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Color Mismatch in Compounding of Polycarbonate Composition: Processing Parameters and Pigment Dispersion Effects

Jamal AlSadi[1]

[1] Department of Mechanical Engineering, Higher College of Technology Abu Dhabi, UAE

E-mail: *jalsadi@hct.ac.ae*, *jalsadi@uoit.ca*

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[1]**AlsadiJ**
jalsadi@hct.ac.ae
jalsadi@uoit.ca
(+971-2062938)

Abstract

The purpose of this research is to study the variations of the independent variable of processing conditions such as temp, speed, and feed rate that affect the dependent responses for consistent output color (L*, a*, b*, dE*). In this study, the compounded material prepared on an intermeshing twin-screw extruder (TSE) and injection molded to evaluate their effect on the color stability, rheology, and dispersion of the polycarbonate resins. The focus was continued to the interaction of the speed which correlates to the dispersion and color changes. The interaction relationship between tristimulus color values (dL*, da*, db*, dE*) and processing parameters showed that the minimum color difference throughout the experiment was 68.42 for L*, 1.47 for a*, 15.35 for b*, and 0.34 for dE* respectively.The color difference values (dE*) decrease significantly with the increase of the temperature and feed rates.

1. Introduction

Manufacture the best color; it is essential for the design and the control of most manufactured colored materials to take into consideration the mastery of the material science including physics, chemistry, and sensibility [1,2,3,4]. In the 21st century, color science is more significant than ever. Manufacturing plastic with a favorite color involves merely adding to one another, one or more polymers; nevertheless reaching the correct color in the first shot is a challenge. Apart from pigment formulations, the color properties of plastic are directly affected by the processing conditions for material compounding during the extrusion system. Data mining, in which historical data are analyzed to select formulations (PC compound grades, e.g.G-3), pigments, e.g. (red pigment), processing parameters (temp, rpm, feed rate) were made color mismatches. Blending mixer, co-rotating intermeshing- twin screw extruder and injection molding were performed. General factorial design, box Behnken design (BBD) with the threelevels of the experiment were conducted [5,6,7,8]. ANOVA of the obtained experimental data was utilized to study the effects of these processing parameters. The regression model was generated based on the ANOVA to predict the optimal matching color. Producing the right to with minimal wastage has been a big challenge [9]. The Polymer color varies with changes in the light, the object, and the observer sources [10, 11, 13]. The effects of screw geometry and operating conditions on dispersion have also been studied by Philipp et al. [12]. The results show that the controlling the particle size and distribution of a yellow pigment, PY62 directly affects properties such as film, transparency, color development, extruder pressure build and processing time [13,14]. The color variation is due to degradation, temperature, particle size and colorant [15]. Screw speeds have no apparent effect on the kneading block performance [16]. Shear forces that occur in the extruder are in a good determinant of the level of mixing with a different polymer [17]. The high shear rates, processing temperatures, and processing pressures involved in the manufacturing processes. The increasing speed (screw speed) will enhance the longitudinal distribution [18, 19]. Processing affects the rheological properties and dispersion ability of pigments in the resin [20, 21, 22, 23, 24]. The colors are metallic products because they do not exhibit exact and uniform size or range of sizes [25]. Narrower particle size distributions are superior for Chroma Scattering, and absorption is functions of particle size. The control of properties denotes associated with particle size and morphological structure. Characteristically, narrower particle size distribution shows a cleaner effect and wider provides greater hiding power. Therefore, the shapes offer different levels of reflectance and opacity [26]. To obtain primary particle size, it is necessary to have a smaller particle which has a higher surface area and consequently stronger the color [27, 28, 29, 30]. The Systematic progress may broadly denote divided into two types of reducing the particle size, shear and collision. The best superiority of the dispersion grade depends on the characteristic of the concentration of Pigment, volume, time spent, rotation speed, energy input, and temperature [31,32].Thedispersion degree depends on the energy use in, i.e., speed and the residence time in the chamber. The intensity of scattered light by a particle depends on its molecular weight, molecular size and geometrical shape [33].

This research presents experimental observations and statistical analysis to investigate scientific reasons for color mismatches in compounded plastics. Material processing issues were observed. Different methodologies were developed and applied to study and improve the understanding of color matching, color stability and consistency of compounded plastic materials, to minimize wastage. The first used Data Mining, in which historical data were analyzed to select formulations, particularly for pigments and polycarbonate blends of compounded plastics, which were known to suffer from the color mismatch.

Two data mining techniques were utilized. One was online analytical processing (OLAP), and the other was a decision tree classifier (DTC). The DTC will be used for exploring parameters most likely to effect color failure problems with compounded plastics. Therefore, Online Analytical Processing (OLAP), DTC and neural network modeling (NNM) are sorting through large data sets approaches have been executed to discover such parameter [34,35,36,37,38,39]. The second data mining used the parametric study to investigate issues in the dispersion of pigments by determining and analyzing the effects of processing parameters on color. Finally, the third method studied the effects of rheology.

The results indicate that the variation in temperature significantly affected rheological properties and hence color deviations. The fourth method looked at effects of processing parameters on dispersion, pigment size distribution (PSD) and morphology of pigments in polycarbonate compounds

The goal of this research is to study the impact of processing conditions, rheology, and dispersion. Experiments were produced regarding three different processing parameters (Temp, feed rate, Screw Speed), while keeping the other parameters fixed at (255 °C, 25kg/hr., 750rpm). In our earlier work [46, 47] found that the achieved results of the deviation in polycarbonate content and temperature crucially effect on rheological characteristics and the obtained viscosity data were correlated to dispersion and color changes. In this study, we use the same translucent PC compound grade at three level design, each of the runs was replicated three times to allow estimation of experimental error or trend analysis (GT). This work investigated the variety of independent of processing parameters such as temp, screw speed, and feed rate are affected the dependent responses for consistent output color (L*, a*, b*, dE*). Focus extended on the speed, correlated to dispersion and color changes to evaluate their effect on the color stability, rheology and dispersion of the translucent compounded plastic grade -3 of polycarbonate (PC) achieve minimum deviation of color differences.

2. Experimental Setup

2.1 Materials

The material used was a blend of two different Lexan polycarbonates, having different a melt flow index; (MFI) for R1 was 25g/10min and that for R2 was 6.5g/10min. Also, it contained four different color pigments (black, white, red, yellow) and three additives (a stabilizer, light stabilizer, and weather resistant). The compounding for one polycarbonate grade (Resin-1 30%- Resin-2 70%) is shown in Table 1.

Table 1: Composition of compounding material for polycarbonate Grade-3 (R1 & R2)

S.No	Ingredien	Material symbol	PPH	Wt.	Unit
1	R1	Bisphenol A (BPA)	30	4.95	gm
2	R2	Bisphenol A (BPA)	70	10.05	gm
3	F 1	Weather resistant(L)	0.035	0.00525	ml
4	F 2	Stabilizer (Liquid)	0.065	0.00975	ml
5	F 3	Light Stabilizer	0.2	0.03	gm
6	White	White Pigment	0.278	0.041625	gm
7	Black	Black Pigment	0.036	0.0054	gm
8	Red	Red Pigment	0.175	0.02625	gm
9	Yellow	Yellow Pigment	0.071	0.01065	gm

Experimentation was carried out at the industrial plant, Canada. The materials were extruded in an intermission a 25.5 mm, 27 kW twin co-rotating screw extruder (TSE), with ratios L/D=37 and D_o/DI = 1.55. The extruder had ten heating zones, nine identified on the barrel and one of the die. The experiment has been designed with the three processing parameters (temperature, speed, and flow rate). This extrudate compounding material is related to as (SB). The additives were mixed with the resins at a 100:0.86 ratio is shown in figure 1 and were batch blended by a super floater in ratio per weight to assure higher consistency [46].

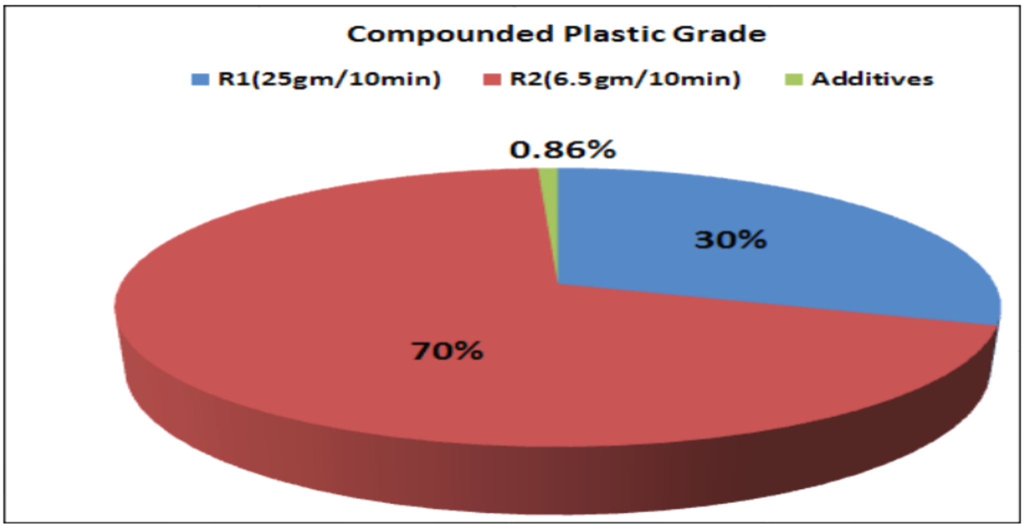

Figure 1: Typical compounded plastic grade of polycarbonate

The batches were prepared both with pigments and additives for characterization of the viscosity. The prepared (transulent-G3) PC grade was used to study the rheological properties. This helped in understanding the factors of rheology that have bearings on color variations by examining the effect of processing, rheology, particle size distribution, and the morphology of the dispersion of the three processing parameters.Figure 2 presents a schematic that summarizes the steps in the compounding process.

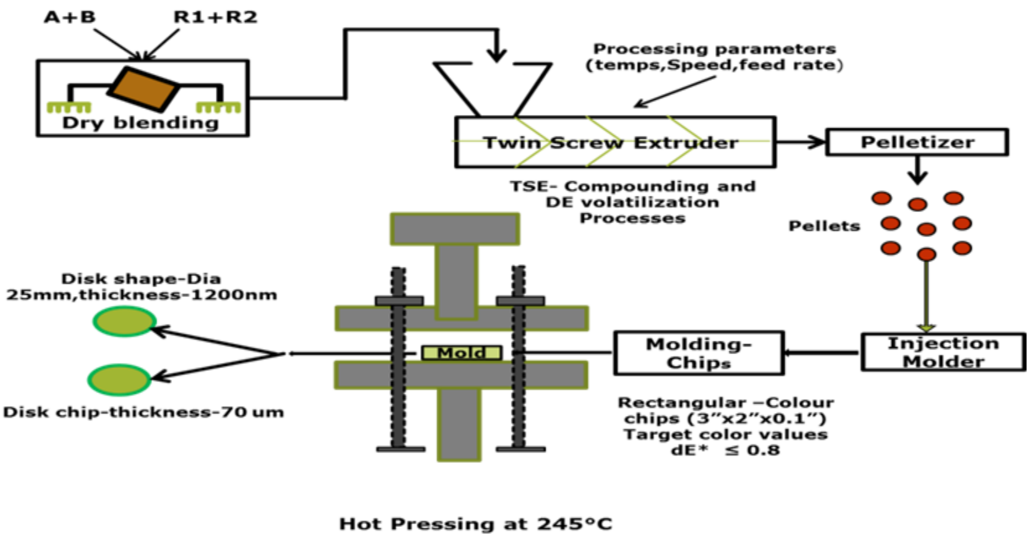

Figure 2: Schematic diagrams of process methods of plastics

2.2 Data Mining

To achieve a right color in plastic compounding, certain pigments with specific weight percentages (called a formulation) mix with the base resin (plastic). If the final color does not match the target color, a new batch of material is processed again after adjusting the pigment formulations, accordingly. This procedure may sometimes be repeated before the desired result (color) is achieved.As mentioned earlier, a large number of material data formulations and processing parameters are available at manufacturing plant Innovative Plastics, that automated and statistical tools are required to analyze them. Analysis of these data can provide valuable information for enhancing the color matching process. A Comprehensive study has conducted these data to find any existing correlations between color deviations, and material formulations and processing parameters. [46]

2.3 Color Difference (Delta E)*

A colorist may be asked to match a color with a known reference color or to compare two colors. Delta E* is a single number indicating the difference in color between two readings and is based on the L*, a*, and b* color space system. This is the geometric distance, delta E*, between two points in the three-dimensional space. But delta E* is not linear throughout color space and is not a very good measure of color perceptions, as displayed in the equation (1). Therefore, most complicated computational methods have been developed to predict color differences between two samples [41, 42].

$$dE^* = [(dL^{*2}) + (da^{*2}) + (db^{*2})] \quad (1)$$

The L*-axis have represented the lightness and ranges from 0 (black) to 100 (white), the* and b*, shows redness-greenness and yellowness-blueness, for the other two coordinates respectively. Allowable tolerance limits, in the particular terms of dL*, da*, db* or dE* are usually chosen by the client; however, for the polycarbonate grade-3 under this study, limits were equal or less ≤ 1.0 for dE or ≤ 0.6 for dL*, da*, db*

2.4 Processing Parameters (General Trends)

Manufacturing a precise a coloring by injection is required a proper operating process. Changes in the processing parameters will affect changing color. In the current work, the operating parameters were varied in a controlled method to study their effects on pigmentation. Three processing parameters including temperature, speed, and feed rate were varied individually in three different stages. While keeping all other settings fixed (GT), strong interactions between the processing parameters and coloring were observed.

The setup of the experiments were as follows: The recommended processing temperatures were 230°C, 255°C and 280°C with a speed of (750 rpm) and flow rate of (25 kg/hr) fixed. A similar procedure used for both the speed and flow rate. The following are recommended: flow rate was 20 kg/hr, 25kg/hr, and 30 kg/hr, with a constant speed (750 rpm) and temperature (255°C). Lastly, focus extended on the recommended processing speeds of 700 rpm, 750 rpm, and 800 rpm with a flow rate (25 kg/hr) and temperature (255°C) fixed, shown in Table 2, 3 and 4.

Table 2: Processing conditions with temperature variation

RPM	BZ1 (°C)	BZ2 (°C)	BZ3 (°C)	BZ4 (°C)	BZ5 (°C)	BZ6 (°C)	BZ7 (°C)	BZ8 (°C)	BZ9 (°C)	DZ1 (°C)	Feed Rate (kg/hr)
750	70	195	230	230	230	230	230	230	230	230	25
750	70	195	255	255	255	255	255	255	255	255	25
750	70	195	280	280	280	280	280	280	280	280	25

Table 3: Processing conditions with speed variation

RPM	BZ1 (°C)	BZ2 (°C)	BZ3 (°C)	BZ4 (°C)	BZ5 (°C)	BZ6 (°C)	BZ7 (°C)	BZ8 (°C)	BZ9 (°C)	DZ1 (°C)	Feed Rate (kg/hr)
700	70	195	255	255	255	255	255	255	255	255	25
750	70	195	255	255	255	255	255	255	255	255	25
800	70	195	255	255	255	255	255	255	255	255	25

Table 4: Processing condition with feed rate variation

RPM	BZ1 (°C)	BZ2 (°C)	BZ3 (°C)	BZ4 (°C)	BZ5 (°C)	BZ6 (°C)	BZ7 (°C)	BZ8 (°C)	BZ9 (°C)	DZ1 (°C)	Feed Rate (kg/hr)
750	70	195	255	255	255	255	255	255	255	255	20
750	70	195	255	255	255	255	255	255	255	255	25
750	70	195	255	255	255	255	255	255	255	255	30

Extrusion was performed in co-rotating intermeshing-TSE to assure a uniform melt mixing. Three parameters, showing variation individually on three different levels. While maintaining the other processing parameters constant, one parameter was varied; the others remained fixed at a feed rate, screw speed, and temperature, while studying their effects on color shifts. Experimentation was a focus on varying the speed parameter; the others remained fixed at federate and temperature. Upon exiting the die, the extrudate was quenched in cold water, dried using air and then converted into pellets using a pelletizer. These pellets then molded by using injection molding into three rectangular color chips (3x2x0.1") size. These processes set at 85 tons, at about 1000 PSI, and at 280 °C. The specimens dried in the lab at room temperature, measured at three different spots. The color difference (dE*) tristimulus values of these coupons was measured and characterized by a spectrophotometer, using the CIELAB Color Space system which widely used in the industry. It provides 3 tristimulus color readings L*, a*, and b* values [41], target values (Tg): CIE (L*, a*, b*) = (68.5,1.43,15.7). The color chips pressed into a 25mm disk shape, mold by hot a presser to prepare 25mm DIA and 1.2 mm thick chips for rheological characterization measurement. For the microscopy dispersion test, tin sheets were prepared either by molded color chips by hot presses or microtomed into thin slices.

3. Resultsand Discussion

The fundamental goal of this research is to improve the color matching on the PC grades.

In this study, different scientific methodologies were developed to reduce material rejects by the first badge color prospects. This issue is involved the investigating the effect of incorrect formulations and the processing conditions, poor pigment dispersion, an interaction between materials and processing conditions, and degradation during processing.The research refers to the systematic investigation of a series of experimental and statistical investigation techniques of the rheological characteristics and the interaction of processing conditions, by three stages as follows: First is temperature, the second is feed rate, and the third is screw speed. Color measurements were obtained from the experiments. The fourth methodology utilized an Optical Digital Microscope to evaluate the dispersion quality process. This work assessed and analyzed the dispersion process of pigments as well as the effect of processing parameters on dispersion, pigment size distribution (PSD), the morphology of pigments in polycarbonate compounds and the relationship between rheology and color.

3.1 Data Mining

3.1.1 Diagnosis and Detecting Processing Data

Data mining techniques were applied using MS ExcelwithOLAP to detect patterns of adjustments for the runs conducted in 2009. Trends in the data that could explain the causes of color mismatches and formulations were sought [46].

3.1.2 Red Pigment and the Polymer Grades

The manufacturing plant IP produces many grades of PC. Classes are either a single resin or more commonly, a blend of resins formulated to impart specific properties to the final rinse. Based on the historical records, the grades formulated with red pigment (P1) or diluted red pigment (P1L01) and requiring the highest rate of adjustment identified and shown in Table 5.

Table 5: Identifying the percentage of adjustment of grades formulated with red pigment

#	Grades	% Adjusted caused by P1	% Adjusted caused by P1L0[38]1	NB. Of adjust. lots
1	G1	21.95%		9
2	G2	19.51%		8
3	G3		19.44%	7
4	G4		11.11%	4
5	G5	9.75%		4
6	G6		8.33%	3
7	G7		8.33%	3
8	G8	7.32%		3
9	G9	7.32%		3
10	G10	4.88%		2
11	G11		2.78%	1
12	G12	2.43%		1
13	G13	2.43%		1
14	G14	2.43%		1

As an example, the translucent grade (G3) including the diluted red pigment (P1L01) underwent the highest rate of adjustment amongst the grades with diluted red color (P1L01).
Note that designation L01 indicates that the pigment content is 1%, the rest being resin [46].
Table 5 shows the fourteen grades containing P1 that had the highest rate of adjustment. Six of these grades were selected for additional statistics and experimental investigations to study the effects of the formulations on the color shift. The demonstrating of the six grades with the highest rate of adjustment were selected from the fourteen color grades chips as illustrated in Figure 3.

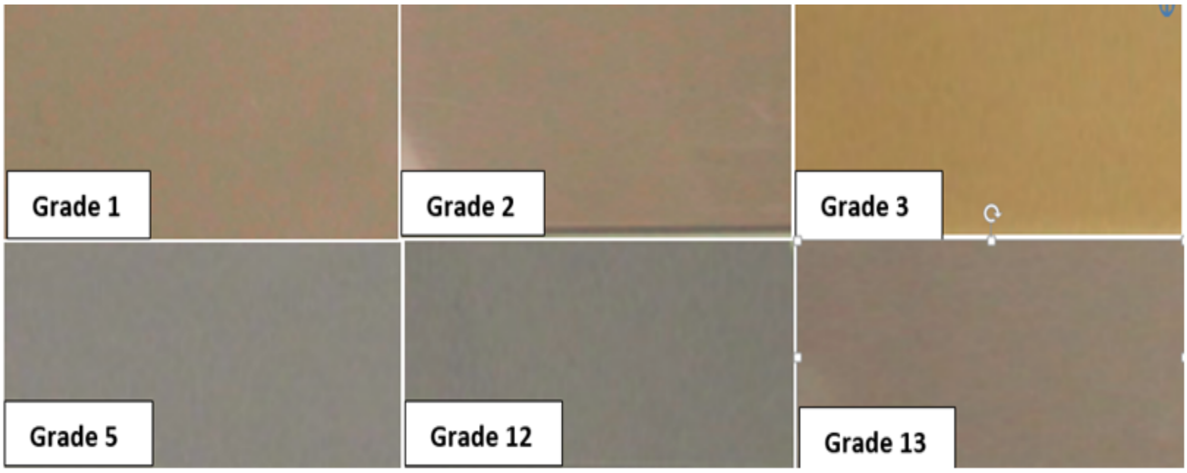

Figure 3: Demonstrating the six grades with the highest rate of adjustment

3.2 Effect of processing conditions
The influence effect of processing parameters on the color of tristimulus values (L*, a*, b*), this process is characterized by using three processing parameters (General Trends) (GT).
3.2.1 Effect of temperature parameters on dE*
Figure 4.1 shows an Increase in temperature and decreases the color differences (dE*). The color difference (DE) approaches to 0.3 as temperature range approach to 255°C and stays such as 280°C.

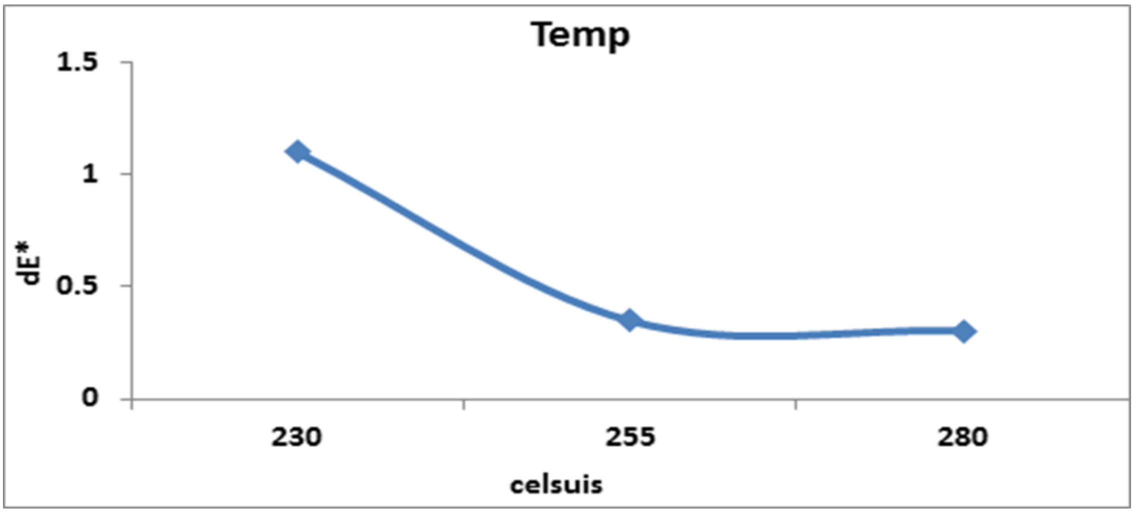

Figure 4.1: Effect of temperature variation, at fixed 25kg/hrs. 750rpm

3.2.2 Effect of feed rate on color values at 255 °C, 750 rpm.
The feed rate increases from 20 kg/hr to30 kg/hr, while the speed at 750kg/hr and temperature at 255 °C, are fixed. The color difference initially decreases as the feed rate increases to 30 kg/hr as described in Figure 4.2.

3.2.3 The effect of speed on color values at 255 °C, 25kg/hr.
The speed increases from 700 rpm to 800 rpm, while the feed rate at 25Kg/hr and temperature at 255 °C rpm, are fixed. The color difference initially decreases and increases as the speed exceeds 750 rpm as described in Figure 4.3.

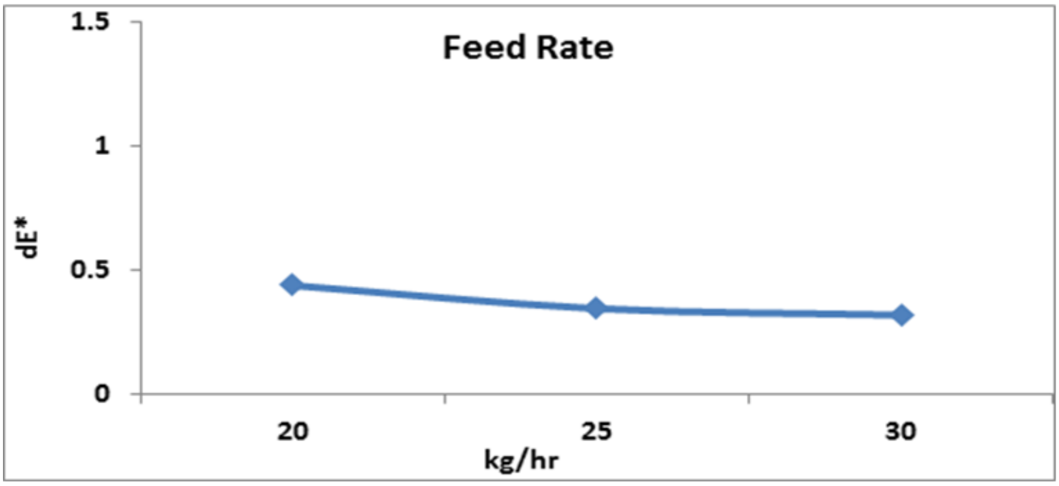

Figure 4.2: Effect of feed rate variation, at fixed 255 °C, 750rpm

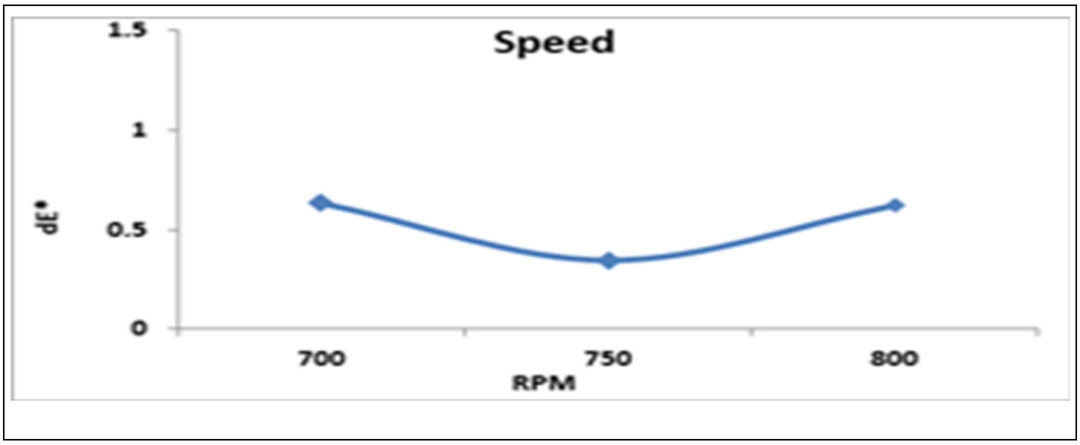

Figure 4.3: Effect of Speed variation, at fixed 25kg/hrs. 255 °C

The color values of dL* and db* are lower than the target values at three levels; except the da* color difference value is slightly positive at 750rpm as shown in Figure 5.

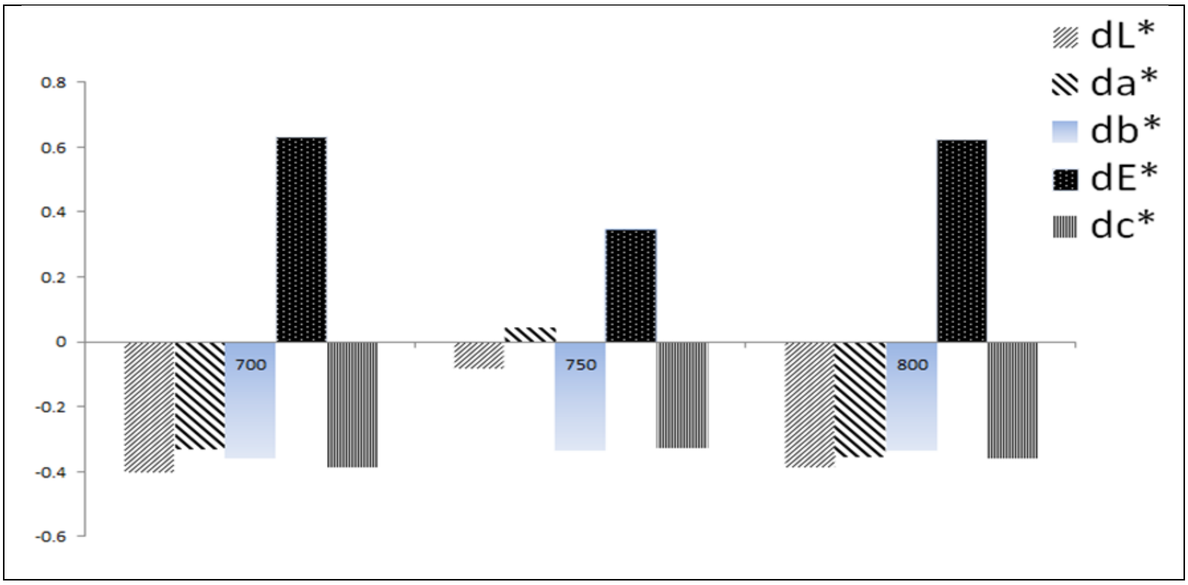

Figure 5: CIELAB Color differences for 700, 750 and 800 rpm speed parameter samples

Fundamentally, this is an indication of the red inorganic pigment was greater dispersed at the center point than in 700 and 800 rpm samples.

Color differences are (dL*, da*, db*, dE*, dC*,): dL* is in negative for darker, da* is in positive for more red, and db* is in negative for bluer.DE or dE* is the total color difference. The lower color difference is at 750

rpm; dC* is negative for chromaticity. The negative dC* and db* values indicate the chromaticity of a blue hue originate from the incomplete dispersion. The transparent polycarbonate plastics do not scatter light; consequently, to accomplish the assured opacity level, white pigment is added to create scattering. Therefore, it affects the apparent color, strength [43, 44, 45]. The negative of chromaticity may be due to the low Chroma in the compounded plastic grade of the translucent polycarbonate resins.
At low speed, e.g., 700 rpm, the extruded material has shown lower shear heat or lower shear rate. Agglomeration, can, in principle, take place in zones with low shear.
By increasing the speed to 750 rpm, deagglomeration occurs in zones of high shear. Raising the screw speed of the extruder to more than 750 rpm will cause the color differences to decreased, because of the relatively low overall shear forces through the entire mixing zones, which separate the pigment particles immediately from the composition.
Also, directly after raising the speed to 800 rpm, extruded resin material was increased with shear heat transition, and the PC composites defined to higher shear rates at the more top speed of 800 rpm
The variation of the color dispersion verified by the value of the color differences (dE*), itis also correlated to the speed values of 700 rpm, 750 rpm, and 800 rpm samples,
The statistics data displayed in Figure. 5. The total color variation dE* increases at 700 and 800, but decreases at the center point 750 rpm. The negative dC*, da* and db* values designate the green-blue hue, originating from the incomplete dispersion of the pigments. Color pigment in sample 750 rpm was enhanced better dispersed than the other two samples. Once again, variation in color measurement is in good agreement with the results of the -image and the particle size distribution analysis results.

3.3 Rheological behaviours

When cropping a circular shape specimenof one inch sized from the rectangular color chips, the sample applied for rheological measurement was conducted by Rotational Rheometer at 230 ^{o}C, 255 ^{o}C, and 280 ^{o}C.
The leading factor influencing the pigment dispersing in the polymer is the viscosity. For the rapid wet color, the viscosity value is low, however, for accelerated deagglomerates, should be high. The applied temperatures for extrusions of the polycarbonate compound are 230, 255, and 280 °C. As temperature increases, η* decreases.Figure 6 shows that when frequency increases, it causes a drop in the melt viscosity (Shear thinning).

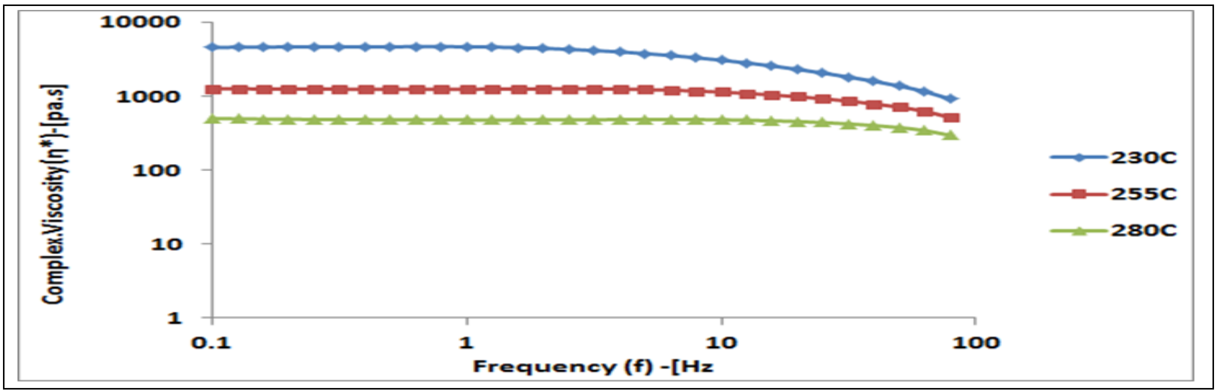

Figure 6: Complex viscosity of polycarbonate composite as a function of angular frequency.

As temperature increases, the onset of shear thinning occurs at a higher frequency wavelength.
Describe the link between the shear stress **τ** and shear rate $\dot{\gamma}$, as displayed to the equation (2 and 3) as follows.

$$\tau = \eta\dot{\gamma} \qquad (2)$$

$$\dot{\gamma} = \frac{\pi x D x N}{60 x h} \qquad (3)$$

Wetting is the more important factor for better dispersion, since the shear forces, created during extrusion, must be transferred onto the pigments. As a result, to increase the efficiency of deagglomerates [45]. The results of low viscosity which was produced by high temperature; therefore, it improves both pigment wetting and the colloidal stability of the dispersed pigment [46, 47, 48, 49].

3.4 Evaluate Dispersion at variable speed

Extrusion was carried out at a screw speed of 700 rpm, at the center point (750 rpm), and 800 rpm, for which a screw speed of 750 rpm was used and found a significantly lower color difference. The examined results of the particle size and dispersion analyses of the samples shown in Figure 7

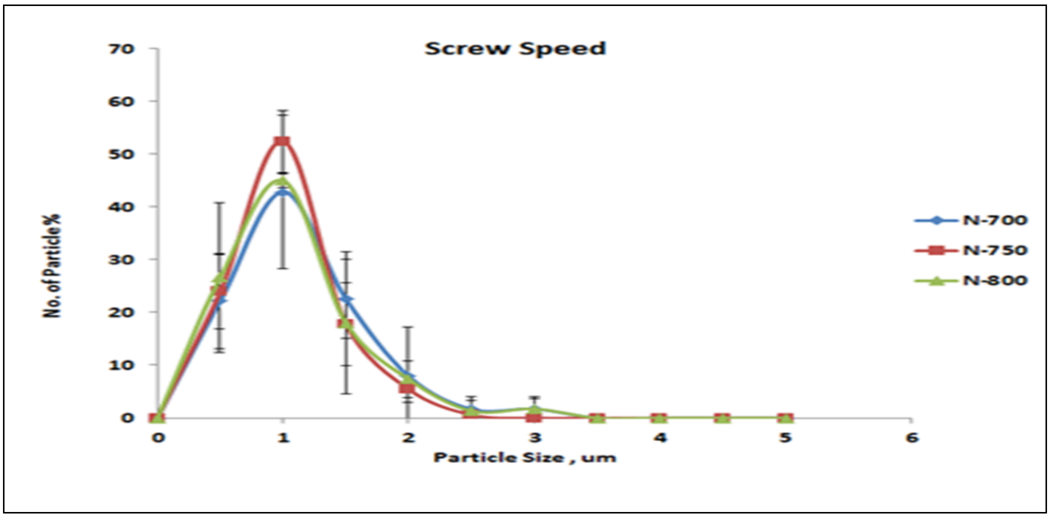

Figure 7: Pigment size distributions (PSD) or Screw Speed parameters, at fixed 255C and 25kg/hr.

The dispersions characterized by digital optical microscopy (DOM) analysis in combination with the scanning electron microscopy (SEM) and Micro-computed tomography or "micro-CT." Figure 7 also shows the particle size distribution (PSD) graphs for the samples used; they are in good agreement with the input values in the process.The imagesillustrate the characterization of the pigment size distribution for temperature, screw speed, and feed rates. When increasing the screw speed, the highest peak of the pigment distribution becomes more narrow except the one with high and low speed, the average size of a particle are, 0.96, 0.79, and 0.88 *um* for 700,750, and 800 rpm respectively.

At 750 rpm has shown higher peaks at 52.43 % in comparison to 42.8 % at 700 rpm and 44.98 % at 800 rpm.

For the optical microscopy tin sheet samples were made by hot presses or rotary microtomed. Color chips were used to get the images into the DOM at a magnification (5000X) as shown in Figure 8. Agglomeration can, in principle, take place in zones with low speed and with high speed.

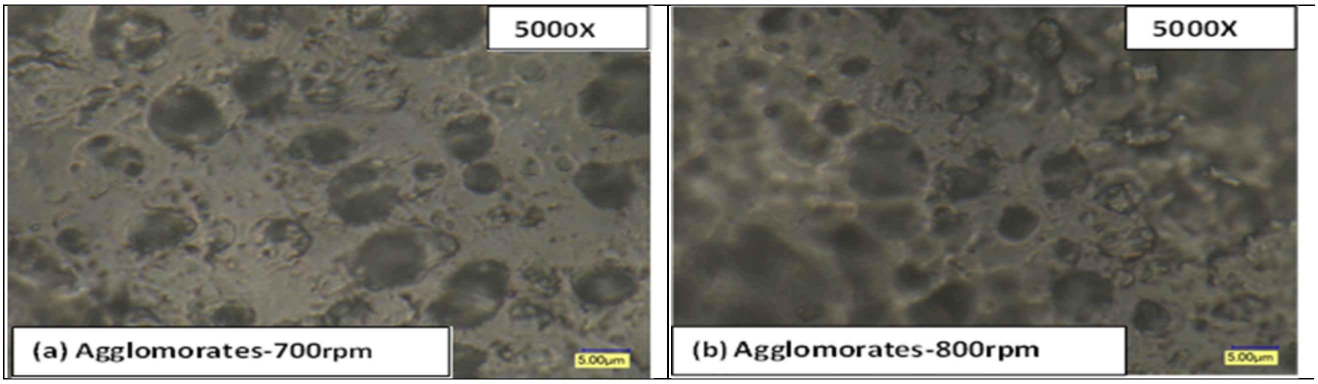

Figure 8: DOM micrograph of compounded grade at (a) 700 rpm and (b) 800 rpm: (agglomerates) at 255 ^{o}C and 25 kg/hr

Figure 9 shows the micrographs of Polycarbonate grade chips, by using scanning electron microscopy (SEM-Joel 5500), with a high-resolution microscopy scan system.

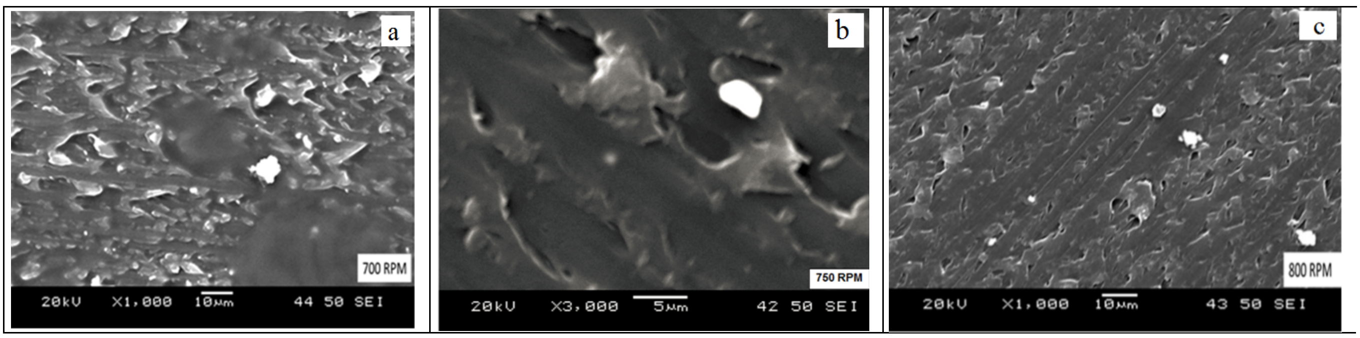

Figure 9: SEM micrograph of Polycarbonate grade compound at (a) 700 rpm (b) 750rpm (C) 800rpm

The samples were covered with a thin conductive colloidal graphite coated, used to characterize the compounding material, having a magnification of 3000X-1000X. The results yield at an optimum set of processing screw speeds at (a) 700 rpm (b) 750rpm (C) 800rpm, SEM micrograph of chips are shown the lowest agglomerations take place in the zones with medium processing at a speed of 750 rpm(Center Point).
Figure 10 shows the 3D-X-ray microtomography measurements for the center point treatment chip were carried out by using X-ray micro CT scanner, with processing at a speed of 700, 750 and 800rpm.

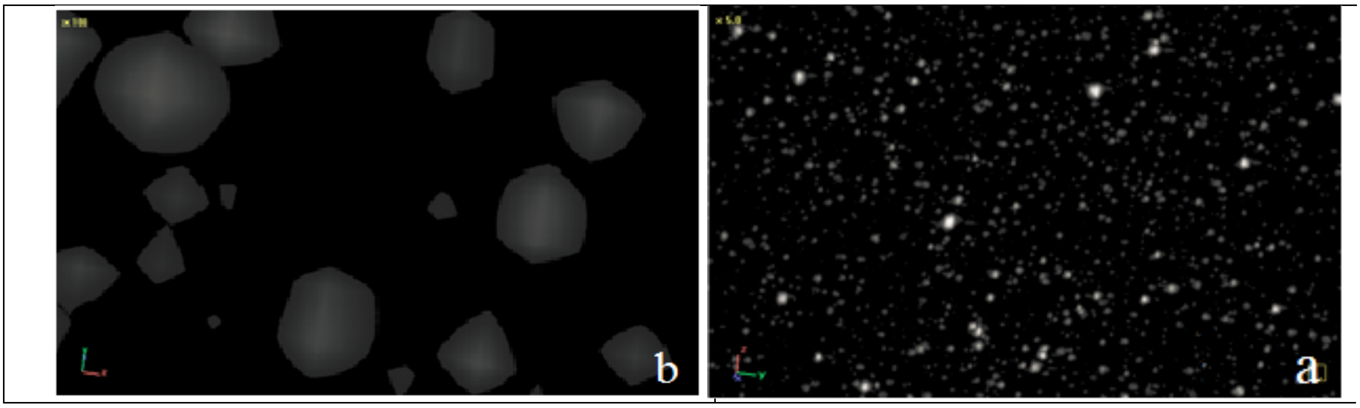

Figure 10: Pigment distribution of PC grade (a) distribution (b) particle shape, Process at c 750rpm, 255 ^{o}C, and 25kg/hr using a µCT Scanner.

High resolutions characterized the data collected at 32kV and 187µA, and the image. Typically the agreement with the minimum color difference and with lower agglomerations and the microscopic images utilized a uniform distribution and spherical particle shape.
In general, the total color differences decreased when processing parameters results were increased. De-agglomeration occurred in zones of high shear and was found to raise the number of particles and lower color differences significantly.
Agglomeration can, ultimately, occur in zones with low shear, deagglomeration take place in zones of high shear. This spectacle is employed to increase pigment wetting, reduce particle size or prevent pigment agglomeration, improve the rheological behavior of flow, dispersion process, and a higher peak distribution occurs, ultimately reduce the color mismatch differences.
The results yield an optimum set of processing parameters for the grades-3 of the polycarbonate compounding. The optimized measurements of processing conditions are typically in agreement with the minimum color difference. Furthermore, many conclusions found here can be used to optimize compounding materials and generate an efficient dispersion process, and hence reduce color mismatch so that wastage reduced.

Conclusion

The interaction relationship between tristimulus color values and processing parameters showed that the minimum color difference throughout the experiment was 68.42for L*, 1.47 for a*, 15.35 for b*, and 0.34 for dE* respectively.The color difference values (dE*) decrease significantly with the increase of the temperature and feed rates. Therefore,it shows a consistent higher peak distribution. As temperature increases, the onset of shear thinning occurs at a higher frequency.
Steadily, increasing the speed to a medium range (*the, i.e.,* center point at 750 rpm) shows a significant minimum color difference; therefore,it shows a consistent higher peak distribution and a spherical pigment shape. At a higher screw speed, these processing parameters can generate large shear forces and a frictional heat state that may arise and affect the heat stability of pigment and damage other components of the polymer matrix. The high velocities raise the material temperature; the failures of appearance, physical properties, or degradation is possible.

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