STUDIES ON PROPERTIES OF PAPER LIKE SYNTHETIC POLYMER FILMS

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Abstract

A paper like synthetic polymer film is a film made up of synthetic polymers and is a synthetic alternate to conventional cellulose paper. These films have good whiteness index. Papers like synthetic polymer films have better resistance to water, oil and grease as compared to conventional papers. In present work paper like synthetic film was prepared by blown film extrusion process with Linear Low Density Polyethylene and coated Calcite, Talc and Titanium oxide as filler. Effect of various filler on Opacity, Whiteness index, Tensile strength, Tear strength and Surface Gloss were studied. Linear low density polyethylene with calcite as filler (10%,20%,30%,40%) and mixture of calcite and talc(45%,50% and 55%) and titanium oxide (5% and10%) were compounded. The compounded pellets have been processed to synthetic paper with the help of blown film process. Blown film unit consist of a single screw extruder of size 25mm. The twin screw extruder used for compounding is counter rotating extruder with L/D ratio of 28:1. The size of extruder is 45mm with four zone temperature controller. There was increase in opacity and whiteness index with increase in filler percent with calcite as filler. However surface gloss, tensile strength and tear strength decreases with increase in filler percent with calcite as filler. There was increase in opacity and whiteness index with increase in filler percent with mixture of calcite and Talc and 5% Tio_2 as filler. However surface gloss, tensile strength and tear strength decreases with increase in filler percent. There was increase in opacity, whiteness index, surface gloss and tensile strength with increase in filler percent with mixture of calcite and Talc and 10% Tio_2 as filler. However tear strength decreases with increase in filler percent. Mathematical modeling and optimization process was carried out.

Key Words: Synthetic Polymer Film, Linear Low-Density Polyethylene, Calcite, Talc, Titanium oxide

INTRODUCTION

A paper like synthetic polymer film is a film made up of synthetic polymers like linear low density polyethylene (LLDPE), Polypropylene (PP), Polyvinylchloride (PVC) etc. These films have good whiteness index. Papers like synthetic polymer films have better resistance to water, oil and grease as compared to conventional papers. These films are writeable and can be used for writing purpose also. These films have much better tear strength as compared to conventional papers. These papers like synthetic polymer films are used for applications like labels, maps, outdoor banners etc. The early developments in synthetic paper were restricted to imparting a thin coating of epoxy on to a conventional paper to improve strength and appearance [**1**]. A film is produced from high or medium density polyethylene containing dispersed calcium carbonate between 10 and 50 percent by mass to provide a film having properties the same as or similar to natural paper having regard to parameters such as dead fold, feel and rigidity or stiffness and also with superior strength [**2**]. Violette et[**3**] al reported an improved method of producing coated paper and to the coated paper produced thereby, and more particularly to a method of producing polyolefin coated paper having heightened resistance, i.e., improved barrier properties, to the passage of gases such as water vapor and solvents such as fats and oils. Kawazoe[**4**] et al reported continuous process for the preparation of synthetic paper by treatment of a polymer film to produce an opaque printable surface, the process including treating the surface with a swelling agent followed by a coagulating agent with, intermediate treatment in one or more baths containing adjustable quantities of swelling and coagulating agents. K.Tani[**5**] et al reported process for the production of novel synthetic paper from thermoplastic polymer films in which the surface of the films are opacified by treatment with a liquid which swells and dissolves the polymer and thereafter treating with another liquid which coagulates the polymer. Intermediate treatments are employed to improve the products. Takanori [**6**] reported of production of paper-like polyester fiber sheet useful for printing, using fine polyester staple fibers having a round cross-sectional profile. Hoge[**7**] reported process for the cold stretching at high stretch tension and at low stretch ratios of a film of a blend of synthetic orient able thermoplastic polymer and at least 50 weight percent of a coated inorganic filler selected from the group consisting of calcium carbonate, clays and titanium oxide and coated with a fatty acid ester of silicon and titanium to form a highly porous thermoplastic film exhibiting paper-like properties. Lare [**8**] reported synthetic wood pulp, characterized by the presence of polyolefin fibrids, having both film and fiber morphology, is useful for the production of paper-like films. He describes a technique, whereby this morphology may be preserved by transferring such fibrids from the refining dispersant into a preservative medium. After again being refined in the preservative medium, the fibrids can be formed directly into paper-like substrate products. More usually, however, they are first dispersed in water to facilitate this casting.

EXPERIMENTAL

Materials

On the basis of require values of properties like opacity, whiteness index, tear strength, surface gloss and tensile strength the materials surveys have been done. The various materials have been analyzed on the basis of their cost and performance ratio, then on the basis of that, base material Linear low density polyethylene of blown film grade (Indothene-LL20FS010) has been selected as a base material. Coated calcium carbonate, Talc (Trade name Gaycro Talc, Hydrated Magnesium Silicate) and Titanium dioxide of fine grade have been selected as fillers to be used. Low molecular weight polyethylene wax has been used as a melt flow promoter. A quality paper to be used for the applications like labels, visiting card should have opacity above 85 percents. The filler must provide opacity at lower cost and least loss in strength of paper. On the basis of above factor and other properties required for synthetic paper the fillers like coated calcite, talc and titanium dioxide have been used. Firstly the low cost filler coated calcite has been experimented. In first four formulations the coated calcite has been increased from 10 to 40(%). The thickness of first four formulation has been in the range of 74 to 80(microns) which is nearby same and this small variation has negligible effect on opacity variation. The next formulations in which there was need to enhance the opacity and whiteness index the rutile grade TiO_2 was used. So in the next formulations titanium dioxide was experimented with the mixture of fillers. The 5 and 10(%) titanium dioxide was used during formulations. The total loading of fillers was increased from 45 to 55(%) at the regular interval of five. The coated calcite compositions were kept 70% of total of mixture used in all formulations where titanium dioxide has been used. However their tensile strengths values, decreases with increase in filler content. But as there was need to increase in opacity and whiteness index so other option left was to increase the thickness under acceptable limit to compensate for decrease in strength. The thickness has been increased in the next formulations to have acceptable strength. These formulations have been with the thickness of 90 to 120 microns. The tensile strength value obtained is combined effect of percentage content of filler and thickness of paper like synthetic polymer film.

Process

Compounding

Compounding has been done in twin screw co-rotating extruder to achieve uniform mixing of base material with the fillers. The size of extruder is 45mm. Compounding have resulted pellets with the uniform mixture of filers and LLDPE.

Processing

The compounded pellets have been processed to synthetic paper with the help of blown film process. Blown film unit consist of a single screw extruder of size 25mm. A die for hollow section crosshead side fed die. The pellets are melted in a single screw extruder with the help of heat produced from heater and shearing action of screw. The melt is passed through the die to form hollow tube. Compressed air is passed from compressor to blown the film. The blown ratio of 2 to3 is maintained by volume control valve at the inlet of a die. Blown film is cooled with the help of air cooling ring provided around the blown film. The blown film is guided through guiding frame. Then the blown film is drawdown with the help of a nip roll assembly. Nip roller assembly consists of a stationary roller, a moving roller and a mechanism to adjust the gap between rollers. Then finally this synthetic paper like film is collected after nip roller assembly.

Composition

Compounding was carried out with following three different compositions:

1) LLDPE-Calcite Composite(with 10%,20%,30% and 40% Calcite)
2) LLDPE- Filler as a mixture of Calcite (70%) and Talc (20%) (with 45%,50% and 55%),Titanium oxide -5%
3) LLDPE- Filler as a mixture 30% of Calcite (70%) and Talc (20%) (with 45%,50% and 55%), Titanium oxide -10%
4) LLDPE (65%) Filler (30%) as a mixture of Calcite (70%) and Talc (30%) and mixture of Calcite (60%) and Talc (40%)

All formulations contain 5% of low molecular weight polyethylene wax used as a melt flow promoter.

TESTING

The opacity of testing specimens is evaluated as per ASTM D1003 procedure. A recording spectrophotometer has been used for evaluating opacity. The tensile strength of plastic film is determined as per ASTM D 882. Universal testing machine has been used for tensile testing. Tear strength test was carried out as per ASTM 1922 using Pendulum impulse type testing apparatus. Surface gloss test was carried out as per ASTM D2457.

Results and Discussion

Opacity

From **figure 1** it can be seen that the opacity value is increasing from24.61 to 41.35 (%) when coated calcite is increased from 10 to 40 (%). This increase in value is non linear. This has been attributed only due to increase in coated calcite loading .Then mixture of talc with coated calcite with loading of 30% has been experimented. The talc has been increased from 30 to 40 (%). The opacity values have been nearby same as when mixture of calcite and talc as filler is used. Thus addition of talc has not been much effective in enhancing the opacity values. This was observed that even when 5% of talc was replaced by TiO_2 in formulation number seven the opacity value increased drastically from 41.35 of earlier maximum value to 72.52 which are nearby double. The opacity has been much improved by adding TiO_2 as compared to increase in thickness because for nearby same thickness as of formulation number 4^{th} an $8^{th,}$ with the addition of TiO_2 by 10% of total 45% the opacity has been increase by more than 100%. The formulation number 8^{th} was prepared by adding 10% TiO_2 to total of mixture filler. The resultant value leads to more enhancements in opacity. The opacity was 87.15%. This value was quite acceptable as it was above 85%. The next formulations were prepared with increase in total loading of mixture by interval of 5%. The TiO_2 compositions were 5 and 10(%). The values of opacity obtained are excellent to be used for applications like labels, visiting card. The maximum value of opacity was obtained 97.28% when total mixture loading of filler was 55% and TiO_2 was 5% of total filler.

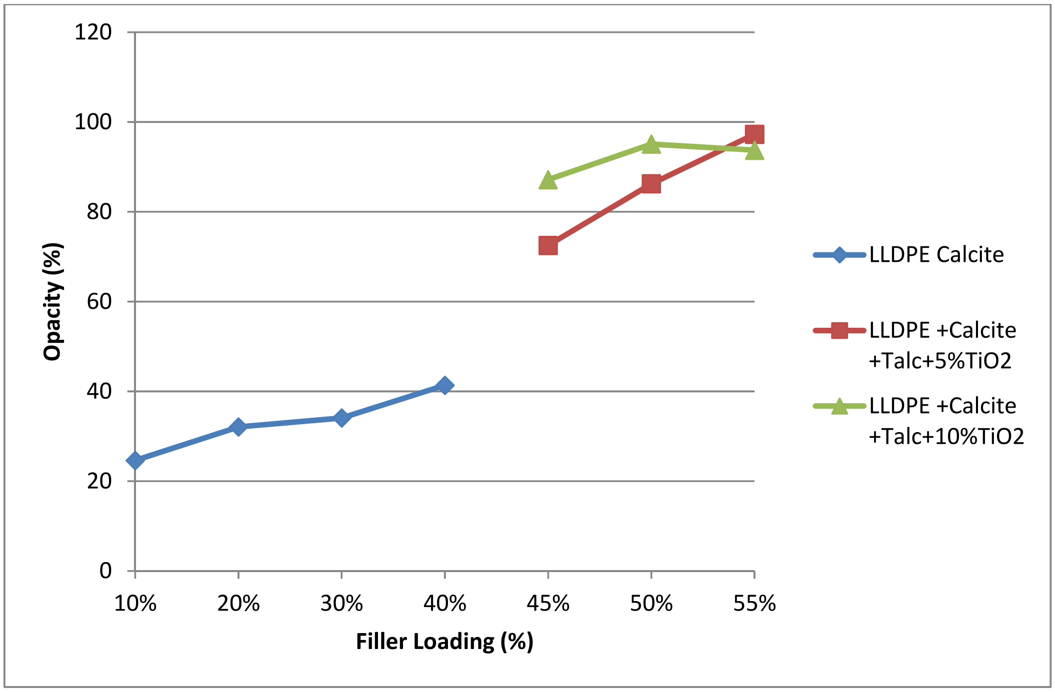


Figure 1 Variations of opacity with filler loading. All formulations content 5% of low molecular weight polyethylene wax.

Whiteness index

Figure 2 shows that the whiteness index value obtained for first four compositions was in the range of 46.28 to 56.73, when coated calcite percentage was increased from 10 to 40(%).The whiteness index value was highest 56.73 for the fourth composition when coated calcite was added at 40% as filler. The value 46.28 was lowest when coated calcite loading was 10%. Whiteness index was increasing with increase in loading. The increase was non linear. There was increase in value nearby 15% when loading was increased from 20 to 30(%). The percentage increase in value was less than 5% when coated calcite percentage was increased from 30 to 40(%).The mixture of talc and coated calcite was also tested for whiteness index. This was observed that for the same percentage of filler when without mixture only coated calcite was used, whiteness index value was little percentage high.

The whiteness index values obtained by these formulations were not acceptable for required applications like labels, writing paper and visiting card. The whiteness index value for such applications should be more than 70.The next compositions with titanium dioxide have been experimented. The whiteness index values were increased significantly with the addition of TiO_2.The whiteness index values were in the range of 65.48 to 77.87 for formulations number 7^{th} to 12^{th}. The increment in whiteness index values was non linear. The maximum value obtained was 77.87 when the loading of filler was 55% and 5% of TiO_2 was used. The whiteness index values obtained were satisfactory with the addition of TiO_2.

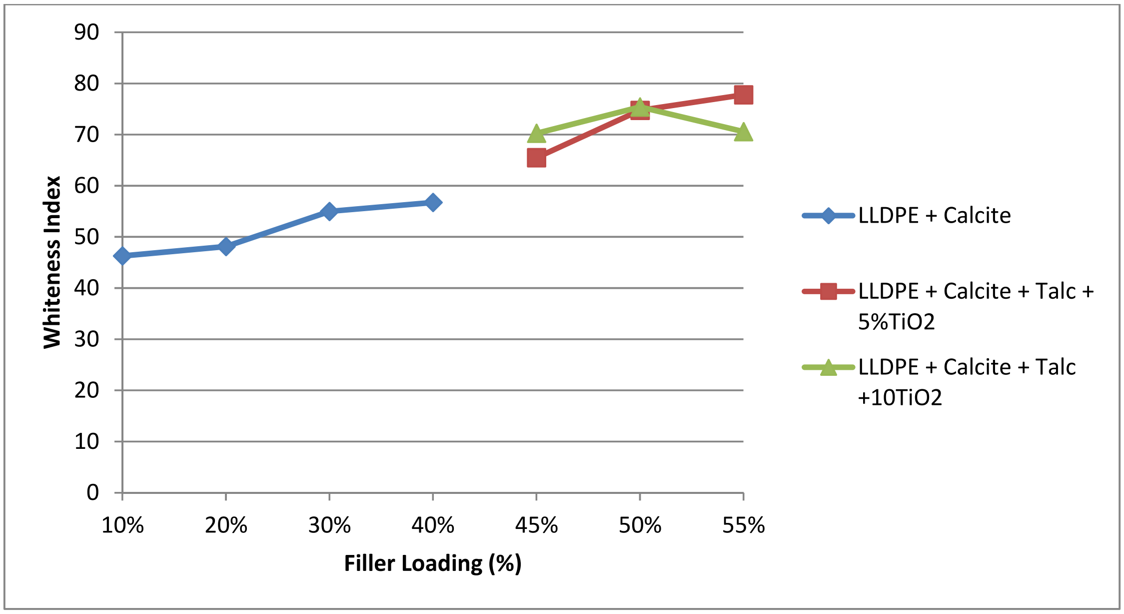


Figure 2 Variations of whiteness index with filler loading. All formulations content 5% of low molecular weight polyethylene wax.

SURFACE GLOSS

The effects of fillers have been observed to surface gloss of the films of various formulations. **Figure 3** shows variations of surface gloss with filler loading. The surface gloss for first four formulations where coated calcite has been increased from 10 to 40(%) is in the range of 4.46 to 2.6. The surface gloss is decreasing as filler content of coated calcite is increasing. The decrease is non linear. Although surface coated calcite has been used for maintaining the surface gloss but with increase in filler content surface irregularities have been increased, which leads to decrease in surface gloss. The talc which contains silica has been used in the next formulations with the mixture of other fillers to observe the effect of talc with the mixture of fillers on the surface gloss of synthetic paper. This was observed that with the mixture of filler, surface gloss was still decreased although talc with 30 and 40(%) of total filler of 30% was used. This may be due to the reason that when mixture of fillers were used surface irregularities increases. The increase in surface irregularities leads to decrease in surface gloss. The talc used individually may have increased the somewhat surface gloss but it needs to be mixed with the other fillers like TiO_2 and coated calcite, which are used for enhancing the opacity and whiteness index. When mixtures of fillers are used with TiO_2, surface gloss has decreased again. The values of surface gloss have been in the range of 1.6 to 1.9.This surface gloss is indicating the matte surface like finish and which is almost equal to the newspapers.

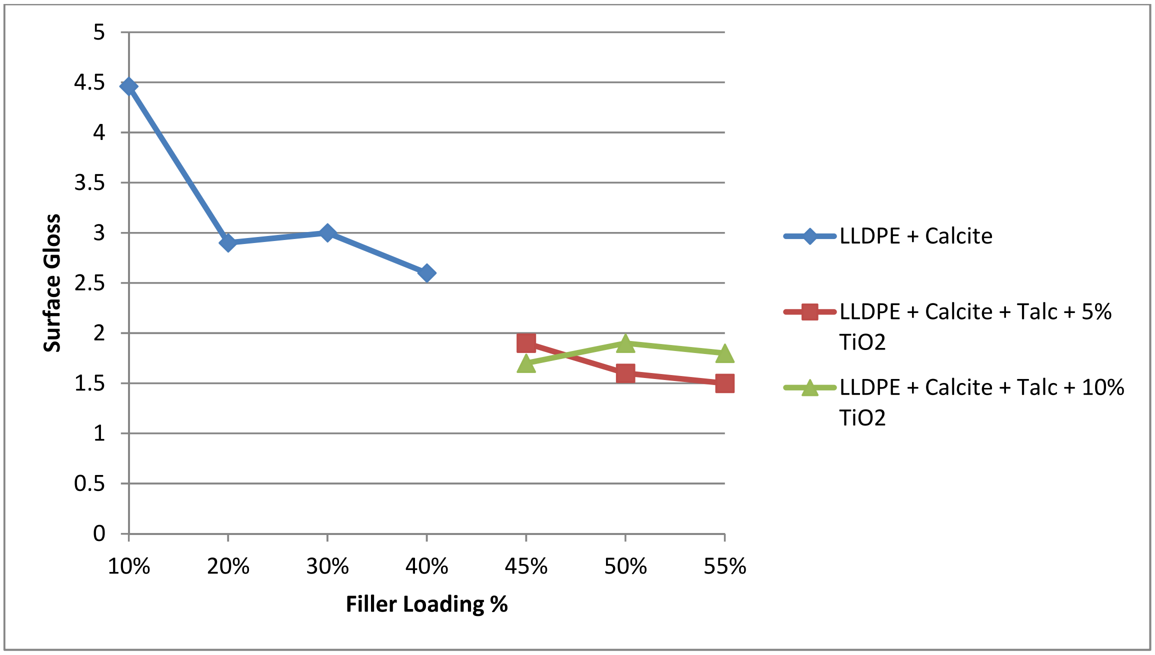


Figure 3 Variations of surface gloss with filler loading. All formulations content 5% of low molecular weight polyethylene wax.

TEAR STRENGTH

Figure 4 shows variations of Tear Strength (in machine direction) and **Figure 5** shows variations of Tear Strength (in transverse direction) with filler loading. The effects of coated calcite, talc and TiO_2 have been analyzed on tear strength of paper like synthetic polymer film. The effects of thickness variation, mixture of filler and loading content have been analyzed. The tear strength in machine direction or stretching direction and transverse direction which is perpendicular to machine directions has been observed. In the first four formulations when coated calcite has been increased from 10 to 40(%), the tear strength has been varied from 7.71 to 5.48 (gmf /microns) in machine direction. The value has been 6.56 to 3.57 in the transverse direction. The thicknesses of the synthetic papers from these formulations have been in the range of 70 to 80 microns. With the increase in loading content the value of tear strength is decreasing except for formulation number (3), this may be attributed to the effect of combination of thickness and loading content. The results obtained are combination of thickness value and loading content. Theoretically with increase in loading of coated calcite tear strength value decreases and with the increase in thickness value tear strength increases. The next formulations number 5th and 6th with mixture of coated calcite and talc has been used to analyze the tear strength. The tear strength values have been decreased from earlier formulations. The values have been 4.03 and 4.80 (gmf/microns) when talc in 30 and 40(%) with total of 30% filler has been used. This decrease in value is due to increase in loading as well as mixed effect of talc and coated calcite. The compositions from number 7th to 12th in which TiO_2 has been added to enhance the opacity have been analyzed for tear strength. The thicknesses values of these papers like films have been more than earlier thickness values. The thickness value has been in the range of 90 to 120 microns. The tear strength value ranges from 11.63 to 21.24 (gmf/microns) in machine or stretching direction. The tear strength value 11.63(gmf/microns) is at 55% loading and at thickness of 100 microns. This value is also quite acceptable and of good quality. The tear strengths values for paper like synthetic polymer films are much better compared to conventional cellulosic paper. The tear strength values in transverse direction are less comparable to stretching direction, when stretching is performed, there is alignment of chains in particular direction and these alignments of chains opposes strongly the forces which are applied to tear out.

TENSILE STRENGTH

Figure 6 shows variations of Tensile Strength (in machine direction) and **Figure** 7 shows variations of Tensile Strength (in transverse direction) with filler loading. The effects of coated calcite and mixture of coated calcite with talc and TiO_2 have been analyzed on the tensile strength of synthetic paper. In the first four formulations coated calcite has been increased from 10 to 40% to observe the effect on tensile strength. The thicknesses of these papers like films have been for these four formulations in the range of 70 to 80 microns. The tensile strength in stretching direction when coated calcite has been increased from 10 to 40 (%) is in the range of 136.42 to 108.54 (kgf/cm^2). The value of tensile strength is decreasing. The decrease in tensile strength is due to increase in filler content of coated calcite, as with increase in filler content they get incorporated into the chains of LLDPE thus decreasing the ability to resist pulling forces although the thickness of paper like synthetic polymer films have been varied. The effect of this small variation is insignificant on tensile strength. The tensile strength values in transverse direction for above formulations have been from 107.97 to 84.51(kgf/cm^2) when coated calcite percentages has been increased from 10 to 40(%) respectively. The tensile strength values in transverse direction are comparatively significant less as compared to stretching direction. This is due to the reason that during stretching polymer molecular chain alignment occurs which leads to more tensile strength as compared to un stratched in the transverse direction. The formulation number 5th and 6th have been prepared to observe the effect on tensile strength of mixture of coated calcite and talc. Total loading of fillers has been kept 30% in which 30 and 40 (%) of talc has been used. The tensile strength value has been decreased when mixture of talc and coated calcite has been used. The decrease in tensile strength has been observed in both machine direction and transverse direction. The next formulations in which there was need to enhance the opacity and whiteness index the rutile grade TiO_2 was used. This was clear from above formulations with their tensile strengths values; the mixture of fillers as well as increase in filler content was resulting in decrease in strength. But as there was need to increase in opacity and whiteness index so other option left was to increase the thickness under acceptable limit to compensate for decrease in strength. The thickness has been increased in the next formulations to have acceptable strength. These formulations have been with the thickness of 90 to 120 microns. The tensile strength value obtained is combined effect of percentage content of filler and thickness of paper like synthetic polymer film. The tensile strength value obtained in stretching direction is from 150.19 to 95.26 (kgf/cm^2). The strength is 150.19 kgf/cm^2 when thickness is 120 microns and loading of filler is 45% and value of 95.26 kgf/cm^2 is at 100 microns and 50% loading.

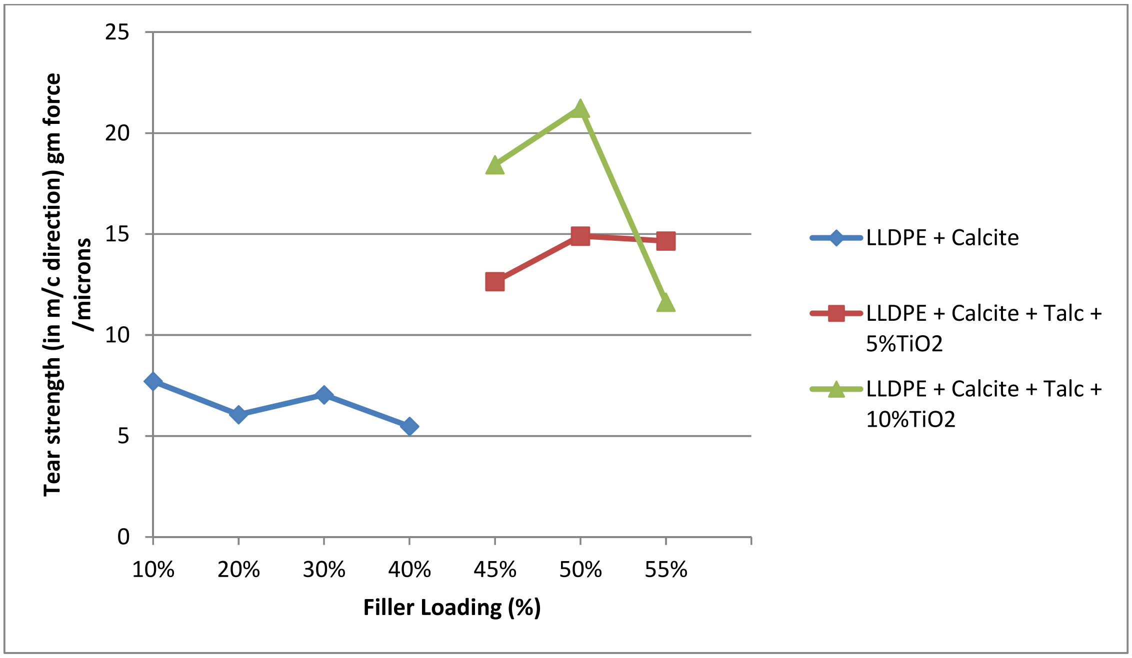


Figure 4 Variations of Tear Strength (in machine direction) with filler loading. All formulations content 5% of low molecular weight polyethylene wax.

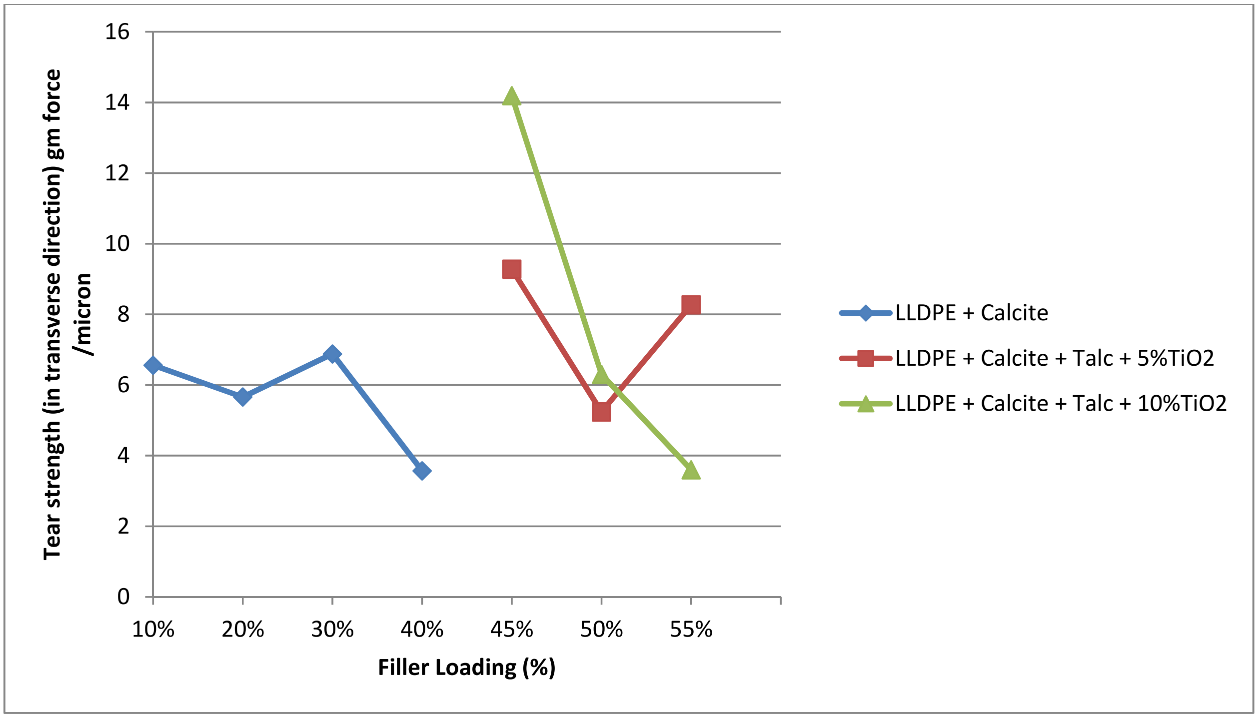


Figure 5 Variations of Tear Strength (in transverse direction) with filler loading. All formulations content 5% of low molecular weight polyethylene wax.

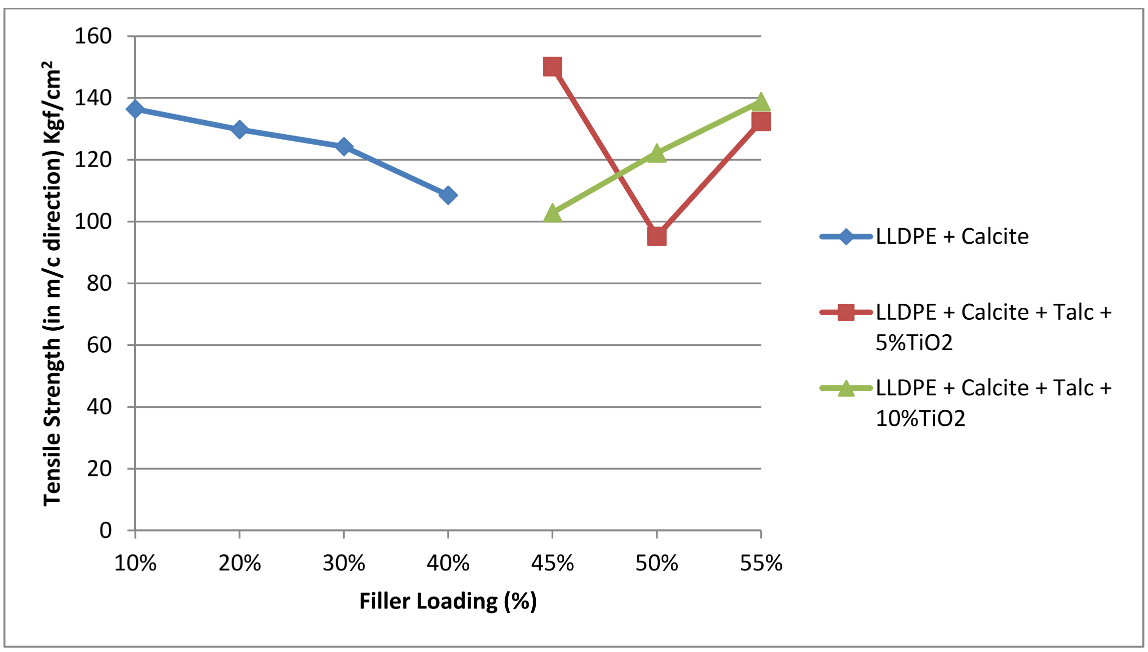


Figure 6 Variations of Tensile Strength (in machine direction) with filler loading. All formulations content 5% of low molecular weight polyethylene wax.

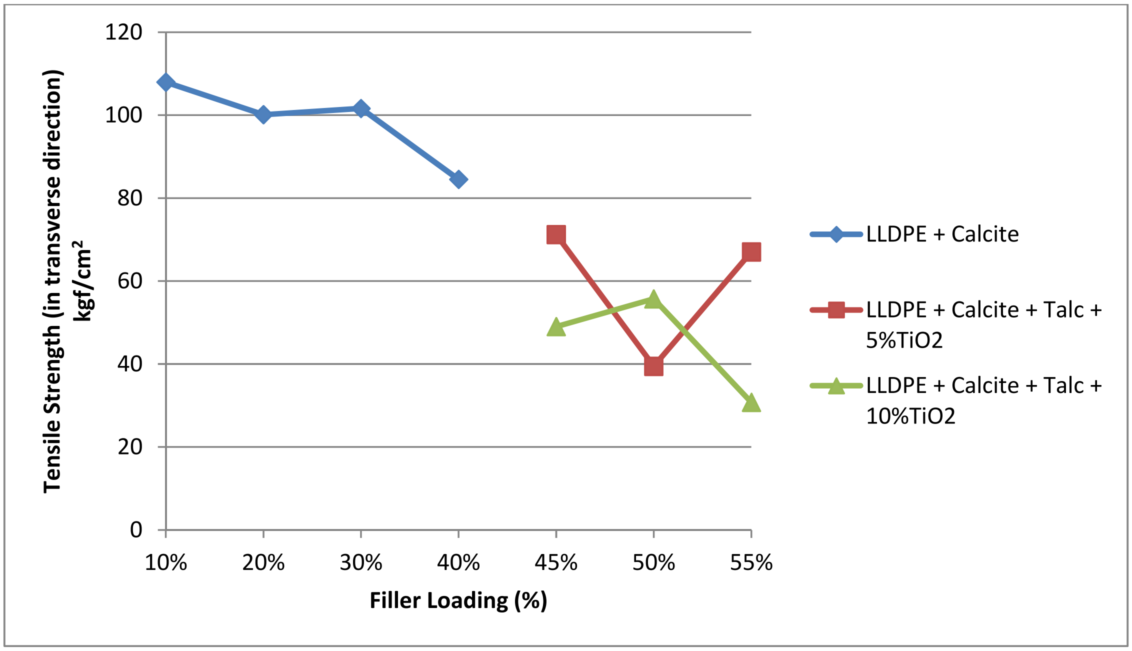
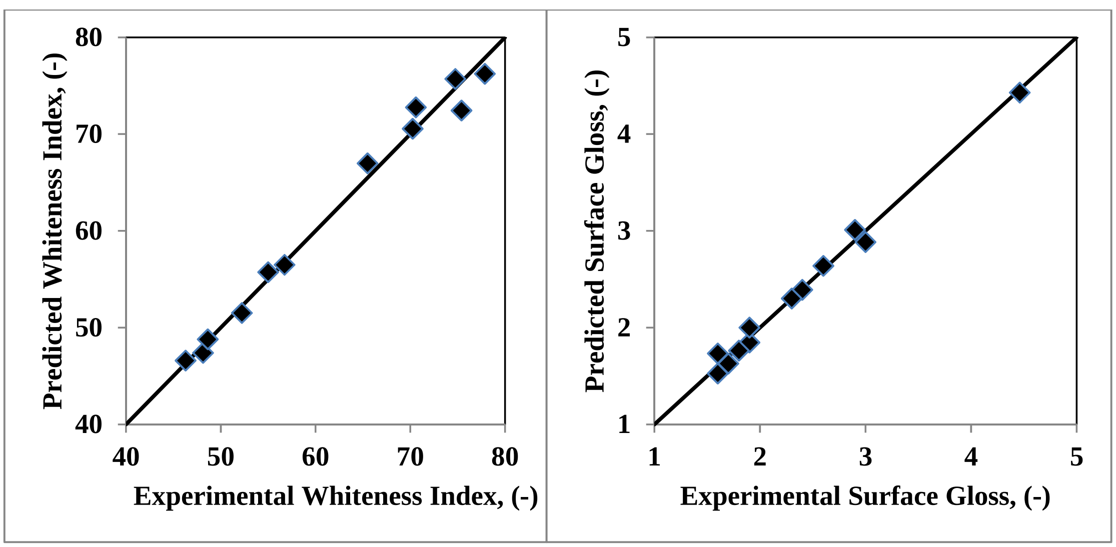


Figure 7 Variations of Tensile Strength (in transverse direction) with filler loading. All formulations content 5% of low molecular weight polyethylene wax.

Mathematical modeling and optimization process

The actual design by the experimentation was obtained as shown in the table. Variation in whiteness index, opacity, tear strength, tensile strength and surface gloss is shown in figures. The results in the model fit summary are shown in table. Second order polynomial for the description of the properties is used. This model is most suitable for describing properties. Second order polynomial has shown lowest standard deviation for all the parameters. The model constant for all the parameters are reported in table no8. The parity plots are shown in **figure 8**. It can be seen that except tensile strength all other parameters has been reasonably predicated.



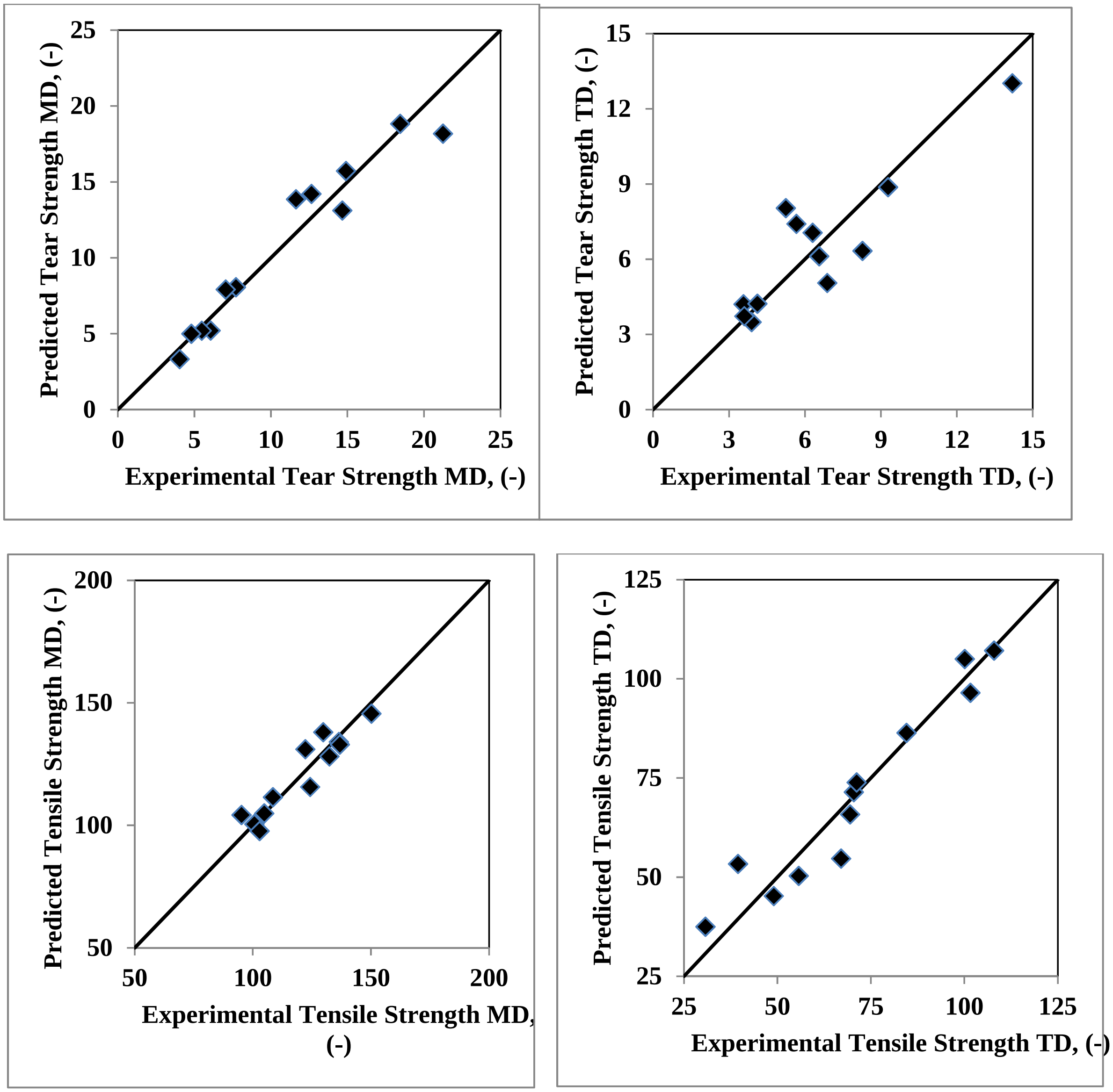


Figure8: Parity plot (A) Whiteness Index (B) Surface Gloss (C) Tear Strength MD (D) Tear Strength TD (E) Tensile Strength MD (F) Tensile Strength TD

TABLES

Effects of Fillers on Opacity

Serial number	Compositions	Thickness(microns)	Opacity (%)
01	LLDPE-85,Calcite-10	74	24.61
02	LLDPE-75 ,Calcite-20	70	32.07
03	LLDPE-65 ,Calcite-30	75	34.07
04	LLDPE-55, Calcite-40	80	41.35
05	LLDPE-65, Mixture-30, Calcite-70, Talc-30	75	38.53
06	LLDPE-65, Mixture-30, Calcite-60, Talc-40	68	33.90

07	LLDPE-50,Mixture-45, Calcite-70, Talc-25,TiO_2-5	120	72.52
08	LLDPE-50,Mixture-45, Calcite-70, Talc-20,TiO_2-10	90	87.15
09	LLDPE-45,Mixture-50, Calcite-70, Talc-25,TiO_2-5	100	86.23
10	LLDPE-45,Mixture-50, Calcite-70, Talc-20,TiO_2 -10	110	95.08
11	LLDPE-40,Mixture-55, Calcite-70, Talc-25,TiO_2-5	105	97.28
12	LLDPE-40,Mixture-55, Calcite-70, Talc-20,TiO_2-10	100	93.73

Table 1 showing the effects of fillers on opacity of synthetic papers. All formulations contain 5% of low molecular weight polyethylene wax

Effects of fillers on Whiteness index:

Serial number	Compositions	Thickness(microns)	Whiteness index
01	LLDPE-85,Calcite-10	74	46.28
02	LLDPE-75 ,Calcite-20	70	48.12
03	LLDPE-65 ,Calcite-30	75	54.99
04	LLDPE-55, Calcite-40	80	56.73
05	LLDPE-65, Mixture-30, Calcite-70, Talc30	75	52.23
06	LLDPE-65, Mixture-30, Calcite-60, Talc40	68	48.61
07	LLDPE-50,Mixture-45, Calcite-70, Talc-25,TiO_2-5	120	65.48
08	LLDPE-50,Mixture-45, Calcite-70, Talc-20, TiO_2-10	90	70.25
09	LLDPE-45,Mixture-50, Calcite-70, Talc-25, TiO_2-5	100	74.74
10	LLDPE-45,Mixture-50, Calcite-70,	110	75.40

	Talc-20, TiO_2-10		
11	LLDPE-40,Mixture-55, Calcite-70, Talc-25, TiO_2-5	105	77.87
12	LLDPE-40,Mixture-55, Calcite-70, Talc-20, TiO_2-10	100	70.58

Table 2 showing the effects of fillers on whiteness index. All formulations contain 5% of low molecular weight polyethylene wax

Effects of fillers on surface gloss of synthetic papers:

Serial number	Compositions	Thickness(microns)	Surface gloss
01	LLDPE-85,Calcite-10	74	4.46
02	LLDPE-75 ,Calcite-20	70	2.9
03	LLDPE-65 ,Calcite-30	75	3.0
04	LLDPE-55, Calcite-40	80	2.6
05	LLDPE-65, Mixture-30, Calcite-70, Talc30	75	2.4
06	LLDPE-65, Mixture-30, Calcite-60, Talc40	68	2.3
07	LLDPE-50,Mixture-45, Calcite-70, Talc-20, TiO_2-5	120	1.9
08	LLDPE-50,Mixture-45, Calcite-70, Talc-20, TiO_2-10	90	1.7
09	LLDPE-45,Mixture-50, Calcite-70, Talc-25, TiO_2-5	100	1.6
10	LLDPE-45,Mixture-50, Calcite-70, Talc-20, TiO_2-10	110	1.9
11	LLDPE-40,Mixture-55, Calcite-70, Talc-25, TiO_2-5	105	1.6
12	LLDPE-40,Mixture-55, Calcite-70, Talc-20, TiO_2-10	100	1.8

Table 3 showing the effects of fillers on surface gloss of synthetic paper. All formulations contain 5% of low molecular weight polyethylene wax

Effects of fillers on tear strength:

Serial number	Formulation (%)	Average thickness (micron)	Tear strength	
			MD	TD
01	LLDPE-85,Calcite-10	74	7.71	6.56
02	LLDPE-75,Calcite-20	70	6.06	5.66
03	LLDPE-65,Calcite-30	75	7.04	6.88
04	LLDPE-55,Calcite-40	80	5.48	3.57
05	LLDPE-65,Total-30 Calcite-70,Talc-30	75	4.03	3.89
06	LLDPE-65,Total-30 Calcite-60,Talc-40	68	4.80	4.12
07	LLDPE-50,Mixture-45, Calcite-70, Talc-20, TiO_2-5	120	12.65	9.28
08	LLDPE-50,Mixture-45, Calcite-70, Talc-20, TiO_2-10	90	18.44	14.19
09	LLDPE-45,Mixture-50, Calcite-70, Talc-25, TiO_2-5	100	14.90	5.24
10	LLDPE-45,Mixture-50, Calcite-70, Talc-20, TiO_2-10	110	21.24	6.3
11	LLDPE-40,Mixture-55, Calcite-70, Talc-25, TiO_2-5	105	14.66	8.27
12	LLDPE-40,Mixture-55, Calcite-70, Talc-20, TiO_2-10	100	11.63	3.6

Table 4 showing the effects of fillers on tear strength of synthetic papers. All formulations contain 5% of low molecular weight polyethylene wax

Serial number	Formulation (%)	Average thickness (micron)	Tensile strength	
			MD	TD
01	LLDPE-85, Calcite-10	74	136.42	107.97
02	LLDPE-75, Calcite-20	70	129.79	100.12
03	LLDPE-65, Calcite-30	75	124.28	101.62

04	LLDPE-55, Calcite-40	80	108.54	84.51
05	LLDPE-65, Total-30 Calcite-70,Talc-30	75	100.66	69.45
06	LLDPE-65, Total-30 Calcite-60,Talc-40	68	104.83	70.45
07	LLDPE-50,Mixture-45, Calcite-70, Talc-20, TiO_2-5	120	150.19	71.19
08	LLDPE-50,Mixture-45, Calcite-70, Talc-20, TiO_2-10	90	102.89	49.02
09	LLDPE-45,Mixture-50, Calcite-70, Talc-25, TiO_2-5	100	95.26	39.46
10	LLDPE-45,Mixture-50, Calcite-70, Talc-20, TiO_2-10	110	122.21	55.72
11	LLDPE-40,Mixture-55, Calcite-70, Talc-25, TiO_2-5	105	132.43	67.04
12	LLDPE-40, Mixture-55, Calcite-70, Talc-20, TiO_2-10	100	136.86	30.76

Table 5 showing the effects of fillers on Tensile strength of synthetic papers. All formulations contain 5% of low molecular weight polyethylene wa

Temperature profiles

Formulations	**Zone 1 (°C)**	**Zone 2 (°C)**	**Zone 3 (°C)**	**Zone 4 (°C)**
01, 02, 03, 05, 06	150	170	190	210
04	160	180	200	220

Table 6 showing the temperature profiles in different zones in twin screw extruder during compounding for compositions 01 to 06.

Formulations	**Zone 1 (°C)**	**Zone 2 (°C)**	**Zone 3 (°C)**	**Zone 4 (°C)**
07, 08, 09, 10,	165	185	205	220
11,12	170	190	210	225

Table7 showing the temperature profiles in different zones in twin screw extruder during compounding for compositions 07 to 12.

Zone 1-Feeding zone
Zone2- Compression zone
Zone3-Metering zone
Zone4-Die temperature

Mathematical Modeling and Optimization

Model Equation:

$$y = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5 + a_6x_1^2 + a_7x_2^2 + a_8x_3^2 + a_9x_4^2 + a_{10}x_5^2$$

Sr. No.	Model Parameter	Whiteness Index	Surface Gloss	Tear Strength M.D	Tear Strength TD	Tensile Strength MD	Tensile Strength TD
1	a_1	-63.22	4.60	146.09	111.65	-298.58	273.36
2	a_2	-223.50	-47.18	-424.63	40.61	2035.04	215.22
3	a_3	-600.78	-67.12	-686.29	135.95	1992.49	-497.25
4	a_4	-157.19	-109.63	103.41	1149.29	1655.10	91.07
5	a_5	5.24	0.45	3.65	-1.56	-18.21	-2.99
6	a_6	-171.04	-22.99	-345.12	-23.76	1407.79	-29.76
7	a_7	-144.31	22.25	117.66	81.48	-734.69	-94.85
8	a_8	2853.09	286.88	3007.28	-790.45	-5558.66	3594.59
9	a_9	1632.94	1522.68	-79.18	-16032.40	-7503.62	-2523.58
10	a_{10}	-0.03	0.00	-0.02	0.01	0.10	0.02
22	R^2 (Expt and model)	0.9930	0.9952	0.9686	0.8916	0.9393	0.9610

Table 8 Model constant

References

1. Alex Sacher, U.S Patent 3,015,577, (Jan.02, 1962).
2. Le Roux Byron, Taylor Michael William, WO2002102593 A1 (27 Dec
3. Owen D Mosher, Leon J Paquin, Glenn M Violette , U.S Patent 3196063 A (20 July 1965)
4. Kawazoe Shiro, Tani Kaneyasu, U.S Patent 3730667 A, (1 May 1973)
5. Ichihara W, Imoto S, Kawazoe S, Nagai T,Noguchi H, Tani K, Yamada B, Yamada F US Patent 3850667 A, (26 Nov 1974)
6. Shinoki Takanori , EP0235820 A1, (9 Sep 1987)
7. William H. Hoge , U. S Patent 4350655 (21 Sep 1982)
8. Donal W. Lare U.S Patent (20 Sep 1977)