milling process. The milled specimens were tested for surface roughness by using a Surface Roughness Tester, model CS - 3100 FORMTRACER. The specimens were placed on a horizontal platform before running the stylus tip at the center of the slot, on the specimens.

2.5 Temperature and Dimensional Measurements

A Professional Infrared Thermometer was used to measure the temperature of the machined product surface that is in contact with the tool during the drilling operation. A vernier calliper was also used to measure the internal diameter of the three holes drilled on each of the 9 major pattern samples for the dimensional consistency test.

2.6 Chip Formation Observation

The chips for each composite were collected carefully during the milling process to be observed under a Scanning Electron Microscope (SEM). The SEM machine enables

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observation of the chip shape and size characteristics at magnifications of D8.5X30, D5.5X200 and D5.5X100.

3.0 RESULTS AND DISCUSSIONS

3.1 Surface Roughness Result

Table 2 shows the surface roughness result for both LLDPE/PALMAC 95 - 16 and LLDPE/PALMAC 98-18 composites. Figure 1 shows the minimum predicted surface roughness for LLDPE/PALMAC 95 - 16 and LLDPE /PALMAC 98 – 18 composites. The minimum predicted surface roughness can be achieved by LLDPE/PALMAC 95-16 at 40/56.67 composition. The response for the minimum surface roughness is 1.010714 µm. Meanwhile for LLDPE/PALMAC 98-18, the minimum surface roughness of 1.244384 µm can be achieved at 41.67/60 blend composition.

Table 2: Surface Roughness Result

Samples	Surface Roughness (um)	
	LLDPE/PALMAC 95-16	LLDPE/PALMAC 98-18
1	1.98	1.90
2	1.39	1.28
3	1.47	1.67
4	0.87	1.08
5	1.71	1.18
6	1.94	1.59
7	2.12	1.73
8	0.95	2.23
9	2.18	2.13
10	1.43	1.27
11	2.23	1.08
12	2.00	1.84
13	2.62	1.90
14	3.04	2.15
15	1.90	1.59
16	3.07	2.20
17	1.14	1.56
18	1.11	1.54
19	1.57	1.23
20	2.62	1.84

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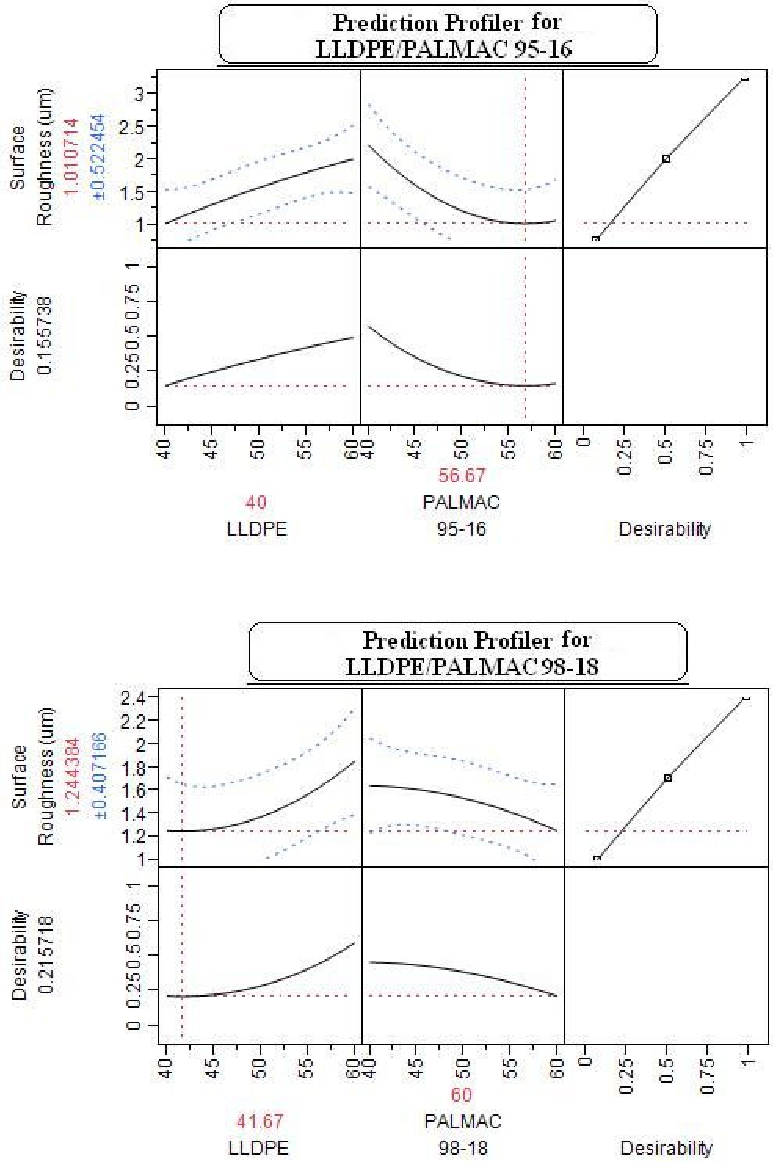

Figure 2: Schematic for the leading edge

Figure 3 presents the temperature of the specimens during the drilling process of LLDPE/PALMAC 95-16 and LLDPE/PALMAC 98-18 composition blends. Both composites show highest temperature on sample 9 at 60/40 composition ratio and lowest temperature on sample 1 at 40/60 composition ratio. This indicates that temperature reduces with the increase of palm oil wax content. The temperatures of samples 4 (50/50 composition ratio), 5 (40/40 composition ratio) and 6 (60/60 composition ratio) for both blends are approximately the same since all three samples contain 50 g of LLDPE and 50 g of palm oil wax. The range of temperature change for LLDPE/PALMAC 98-18 blends is slightly smaller compared to that of LLDPE/PALMAC 95-16 blends. No tool wear was observed since the operating temperature was always lower than the tool melting temperature.

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Figure 4 shows hole dimensions for both LLDPE/PALMAC 95-16 and LLDPE/PALMAC 98-18 blends. No significant dimensional difference is observed between the two blends. All dimensions are within the range of 0.1 mm and smaller than 10.0 mm. This may be due to the shrinking of plastic for both composites. Both composition blends also indicate decrease in dimensional accuracy with the decrease of palm oil wax content. No cracking occurred on both blends as shown in Figure 5. This indicates good interfacial bonding for both composites.

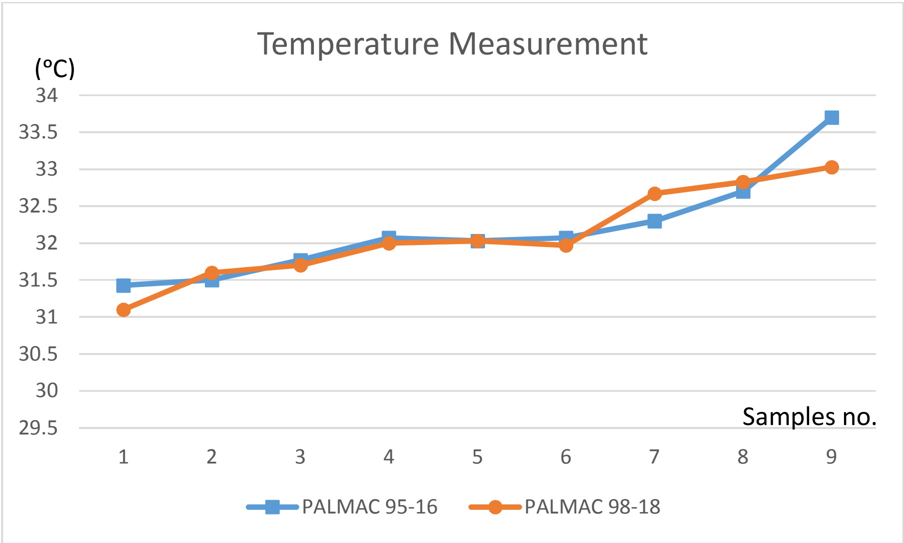

Figure 3: Temperature measurement for different Palmac types (Palmac 95-16 and Palmac 98-18)

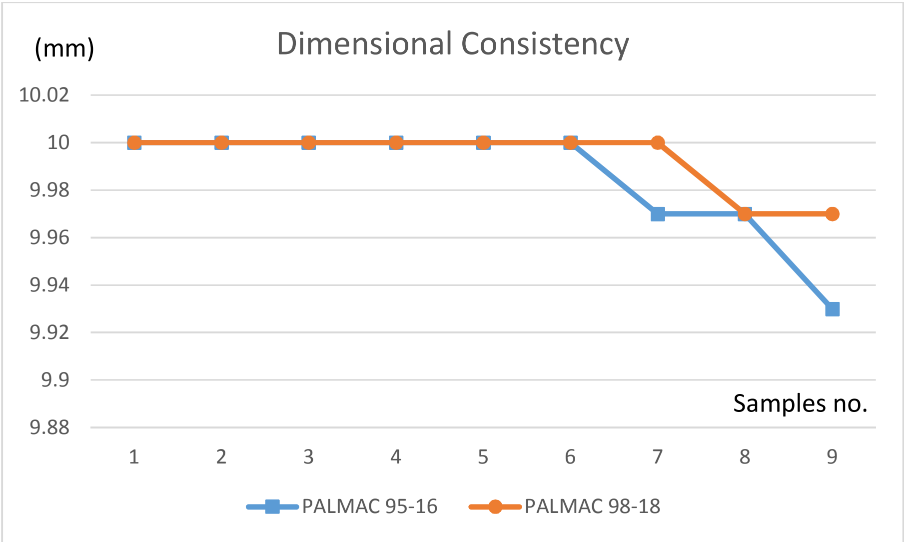

Figure 4: Dimensional accuracy for different Palmac types (Palmac 95-16 and Palmac 98-18)

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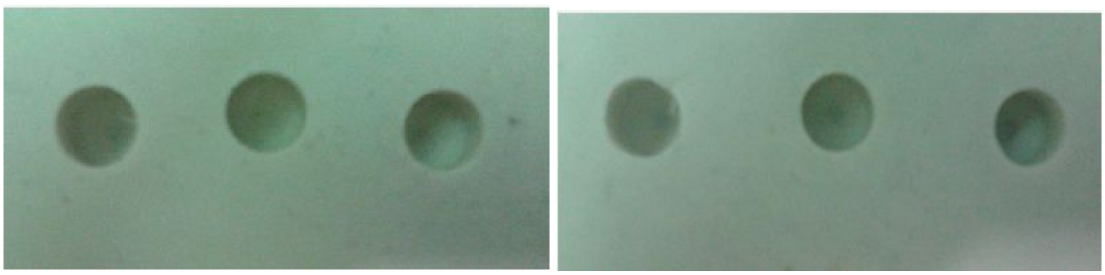
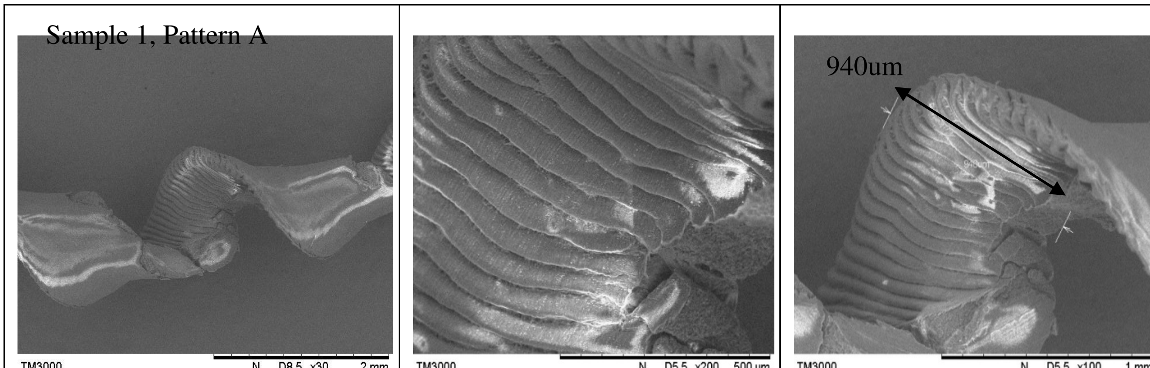
Figure 6 shows the SEM micrograph of chip morphology characteristics for LLDPE/PALMAC 95-16 blends. In Figure 6 (a), a discontinuous chip with a smooth surface on one side was generated. A serrated surface was observed on the other side of the smooth chip surface. The smooth surface is the surface in contact with the tool during the milling operation. Figure 6 (b) illustrates the close-up view of the serrated chip surface known as lamella with spacing between the shear band and the molten debris. The lamella on the chips was uniformly distributed and is of average thickness due to the constant feed rate and cutting speed. The length of the lamella is within the range of 940 μm to 1.12 mm as shown in Figure 6 (c).



(a) (b)

Figure 5: Drilling hole test specimen for different blend compositions. (a) Specimen for LLDPE/PALMAC 95 - 16. (b) Specimen for LLDPE/PALMAC 98 – 18



(a) (b) (c)

Figure 6: SEM micrographs of chip morphology characteristics for LLDPE/PALMAC 95-16 (50/50) composites: (a) SEM micrographs at magnification D8.5X30; (b) SEM micrographs at magnification D5.5X200; and (c) SEM micrographs at magnification D5.5X100.

Figure 7 shows the SEM micrograph of chip morphology characteristics for LLDPE/PALMAC 98-18 blends. Based on Figure 7, it can be seen that the chip morphology

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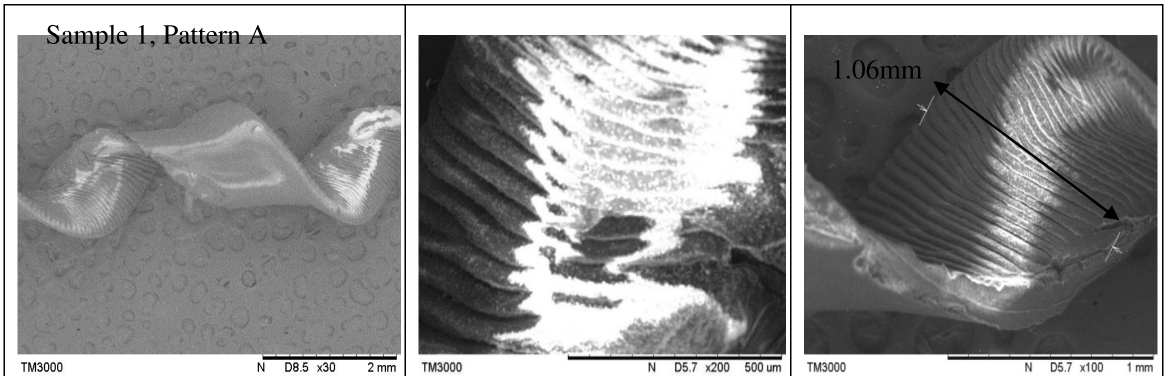
of LLDPE/PALMAC 98-18 blends is somewhat similar to the chip morphology of LLDPE/PALMAC 95-16 blends. The blends also produced discontinuous chips with a smooth surface on one side and a serrated surface on the other side. The length of the lamella is within the range of 928 µm to 1.17 mm. The generated chips are uneven in colour. This can be attributed to the low miscibility between PALMAC 98-18 fatty acid and LLDPE. The chips are also more fractured and smaller in size compared to LLDPE/PALMAC 95-16 blends. These suggest that LLDPE/PALMAC 98-18 blends are more brittle in comparison with LLDPE/PALMAC 95-16 blends. Despite the different compositions of palm oil wax to LLDPE in both blends, the chip morphology is almost similar.



(a) (b) (c)

Figure 7: SEM micrographs of chip morphology characteristics for LLDPE/PALMAC 98-18 (50/50) composites: (a) SEM micrographs at magnification D8.5X30; (b) SEM micrographs at magnification D5.5X200; and (c) SEM micrographs at magnification D5.5X100.

4.0 CONCLUSSION

LLDPE/PALMAC 95-16 blends have been shown to yield lower surface roughness than LLDPE/PALMAC 98-18 blends. This minimum predicted surface roughness is 1.010714 µm and achieved at 40/56.67 LLDPE/PALMAC 95-16 blend composition. For LLDPE/ PALMAC 98-18 composite, the optimal surface roughness is 1.244384 µm at 41.67/60 composition. The dimensional accuracy for both composition blends are in the tolerance range of 0.1mm. Better dimensional accuracy however, were produced by LLDPE/PALMAC 98-18 blends with smaller dimensional tolerance. The dimensions appear to become more accurate at higher contents of palm oil wax. Both blends produce good interfacial bonding within the composite. Higher content of palm oil wax in the composite has been found to lower the temperature during machining operations. No tool wear occurred since the temperature is always lower than the tool melting temperature. Machining of both LLDPE/PALMAC 95-16 and LLDPE/PALMAC 98-18 blends generates serrated discontinuous types of chips. Although the chip morphologies of both composites are almost similar, the chips formed when machining LLDPE/PALMAC 98-18 blends are smaller and more fractured, suggesting that this composite is more brittle than the former composites. It

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appears that the different composition of palm oil wax to LLDPE does not have significant influences on the chip morphology.

Fatty acids mixed with polymer have been shown to be a promising substitute to the existing petroleum-based industrial wax. This material can be produced in a stable form and has good potential for engineering applications. In brief, the development of Palmac Fatty Acid with polymer composite would give a positive impact on a global scale, especially for the product and educational industry.

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