ISPARTA UYGULAMALI BİLİMLER ÜNİVERSİTESİ

Turkish Journal of Forestry | Türkiye Ormancılık Dergisi
2022, 23(1): 51-57 | Research article (Araştırma makalesi)

Investigation of differently coated corrugated cardboard in terms of electrophotographic print chroma and hue angle

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Abstract: Paper-Cardboard production sector renews itself day by day and evaluates alternative options to increase quality. At the same time, it has closely adapted to technological developments in the printing industry and has now managed to enter every home or office thanks to digital printing. Digital printing (inkjet-electrophotographic) has come to a level where it can replace some conventional printing techniques as a result of the quality prints it provides. Considering the ease of use and cost advantage, it becomes inevitable that this printing technique is one of the most common printing methods. In this study, the properties of corrugated cardboard with different coating properties in electrophotographic printing are investigated with parameters such as printing chroma, hue angle and gloss values. According to the results of the research, it is determined that corrugated cardboards coated with precipitated calcium carbonate (PCC) gave more positive results in terms of both optical properties and electrophotographic print quality.
Keywords: Precipitated calcium carbonate (PCC), Eggshell calcium carbonate (ECC), Ground calcium carbonate (GCC), Electrophotographic printing, Corrugated cardboard

Farklı kaplanmış oluklu mukavva kartonların elektrofotoğrafik baskı kroma ve ton açısı bakımından incelenmesi

Özet: Kâğıt-Karton üretim sektörü her geçen gün kendini yenilemekte ve kaliteyi arttırmak için alternatif seçenekleri değerlendirmektedir. Aynı zamanda baskı sektörü de teknolojik gelişmelere sıkı bir şekilde uyum sağlamış ve dijital baskı sayesinde artık her eve ya da her ofise girebilmeyi başarmıştır. Dijital baskı (inkjet-elektrofotografik) verdiği kaliteli baskılar sonucunda artık bazı konvansiyonel baskı tekniklerinin yerini alabilecek düzeye gelmiştir. Kullanım kolaylığı ve maliyet avantajı da göz önünde bulundurulduğunda bu baskı tekniğinin en yaygın baskı yöntemlerinden biri olması kaçınılmaz hale gelmektedir. Bu çalışmada farklı kuşeleme özelliğine sahip oluklu mukavva kartonların baskı kroma, hue angle ve gloss değerleri gibi parametrelerle elektrofotografik baskıdaki özellikleri incelenmiştir. Araştırma sonuçlarına göre PCC ile kuşelenen oluklu mukavva kartonların hem optik özellikler açısından hem de elektrofotografik baskı kalitesi açısından daha olumlu sonuçlar verdiği belirlenmiştir.
Anahtar kelimeler: Çökeltilmiş kalsiyum karbonat (PCC), Yumurta kabuğu kalsiyum karbonat (ECC), Öğütülmüş kalsiyum karbonat (GCC), Elektrofotografik baskı, Oluklu mukavva karton

1. Introduction

Paper, which is one of the most produced and consumed materials in the world and where the development in production and consumption in the countries immediately affects other countries, has an important strategic position in our country as well (Sayın and Malayoğlu, 2001)

The prevalence of usage makes paper one of the products with high social and economic impacts. However, due to its nature, paper cannot be supplied from nature as a material that can be used directly, it emerges by being produced from different raw materials and in different ways with human labor and knowledge (Atik and Ok, 2017).

Paper products today are used in printing, packaging, health, cleaning, etc. It is in a location that we can easily reach in order to make our lives easier in areas. Today, paper is needed for the healthy preservation of foods or for the safe transportation of products.

Corrugated cardboard is a durable paper material due to its construction. It consists of two paper layers, which we call testliner and fluting, and these papers are generally produced in 115 g/m^2 weight. The testliner layer and the fluting layer are cut into suitable sizes using an adhesive material (usually starch). It is generally used for packaging purposes. (Çiçekler et al., 2014).

The use of calcium carbonate has increased further in the last decade and has been approved in the alkaline papermaking process, particularly in Europe. It has taken a large place in the filler and white pigment markets (Harben, 1998). PCC is a type of calcium carbonate that can be produced by chemical processes at a temperature of 900 ºC and under a certain pressure with the desired particle shape

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✓ **Received** (Geliş tarihi): 03.02.2022, **Accepted** (Kabul tarihi): 18.03.2022

Citation (Atıf)**:** Yılmaz, U., Kıllı, U., Kurt, M.B., Tutuş, A., Sönmez, S., 2022. Investigation of differently coated corrugated cardboard in terms of electrophotographic print chroma and hue angle. Turkish Journal of Forestry, 23(1): 51-57. DOI: 10.18182/tjf.1067727

and desired particle size and controllable particle size distribution (Tutuş et al., 2018). GCC can be used in multiple industry applications. If it is produced in appropriate quality standards and logistics opportunities are provided to open to the world market, it can be sold as a product with a high profit level (Ercan et al., 2018). ECC is an inexpensive type of $CaCO_3$ obtained from egg shells. In addition to being used as a filler, it can also be used as a surface coating. The size of ECC used in paper production is 5-190 µm, GCC is around 0.8-8.9 µm, and PCC is around 0.9-6.3 µm. With these values, it is seen that the particle size of the ECC material is larger, while PCC and GCC are close in size (Tutuş et al., 2020). Images of the coated materials used in the study are given in Figure 1 below.

Considering the surface properties of corrugated cardboard, it is seen that the most suitable printing type to be used is flekso printing. The reason why the printing type used for this sector is flekso printing is that the printing plate is elastic and the image can be transferred to the rough surface better than other printing types. The working principle of flekso printing is given in Figure 2 below.

1.1. Digital electrophotographic printing and colors

Today, the digital printing system, which provides benefits in terms of both time saving and cost in the printing industry, is moving towards being an alternative to all printing systems. By eliminating many intermediate elements, it transfers the image on the computer screen to the printing material without the need for any mold.
Digital printing It is a type of printing that can provide high quality, economical and personalized prints for low trajectory jobs. There are two primary digital printing technologies. The first is the technology that we call inkjet printing, which prints by spraying ink on the paper surface. The second is digital electrophotographic printing, which enables the transfer of small particles, which we call toner, to the surface of the printing material with an electric charge. (Özomay, 2021). The working principle of electrophotographic printing is shown in Figure 3 below.

Cardboard coating is generally applied for reasons such as reducing costs, increasing surface strength, and improving print quality (Sönmez, 2008; Gutierrez et al., 2009).

In this study, it has been investigated which surface coated material for corrugated cardboard gives more suitable results for digital electrophotographic printing.

Figure 1. Used ECC, GCC and PCC materials for coating (Tutuş et al., 2020)

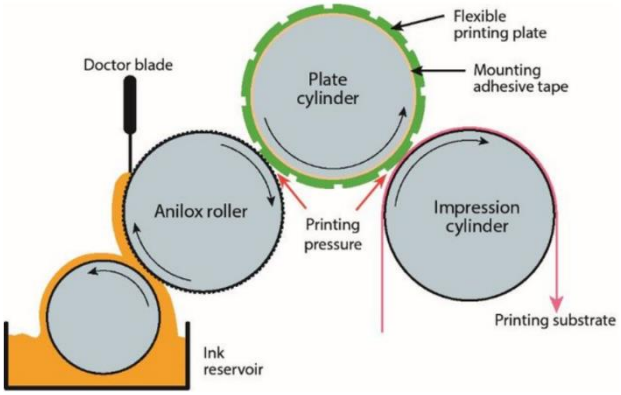

Figure 2. Flexo printing principle (Valdec et al., 2017)

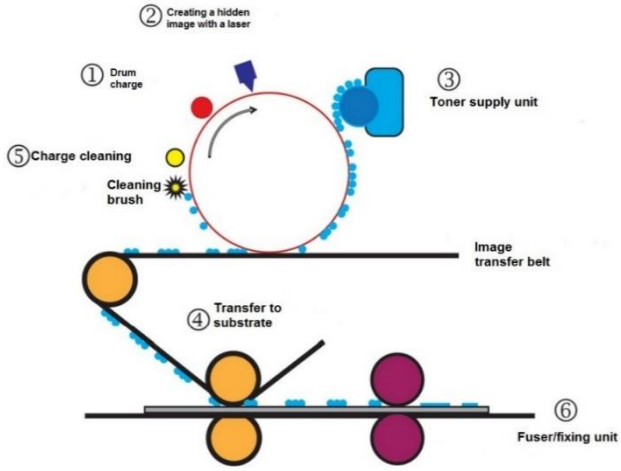

Figure 3. Electrophotographic printing principle (Şahinbaşkan, 2018)

2. Material ve Method

2.1. Material

In this study, 115 g/m^2 testliner paper is used for printing. ECC, GCC and PCC are used as surface coated materials. These materials used are obtained from Kahramanmaraş Sütçü İmam University Paper Production Laboratory.

2.2. Method

2.2.1. Starch preparation (15% g/ml)

30 g starch is weighed into a 250 ml beaker and 170 g distilled water is added. The starch is mixed until homogeneously dissolved and placed on the magnetic heater. The starch is stirred in the magnetic heater until it boils.

2.2.2. $CaCO_3$ preparation (ECC, GCC, PCC) (%50 g/ml)

Weigh 200 g of ECC, GCC or PCC in a 500 ml beaker and add 200 g of distilled water. The mixture is mixed homogeneously for 10 minutes.

2.2.3. Preparation of coated milk

34.68 g 50% $CaCO_3$, 17.33 g 15% starch, 0.06 g CMC (Carboxymethyl Cellulose) these materials are mixed homogeneously in a 100 ml beaker. The obtained coated milk is applied to the paper surface in 3 repetitions at a pressure of 4.5 bar and a speed of 3.30 m/min in the size press device. The coated papers are left to dry at room temperature. The size-press device used for coating is given in Figure 4 below.

2.2.4. Physical and optical testing

The physical and optical values of the papers obtained after the coating process are determined by adhering to the standards given in Table 1 below.

Figure 4. Size press coating machine

Table 1. Standard of physical and optical test

Optical and physical tests	Standards
Grammage (g/m^2)	TAPPI T 410 om-88
Breaking length (m)	TAPPI T 494 om-01
Burst index (kPa m^2/g)	TAPPI T 403 om-91
Tear index (mN.m^2.g)	TAPPI T 414 om-88
Brightness (%ISO)	ISO/DIS 2470
Whiteness (% ISO)	ISO 11475
Yellowness (E313)	ASTM E313
CIE Whiteness (D65/10°)	ISO 11475

2.2.5. Printing process and color measurement

After the coating process, laser prints are made on corrugated cardboard with Canon I Sensys LBP613CDW printing machine. Color measurements of the prints are made using the X-Rite eXactTM Spectrophotometer (D50 illuminant, 2° observer, 0°/45° geometry, black backing) and adhering to the ISO/IEC 19752:2017 standard.

It is calculated according to the formula below.

$$C_{ab} = \sqrt{a^{*2} + b^{*2}} \quad (1)$$

Hue angle is calculated according to the formula below (Yılmaz et al., 2021);

$$h_{ab} = arctan\left(\frac{b^*}{a^*}\right) \quad (2)$$

3. Results and discussion

Some physical and optical properties of corrugated cardboard are given in Table 2 below.

When analyzed in Table 2, it is seen that PCC has a more positive effect on the optical properties of corrugated cardboard. It is seen that the GCC material gives more positive results on the optical properties than the ECC material, while the breaking length of the base paper is 3418, while this value is 3140 m, 2476 m and 3438 m for ECC, GCC and PCC, respectively. It is determined that the GCC material had a negative effect on the breaking length. When the surface roughness values are examined, the values of ECC, GCC and PCC are found to be 3.01, 1.86 and 1.18, respectively. Since the particle size of the PCC material is small, its capacity to fill the gaps between the cellulose fibers is higher than other coated materials, and therefore the surface roughness is lower. Considering the $COBB_{60}$ value, the value which is 110 g/cm^2 in the base paper decreased significantly after the coating process. Looking at the $COBB_{60}$ values, it is seen that the value of ECC is 60 g/cm^2, that of GCC is 74 g/cm^2, and that of PCC is 96 g/cm^2. It is seen that these results are consistent with the information obtained in the literature (Tutuş et al., 2020; 2018; 2013; 2012).

In Figure 5 below, the variation of the surface contact angles of different coated papers over time is given.

The drop volume image of the materials used as surface coating is given in Figure 5 below.

Table 2. Some physical and optical properties of corrugated cardboard

Item	Control paper	ECC	GCC	PCC
Grammage (g/m^2)	112	112	112	112
Brightness ISO (%)	24.18	45.93	47.31	64.16
CIE whiteness ISO (%)	-52.59	16.96	27.55	59.84
Whiteness ISO (%)	32.82	49.90	51.47	65.42
Yellowness (E313)	38.71	15.65	11.96	2.95
Surface roughness (Ra)	2.61	3.01	1.86	1.18
Breaking length (m)	3418	3140	2476	3438
Burst index (kPa m^2 /g)	1.64	1.65	1.22	1.68
Tear index (mN.m^2 /g)	6.28	5.39	4.40	5.25
$COBB_{60}$ (g/cm^2)	110	60	74	96
Surface angle (º)	41.99	39.10	26.98	21.17

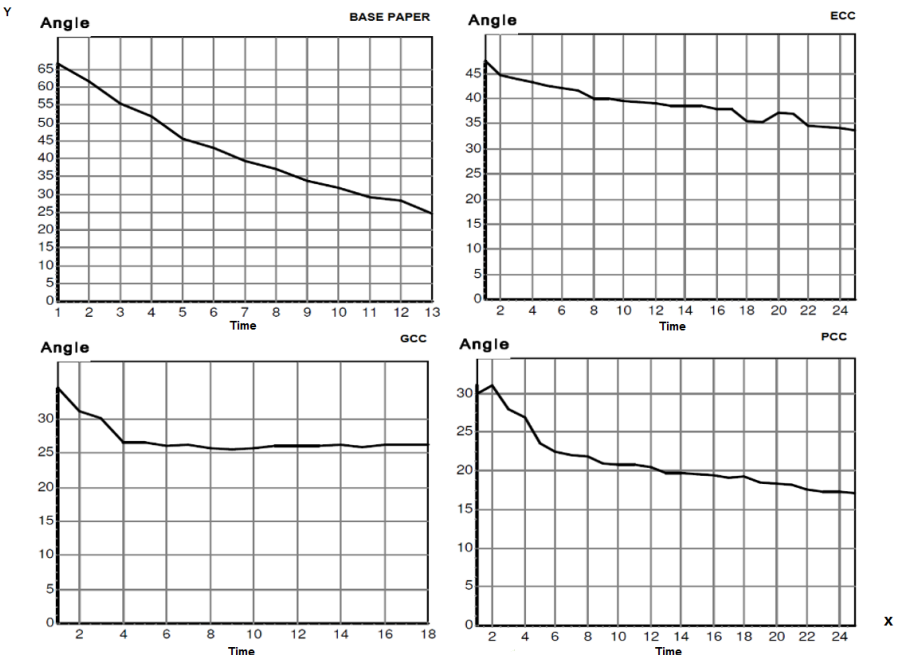

Figure 5. Change of surface contact angles of different coated papers over time

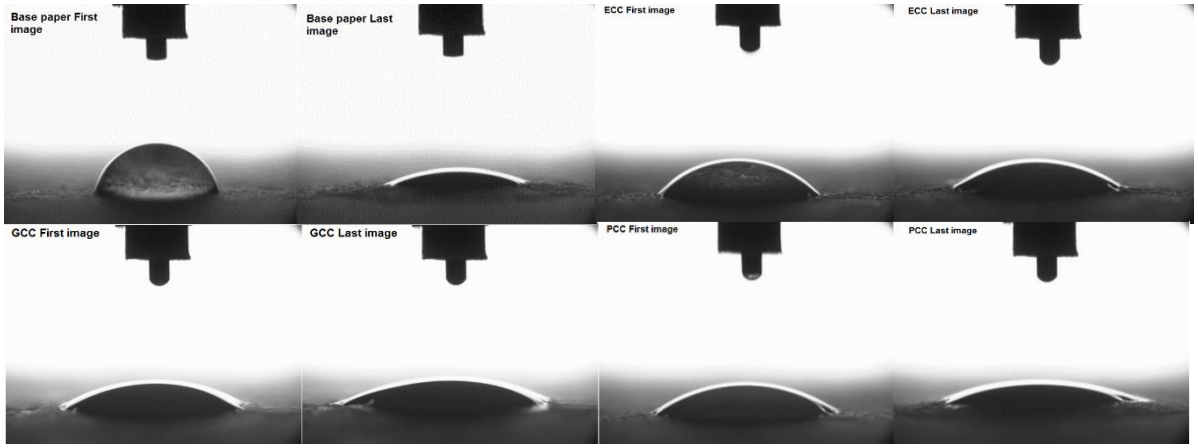

Figure 6. Drop volume images showing the time-dependent change of surface contact angles of different coated papers

When Figure 5 and Figure 6 are examined, it can be seen that the surface contact angle on the control paper decreases regularly depending on time. The contact angle, which is initially measured at approximately 66°, decreased to 25°. In ECC coating, while the initial contact angle is at 47º levels, it is seen that the contact angle determined in the final image is balanced at 34º levels. While the first measurement of the surface contact angle in GCC coating is at 38º levels, it is observed that it stabilized at 25º-27º levels in the future. While the first surface contact angle of PCC coated paper is measured as 30º, it increased to 32º levels in the first place, but the contact angle decreased and stabilized at 17º levels in the following periods. When the obtained graphics and images are examined, it is seen that ECC coated corrugated cardboard is more hydrophobic, whereas PCC coated corrugated cardboard is more hydrophilic.

The term chroma means color saturation, the purity of a color on the color wheel. Chroma is also known as chromaticity in the brightness of a luminous area that appears as translucent or white. (Dini et al., 2019). For a good print quality, chroma and color gamut are expected to be high (Sönmez, 2011).

Electrophotographic chroma values of the materials used as surface coating are given in Table 3 below.

When Table 3 is examined, it is seen that naturally the lowest chroma value in CMY colors is in the control paper. It is seen that the sample with the lowest chroma value belongs to the ECC material. The highest chroma value is found in PCC coated material. It is seen that there is an inverse proportion with this situation in the chroma values of the black color. It can be seen that the highest chroma value of black color is found on ECC coated paper and the lowest value is found on PCC coated paper. The values obtained for ECC, GCC, PCC coated papers are respectively %37.58, %43.13, %47.01 for cyan, %49.41, %52.33, %55.09 for magenta, %57.70, %63.52, %66.45 for yellow, %3.16, %1.50, %1.01 for black showed in Table 2. When this situation is considered in general, it is seen that the best chroma color value is obtained on PCC coated papers.

Table 3. Electrophotographic chroma values of the materials used as surface coating

Color	Control	ECC (%)	GCC (%)	PCC (%)
Cyan	29.76	37.58	43.13	47.01
Magenta	47.66	49.41	52.33	55.09
Yellow	54.22	57.70	63.52	66.45
Black	4.65	3.16	1.50	1.01

Hue angle is the measurable angle of the color value. All possible color changes can be easily calculated using the 360º hue angle formula. Hue angle can change depending on the situation where a color is blue, green and red. Hue angle is blue if it is 270º, if 180º green, if 90º yellow and if 0º red. The diagram in which the colors are ordered according to the tone angle is given in Figure 7 below.

The hue angles of electrophotographic printing are given in Table 4 below.

When the values given in Table 4 are examined, it is seen that the coated material with the highest hue angle in cyan color is PCC with 63.26º, and the coated material with the lowest hue angle is ECC with a value of 57.33º. The cyan hue angle of the control paper is calculated as 49.52º, and the cyan hue angle of the GCC coated material is calculated as 61.95º. In the hue angle of the magenta color, the opposite angle value is calculated. It is seen that the coated material with the highest hue angle is ECC with 13.90º, and the lowest hue angle is PCC coated material with 8.89. Other color angles of ECC, GCC and PCC coated materials are determined as 89.62º, -86.25º, -85.04º in yellow, 47.95º, 21.45º, -5.09º in black, respectively.

Gloss is a function of the directional reflective properties of a surface. It is a property that determines the ability of a surface to show its brightness or to show the brightness quality. Gloss is a qualitative concept, that is, not a basic term (Ferwerda et al., 2001). Gloss is associated with the reflection of unwanted light (Sönmez, 2020).

In the graphic below, the printing gloss values of the materials used as surface coating are displayed. The curve of the print gloss values of the used materials as surface coating is shown in Figure 8 below.

When the graph is examined, it is seen that the highest gloss value is obtained with 2.6 in PCC coating, and the lowest gloss value is obtained with 1.8 in GCC coating. The gloss value of the control paper is 4.55, and the gloss value of the ECC coated material is 2.3. The color universe of the used materials as surface coating is shown in Figure 9 below.

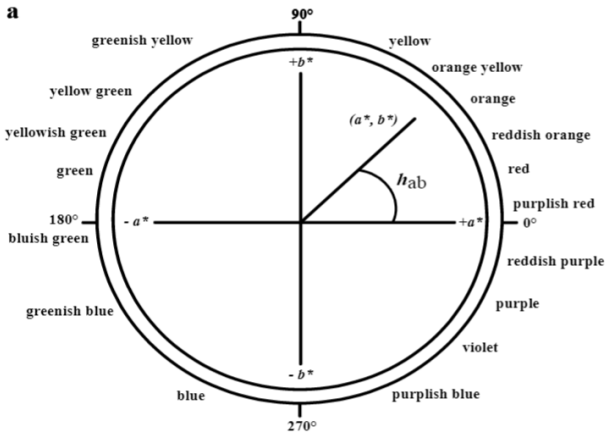

Figure 7. Diagram with the Sequence of Colors According to Hue Angle (Dini et al., 2019)

Table 4. Electrophotographic Hue angles of the materials used as surface coating

Hue angle	Control	ECC (º)	GCC (º)	PCC (º)
Cyan	49.52	57.33	61.95	63.26
Magenta	18.22	13.90	10.10	8.89
Sarı	86.97	89.62	-86.25	-85.04
Siyah	60.79	47.95	21.45	-5.09

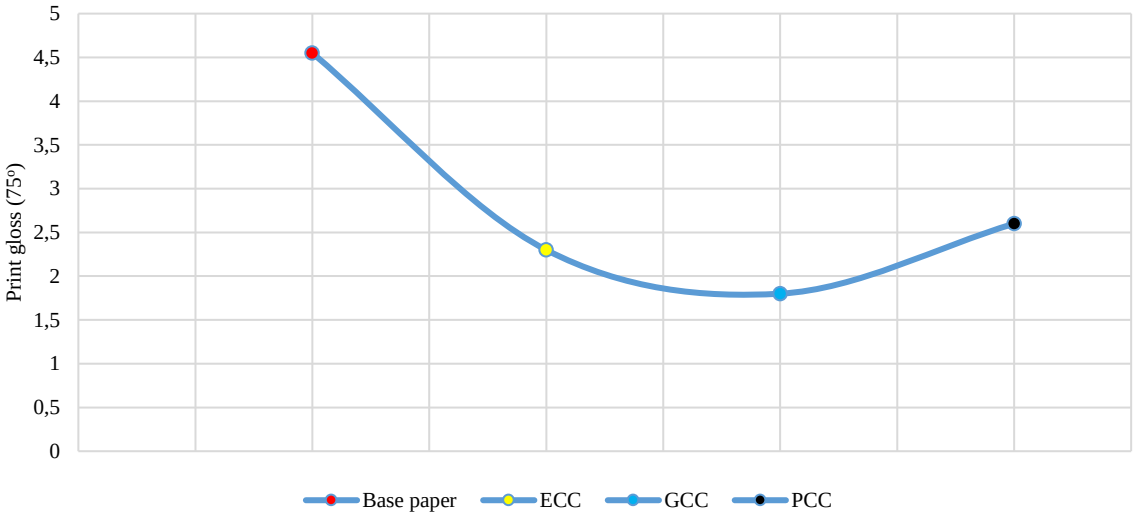

Figure 8. Print gloss (75º) values of the used materials as surface coating

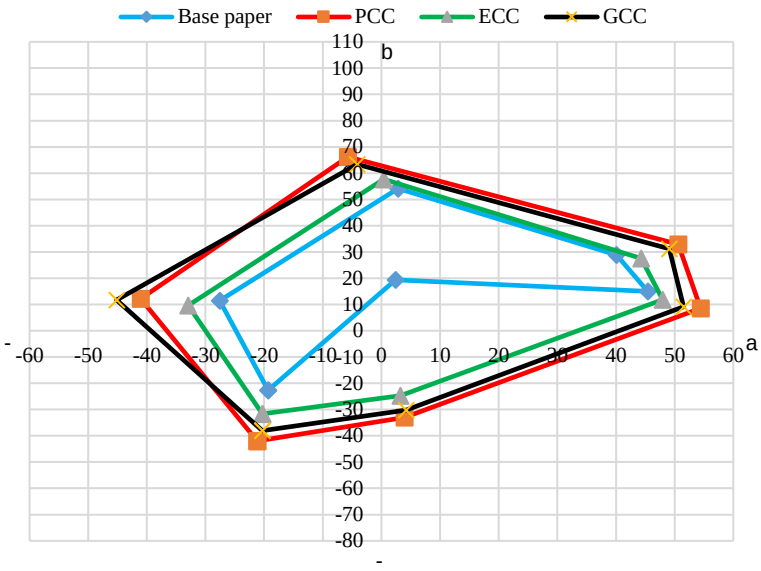

Figure 9. Color universe values of the used materials as surface coating

When Figure 9 is examined, it is seen that the coated material with the highest color universe is PCC, followed by GCC, and finally the coated material with the smallest color universe is ECC. Naturally, control paper is the printed paper with the lowest color universe.

4. Conclusion and recommendations

When the results obtained in general are examined, it is seen that PCC coating gives better results than other coated materials in terms of both paper production and print quality. The color universe obtained as a result of electrophotographic printing on PCC covers a wider area than other coated materials, and the chroma value of the printing obtained is higher than the chroma value obtained with ECC and GCC. It is seen that the results obtained regarding paper production are compatible with the literatüre (Tutuş et al., 2018; 2013; 2013; Penkin et al., 2019; Wahab, 2017).

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