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Experimental analysis on the effects of pigmentation in the defects formation of the polypropylene plastic injection moulding

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Abstract. Pigment levels are known to have an effect on defect formation of the plastic injection moulding parts. Warpage, Shrinkage and Flash are common defects that were found during plastic injection moulding process. It was found that the pigment does play a role in the formation of defects on the plastic injection moulding parts. The main finding of this case study is to analyse and study the warpage, shrinkage and flash defects that were found in the Plastic Injection Moulding (PIM) parts which are moulded with different pigmentation percentages. It is also to identify the effects of the different pigments colours on the moulding quality of the parts when the pigment percentage is made constant. In this research, the dog bone design was used as the experimental specimen. The material used in this study is Polypropylene (PP). The other parameters such as injection pressure, melting temperature and cooling time were set to constant. The only parameter that varies is percentage of pigmentation. Warpage, Shrinkage and Flash defects are measured and calculated to obtain the value of defects. The pigmentation gives a huge effect on Warpage and Flash deformation. The warping and flash increase as the percentage of pigmentation increase. The highest value for warpage and flash are 3.0732 and 1.45304 respectively. Moreover, blue pigment gives the lowest value for Warpage and Flash defect. While yellow has the highest warping and flash defects. However, it was found that shrinkage is not affected by the pigmentation. The shrinkage result is less than 1%.

1. Introduction

The most common method of plastic processing technique is using the injection molding machine. It is the most practical and cost effective method to produce plastic product. There are a few common plastic injection molding defects that can be identified in the plastic injected parts such as warpage, sink marks, flash and shrinkage. Warpage is when the intended shape of the molded part is distorted during the cooling process. Mold warping can cause the part to fold, bend, twist or bow. Shrinkage is the contraction of the molded part as it cools after injection. Most of the part shrinkage occurs in the mold while cooling, while Flash is a molding defect that occurs when some molten plastic escapes from the mold cavity. Typical routes for escape are through the parting line or ejector pin locations.

Industry that has experienced rapid growth is the polymer manufacturing industry, in which polymer production has increased by 300 million tons from 1975 to 2014 [1]. The quality of the injection moldings depends on the material characteristics, the mold design and the process conditions [2].



Polypropylene (PP) is a thermoplastic “addition polymer” formed from the combination of propylene monomers. Polypropylene is a thermoplastic polymer with chemical formula $(C_3H_6)_n$ and chemical name of poly(1-methylethylene) [3]. It is widely used due to its numerous properties of which comprise roughness, strong resistance to chemical solvents, as well as resistance to acids and bases. In addition, polypropylene is translucent and has a high fatigue and heat resistance. Polypropylene can be made translucent if uncolored but is not as readily made transparent as polystyrene, acrylic, or certain other plastics and it is reasonable economically [4].

The molding process parameters play an important role in the plastic injection molding [5]. Process parameters involved are melting temperature, holding time, cooling time and injection pressure. These process parameters will affect the quality of the product produced. It is important to optimize the process parameters to its best condition to reduce any defects in the plastic injection molding parts. It was found that holding pressure and melt temperature affect the tensile strength of material [6]. Since this research focuses on pigmentation, thus the process parameters are kept constant. The best parameters are chosen to avoid any defects formation caused by the parameters. Warpage and shrinkage are among the most significant defects. Rizwan and Gaurav said that process parameters can be modified at any stage of the process while other factors like mold design and material have certain limitations of cost and time [7]. Pujari and Naik found that optimized parameters combinations of different factors are considered as melt temp 235°C; holding pressure 35 bar, injection pressure 65 bar & cooling time 12 sec [8].

The most common problem for injection molded products is warpage [9]. Warpage is a form of distortion that can occur in some materials, such as wood or plastic. This usually results from uneven stresses that can be internal or external to the material being warped [10]. The main cause of warpage in injection molded parts is the uneven volumetric shrinkage from high to low temperatures [11].

Shrinkage is defined as the reduction in the size of part as compared to the size of the mold. Uniform shrinkage does not create part deformation and change in shape, but it becomes smaller [12]. High shrinkage occurs when an inadequate amount of plastic is pushed into the mold and the pressure on the plastic is maintained for a short interval of time [13].

Flash is excess plastic that has extended out past the edge of the part [14]. Flash happens due to clamp force is too weak, gap within the mold, high melt temperature, high injection pressure, very poor venting system [15]. In this study the flash is measured as excess weight of the product. There are many factors that contribute to the warpage, shrinkage and flash defects. The common parameters involved are cooling time, injection pressure, injection speed, holding time. However, in this study the factor that is being investigated is the pigmentation percentage in the specimen mixture. This research focuses on finding out how much pigmentation causes defect to the plastic injection molded parts such as warpage, shrinkage and flash. In the past, very few research works were done to analyze the effects of pigmentation on plastic injection molded part. James et al. worked on similar concepts whereby it was identified that addition of colorants, fillers and process stabilizers affect the molded parts differently [16].

The main objective is to investigate if the concentration levels of pigmentation will produce warpage, shrinkage and flash defects. To ensure the defects produced are only caused by the pigmentation, other parameters such as injection pressure, melting temperature and cooling time were kept constant. The concentration level of the pigment varies from range 1% to 10%.

The other objective is to find out how the different pigmentation colors will affect plastic injection molding parts. There were 3 pigments tested blue, yellow and red. The concentration level of these 3 pigments is kept constant. The result will be obtained from the experiment and after the defects have been identified. However, different pigments will have different preparing processes. So this research is to identify if different pigments will cause different effects on plastic injection molding parts. Thus, it is important to obtain the ingredients or materials that were used and how they affected the result.

Colorant is used in plastics injection molding to provide desired appearance properties which can help in selling the product. Pigment can be divided into two, inorganic and organic. Inorganic pigments have a good heat resistance and weathering properties compared to organic pigments [16]. Moreover, inorganic pigments can be classified into standard metal oxides or complex inorganic colored pigments and effect pigments. Inorganic pigments provide durability and stability in extreme environments. [17]. In this research, inorganic pigments are used, yellow, blue and red. This pigment range from 1% until 10% are used to investigate the defects, warpage, shrinkage and flash.

The significance of this study is able to gain knowledge on the effect of small range percentage of pigmentation on the outer or physical appearance plastics injection molding part. Moreover, by completing this project it might be able to determine most suitable range for percentage of pigmentation in injection process in order to avoid the defects such as warpage and shrinkage from occurring. The outcome of this research will be able to assist the industry to differentiate the effect of different pigments on the physical appearance of the parts. Hence, this improves the quality of existing products and processes and simultaneously minimizes the costs significantly.

2. Methodology

2.1. Process Parameters

In this experiment, the process parameters that taken into account are melting temperature (210°C), injection pressure (100Bar) and cooling time (15s). All these parameters were set to constant. These parameters are chosen based on the default settings of the injection moulding machine used.

The first experiment investigates the effects of different percentages of pigments on the defects formation on the plastic injection moulding part. Hence, the only parameter that varies is percentage of pigmentation which ranges from 1% to 10%. The colour used in this experiment is yellow. Warpage, shrinkage and flash defects are then measured.

In the second experiment, different pigment colours are used to identify the colorant effect on the defect formation on the plastic injection moulding part. All process parameter such as injection speed, melting temperature, and cooling time are set to constant and percentage of pigmentation is set at 5%. Two other different pigment percentages were used to repeat the experiment such as 3% to represent small range percentage while 8% for high range percentage to gauge the results. The pigment colours used are blue, yellow and red.

2.2 Conducting Experiment

Selection of the injection moulding parameters and their levels was carried out on Plastic Injection Moulding machine VDC II series MMC II (Korea) as shown in Figure 1. The material used was Polypropylene resin and was injected into the dog bone mould as shown in Figure 3. First, the Polypropylene was mixed with colour additive, 10: 1 ratio in which 400 g and 4 g respectively. Then they were pre-heated in the hopper and ready for injection moulding shot.



Figure 1. Injection Moulding Machine



Figure 2. Polypropylene and master batch hand mixed.

The experiment was repeated from 1% until 10% of pigmentation by using yellow master batch. It was the same for the next experiment which used 3%, 5% and 8% for each pigment. The polypropylene and pigment were hand mixed before inserted into the machine.

2.3 Defects Investigation

The Figure 3 below is the specimen of the dog bone design that was produce by the machine. These specimens were then taken to be measured for their defects.



Figure 3. Dog bone specimens in yellow, blue and red.

2.3.1 Shrinkage. The first test was to measure the shrinkage defects. The shrinkage defect is measured by the thickness of the product. The actual thickness of the dog bone is 4.15 mm. Any value that is less than 4.15 mm is deemed as shrinkage. The thickness of the specimen is measured by using digital Vernier Callipers. 5 points were taken for each of the specimen to ensure the validity of the result.

2.3.2. Warpage. The following test is the warpage measurement. Warpage test is important in order to determine the allowable warping for the product in industry. Warpage test was carried out by using Quick Vision Ace 250 machine as shown in Figure 4. This machine is able to measure the surface of the specimen and give the exact value. The difference between the highest and lowest value is the value of warpage.

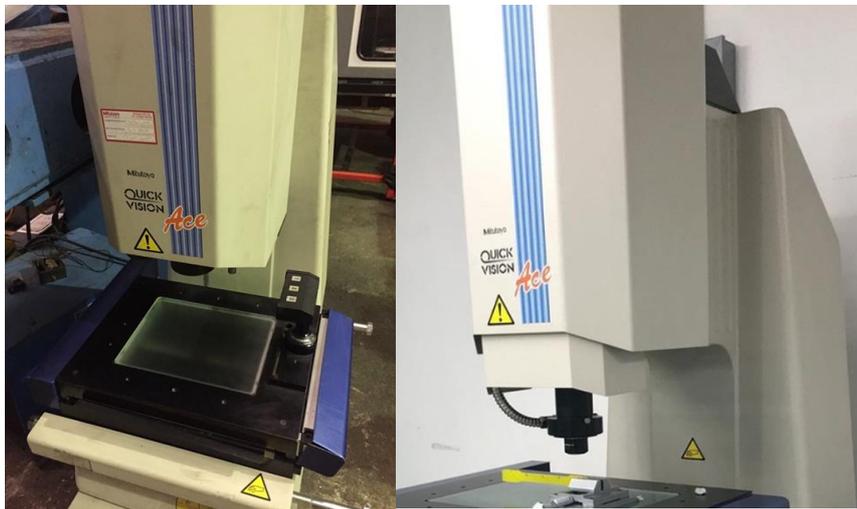


Figure 4. Non-contact Quick Vision Ace 250 machine.

2.3.3. Flash. Flash in this study is measured by the excess weight of the product. All the specimens are weighed using the electronic scale (Figure 5). The actual weight of the specimen is 8.20 gram. Any value more than 8.20 is counted as flash defect. The result is then tabulated.



Figure 5. Weight of the specimen measured using an electronic scale.

3. Results and Discussion

3.1. Shrinkage

The thickness of the specimen is recorded and the average values of the 5 points are taken. The graph of Figure 6 shows the shrinkage rate at small range percentage of concentration level of pigmentation from 0% to 5%. The graph is constant and the shrinkage values are less than 1%. The highest shrinkage value is at 2% concentration level which is 0.530%. 1% and 3% was found to have negative shrinkage.

Next, the Figure 7 show the graph of shrinkage for 6% to 10% of pigmentation. The highest shrinkage value is at 7% which is 0.405%. However, the value still does not exceed 1%. Other concentration level such as 8% and 9% remain the same. This proves that from 0% of concentration level until 10%, it does not affect the plastic injection moulding parts in term of shrinkage defects.

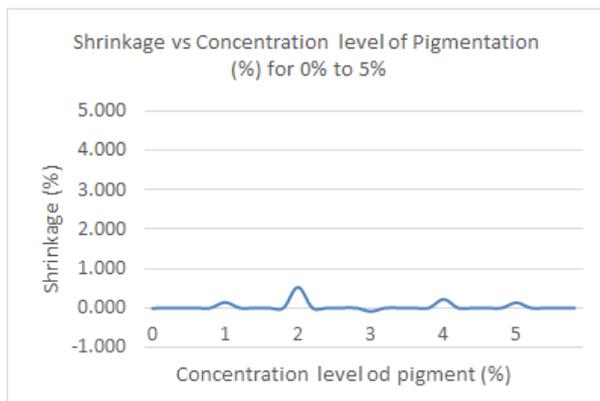


Figure 6. Graph of shrinkage against percentage of pigment for 0% to 5% pigment.

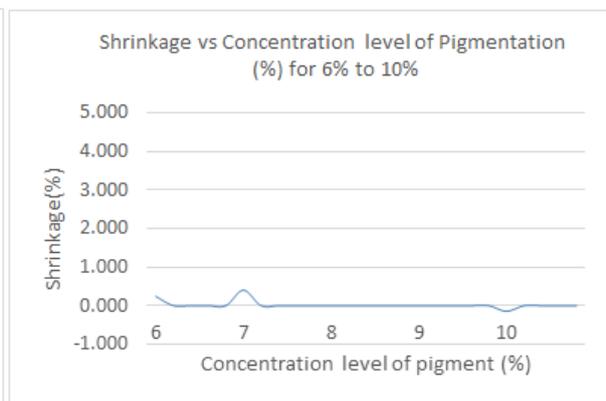


Figure 7. Graph of shrinkage against percentage of pigmentation for 6% to 10%.

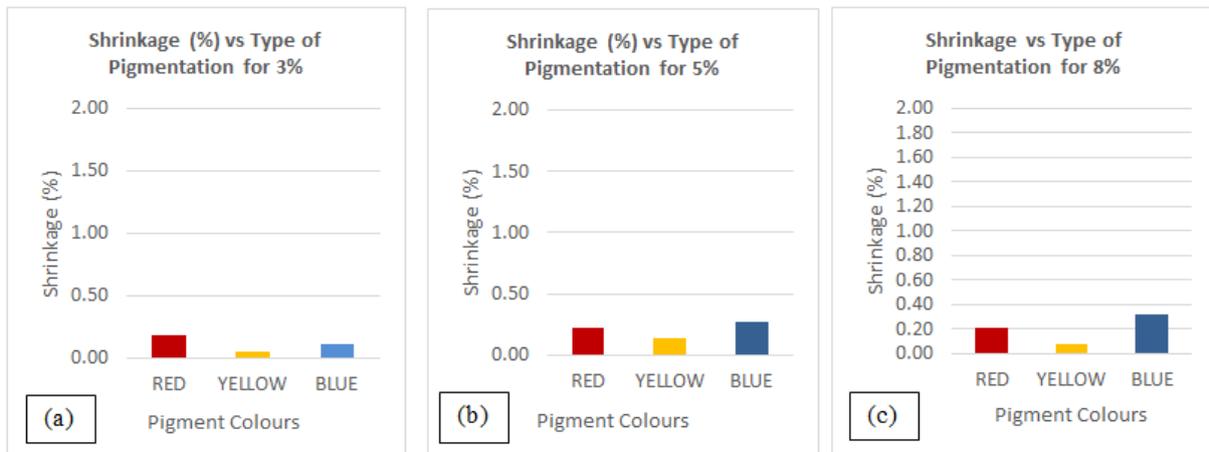


Figure 8. Graph of shrinkage against type of pigmentation for 3% (a), 5% (b) and 8% (c).

Figure 8,9 and 10 shows the graph of shrinkage for the three different type of inorganic pigmentation colours, red, blue and yellow. The first experiment used 3% of each pigment and then was repeated for 5% and 8%. As depicted in all the graphs, the value of the shrinkage defects for blue, yellow and red does not exceed 1% for three different percentages. Overall from these graphs, it can be concluded that inorganic pigment does not have a significant effect on shrinkage formation of plastic injection moulding part as they do not impact the crystallization rates like organic pigment.

3.2. Warpage

Figure 9 and 10 shows the graph of warpage against concentration level for 0% to 5%. It can be seen that as the concentration level increase, the warping also increases. The highest warpage value obtains at 5% of concentration level with 0.8783 mm. This is considered as low warping. However, at 4% the warpage suddenly dropped to 0.8278 mm from 0.84074 mm at 3%. At 4%, the data obtain was negative as it warped on the opposite side. Moreover, Figure 10 shows the warpage graph for the high range of concentration level, 6% to 10%. Based on the graph, it can be seen that the pattern is increasing. The warpage increase as the concentration level increase. At 6% of concentration, the warpage is 0.95036 mm. While at the 10% the warpage increase to 1.45304 mm. However, at 7% the warpage dropped down to 0.70854 mm.

Based on the result shown on Figure 11, the blue pigment has the lowest warping rate which is 0.30486 mm while yellow has the highest warping rate 0.84704 mm for 3% concentration level. This difference is caused by the content of the master batch that were used for both colours. Next, Figure 12 shows the graph of warpage for 5% concentration level of different pigment. The result shows in this experiment; the blue pigment has the lowest warpage formation which is 0.6690 mm while the yellow has the highest warpage rate which is 0.8783 mm.

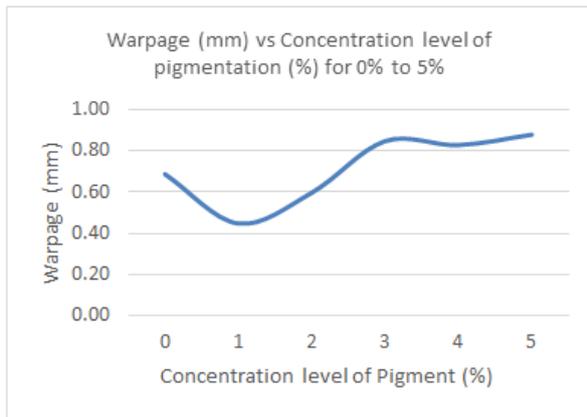


Figure 9. Graph of warpage against concentration level for 0% to 5%.

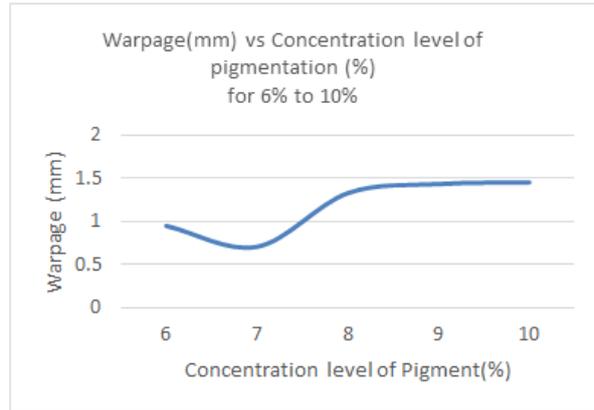


Figure 10. Graph of warpage against concentration level for 6% to 10%.

From both the graphs it can be clearly seen that yellow pigment fares poorer in comparison to the blue and red as it has very low warpage rate. However, Figure 13 shows that the Red specimen has the lowest warping rate which is 0.7332 mm. It is different compare to both result in 3% and 5% which stated blue as the lowest warping rate. But the yellow specimen still remained as the highest warping rate in this experiment with 1.32528 mm. From the warpage result it can be concluded that when the concentration level increase, the warping rate also increases. Moreover, the blue specimen has the lowest warping rate and yellow specimen has the highest warping rate. This is due to the content of pigmentation for both colours.

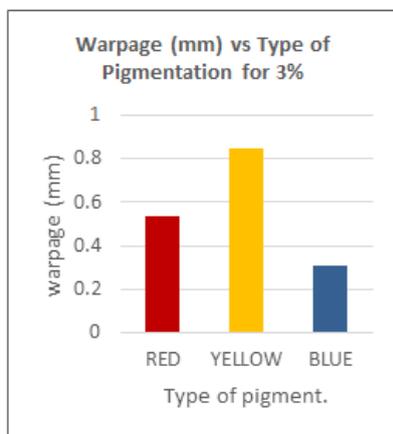


Figure 11. Graph of warpage vs type of pigmentation for 3% of concentration level.

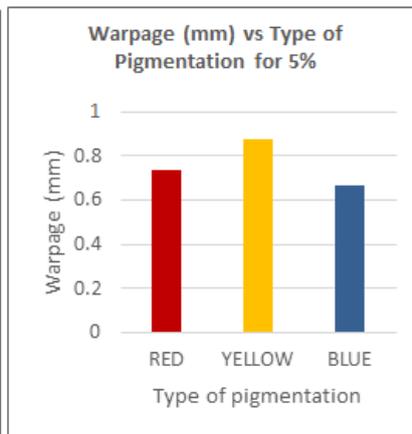


Figure 12. Graph of warpage vs type of pigmentation for 5% of concentration level.

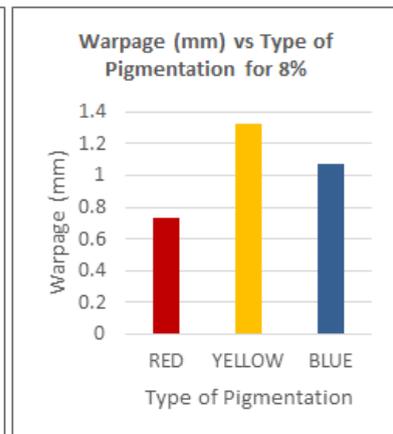


Figure 13. Graph of warpage vs type of pigmentation for 8% of concentration level.

3.3 Flash

The excess weight produce by the specimen is counted as flash. The actual weight for dog bone is 8.20 gram. Based on the Fig. 14, the graph show that as the concentration level increases, the percentage of flash also increases. The lowest flash rate is 1% concentration level which is 0.3098 %. The highest flash rate is at 5% concentration level, 1.80 (%). However, the result is differing for 2% and 4%. The weight is smaller which for 2% and 4% this might be due to error during injection process. Based on Fig. 15, the graph indicates the increase of flash defects as the concentration level increases. The highest flash rate is 3.0732 % for 10% concentration level. However, the graph indicates at 7% the flash rate decrease from 2.1268 to 0.7049. This was cause by the error during injection process.

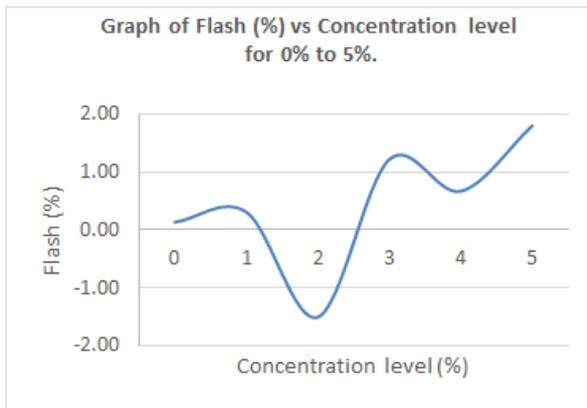


Figure 14. Graph of flash vs concentration level for 0% to 5%.

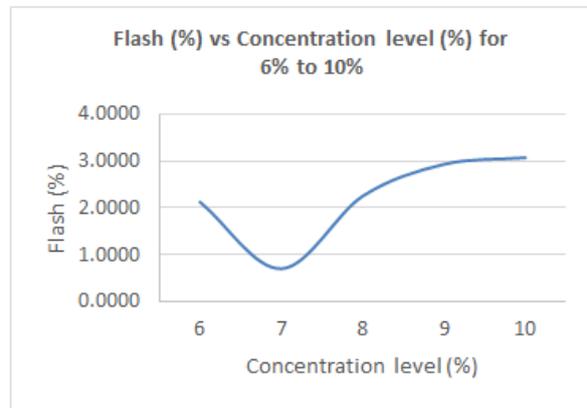


Figure 15. Graph of flash vs concentration level for 6% to 10%.

Figure 16 and Figure 17 shows the graph for flash defects against type of pigmentation for 3% and 5% respectively. The graph indicates that blue specimen has the lowest value of flash which is 0.5073% and 1.2902% respectively. While yellow has the highest value of flash for both experiment, 1.2195% and 1.80% respectively. However, Fig. 18 shows that red has the highest flash value compare to both previous experiment which indicates yellow as the highest flash defect. The value for red is 3.5098%. The blue specimen has the lowest flash value, 1.8756 %. This indicates that blue pigment can minimize the defects that cause by pigmentation.

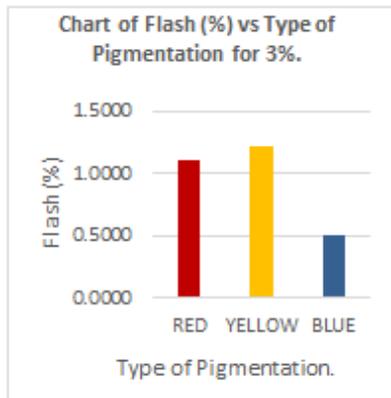


Figure 16. Graph of flash vs type of pigmentation for 3% concentration level.

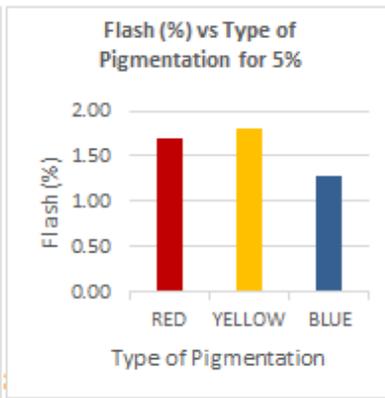


Figure 17. Graph of flash vs type of pigmentation for 5% concentration level.

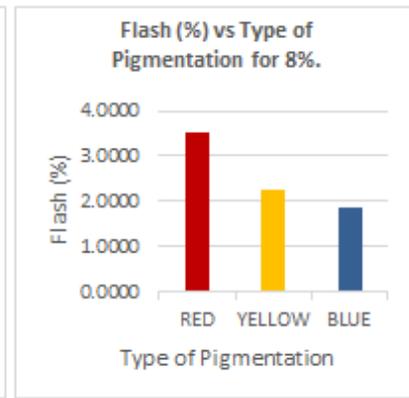


Figure 18. Graph of flash vs type of pigmentation for 10% concentration level.

3.4 Fourier Transform Infrared Spectroscopy (FTIR) Test

Infrared spectroscopy is the microscopy and spectroscopy of material which is the test used for analysis of functional groups. The FTIR technique were prepared and performed to study the surface chemistry of pigment colour that effect the properties of samples [14], leading to the various inconsistency as well variances amongst the pigments. Two samples from different pigment has been chosen to be tested in this FTIR test. Format of Infrared (IR) spectra is Transmittance (T) against Wavenumber (cm^{-1}). The FTIR spectrum in Figure 19, displays the blue spectrum for blue pigment pellet and the red for yellow pigment pellet. For yellow pellet, the spectrum showed strong broad of characteristics transmittance bands at 1409.63 cm^{-1} which corresponds to the Cobalt (II) Oxide (COO) but for blue pellet, the spectrum showed strong properties at 2915.29 cm^{-1} indicate methylene (CH_2) All FTIR spectrum of native hide is indicated in Table 1 and 2 with the functional groups respectively.

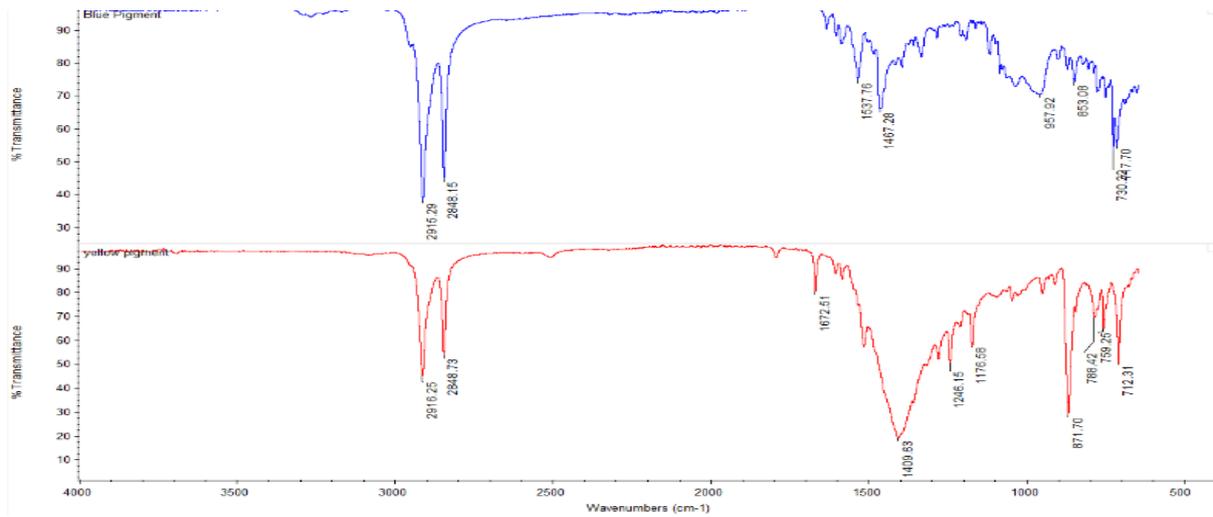


Figure 19. Graph of FTIR test

Table 1. Blue Pigment FTIR

Blue Pigment Pellet	
Wavenumber, cm^{-1} .	Functional Groups
2915.29	Methylene (CH_2)
2848.15	Aldehyde (CHO)
1537.76	Benzene
1467.28	Methylene (CH_2)
957.92	Carboxyl acid (-COOH)
853.08	Nitrogen dioxide (NO_2)
730.447	Benzene

Table 2. Yellow Pigment FTIR

Yellow Pigment Pellet	
Wavenumber (cm^{-1})	Functional Groups
2916.25	Methylene (CH_2)
2848.73	Aldehyde (CHO)
1672.51	Amide
1409.63	Cobalt (II) oxide (COO)
1246.15	Epoxide
1176.58	Ester
871.7	Epoxide
788.42	Alkyl halides
759.25	Meta-disubstituted. benzene
721.31	Monosubstituted Benzene

4. Conclusion and Recommendation

In this study, the effects pigmentation on the defects formation of plastic injection moulding has been conducted and investigated. The shrinkage, warpage and flash defects result has been obtained. The shrinkage rate is less than 1%. The warpage rate increases as the concentration level increases. The highest warpage occurs at 10% concentration level which is 1.45304 mm. It was found that the blue specimen has the lowest warpage value while yellow has the highest warpage value. The warping is considered as low warping as the defects does not exceed 10 mm. For flash defects, it was found that the highest flash occurs at 10% concentration with value 3.0732%. Blue specimen has the lowest flash rate and yellow has the highest flash rate. The result of current investigation is necessary to improve the quality of products from plastic injection moulding in industry where mass manufacturing takes place and a guideline is indeed necessary to minimize wastage, cost and increase production yield. The colorant analysis indicates here that the blue pigment is most stable and the factor is largely due to its chemical composition. To further analyse this factor, an in depth FTIR analysis can be done to understand the contribution of each chemical compound in the stability of the pigments.

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