



T.R.
EGE UNIVERSITY
Graduate School of Applied and Natural Science



**EFFECT OF ETHYLENE ACRYLIC ACID AND
METHACRYLIC ACID COPOLYMERS
ON THE PERFORMANCE OF
THERMOPLASTIC POWDER COATINGS
FOR FLAME SPRAY APPLICATIONS**

MSc THESIS

Müge METİNÖZ

Chemical Engineering

İzmir
2019

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Müge METİNÖZ

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2019

Müge METİNÖZ tarafından yüksek lisans tezi olarak sunulan “ Effect of Ethylene Acrylic Acid and Methacrylic Acid Copolymers on the Performance of Thermoplastic Powder Coatings for Flame Spray Applications ” başlıklı bu çalışma EÜ Lisansüstü Eğitim ve Öğretim Yönetmeliği ile EÜ Fen Bilimleri Enstitüsü Eğitim ve Öğretim Yönergesi'nin ilgili hükümleri uyarınca tarafımızdan değerlendirilerek savunmaya değer bulunmuş ve 27/08/2019 tarihinde yapılan tez savunma sınavında aday oybirliği/oyçokluğu ile başarılı bulunmuştur.

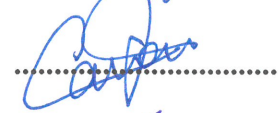
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İmzası



Adı-Soyadı

Müge METİNÖZ

ÖZET

**ETİLEN AKRİLİK ASİT VE METAKRİLİK ASİT
KOPOLİMERLERİNİN ALEV SPREY UYGULAMALARINDA
KULLANILAN TERMOPLASTİK TOZ BOYALARIN
PERFORMANSI ÜZERİNDEKİ ETKİLERİ**

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Temmuz 2019, 49 sayfa

Termoplastik toz kaplamalarda asitle modifiye edilmiş poliolefinler yaygın olarak kullanılmaktadırlar. Metal ve diğer polar yüzeylere uygulandıklarında yapışma performanslarının mükemmel olmasının bir sonucu olarak oldukça iyi nihai korozyon dayanımı sağlamaktadırlar.

Bu araştırmada kapsamında, asitle modifiye edilmiş poliolefin olan etilen akrilik asit ve metakrilik asit kopolimerlerinin ticarileşmiş iki tipinin alev spreyi uygulaması üzerindeki etkilerinin incelenmesi amaçlanmıştır. Bu kopolimerler kullanılarak üretilmiş kaplamaların ultraviyole, darbe ve korozyon direnci, yapışma performansı ve alev spreyi uygulamaları gibi özellikleri değerlendirilmiştir.

Aşağıdaki polimerlerin mekanik, termal, yüzey özellikleri bakımından kaplama performansı üzerindeki etkileri incelenmiştir;

- Eriyik akış indeksi 450g/10 dk ve yoğunluğu 0.93 g/cm³ olarak üretilmiş bir *etilen metakrilik asit kopolimeri*
- Eriyik akış indeksi 38g/10 dk ve yoğunluğu 0.94 g/cm³ olarak üretilmiş bir *etilen akrilik asit kopolimeri*

Araştırma dört ana adımda yürütülmüştür; kaplama formülasyonu ve üretimi, alev spreyi uygulaması, polimer karakterizasyonu ve performans testleri.

Yapılan çalışmaların neticesinde, etilen akrilik asit kopolimer esaslı kaplamada; yüzey portakal kabuğu görünümü, UV maruziyeti sonrası renk değişimi ve parlaklık kaybı açılarından daha fazla geliştirilmeye ihtiyaç duyulmaktadır. Etilen metakrilik asit kopolimer esaslı kaplamanın ise; performans testleri, yüzey ve renk kontrollerinde daha iyi sonuçlar verdiği gözlemlenmiştir.

Anahtar sözcükler: Termoplastik toz kaplama, alev spreyi uygulaması

ABSTRACT**EFFECT OF ETHYLENE ACRYLIC ACID AND METHACRYLIC ACID COPOLYMERS ON THE PERFORMANCE OF THERMOPLASTIC POWDER COATINGS FOR FLAME SPRAY APPLICATIONS**

METİNÖZ, Müge

MSc in Chemical Engineering

Supervisor: Assist. Prof. Dr. Nilay GİZLİ

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In thermoplastic powder coatings, acid modified polyolefins are commonly used due their excellent adhesion performance to metals and other polar surfaces that results as ultimate corrosion resistance.

In this research, effect of two commercial grade acid modified polyolefins, ethylene acrylic acid and methacrylic acid copolymers, for flame spray application were aimed to be researched. Coating formulations of these two copolymers have been investigated in terms of their performance such as UV, impact and corrosion resistance, adhesion performance and flame spray applications.

To investigate their effects on mechanical, thermal, surface properties on final coating performance, the present study focuses on two polymer bases;

- An *ethylene methacrylic acid copolymer*, produced with melt flow index of 450g/10 min and density of 0.93 g/cm³.
- An *ethylene acrylic acid copolymer*, produced with melt flow index of 38g/10 min and density of 0.94 g/cm³.

The research has been done in four main steps. These are; coating formulation and production, application by flame spray, polymer characterization and performance tests.

From the performed study, it can be concluded that ethylene acrylic acid copolymer based one needs further improvement in terms of surface orange peel look, color change and gloss retention after UV exposure. Ethylene methacrylic acid copolymer based coating formulation gives better properties in performance tests, surface and color controls.

Keywords: Thermoplastic powder coating, flame spray application

PREFACE

The basis for this research originally related to my very first job experience, plastic and metal component coatings. I started this scientific journey in 2014 and it is being finalized almost 3 years later than planned due to opportunities that cross my way back then. As the world moves further into the new things, our life is also changing.

Today, I am very happy to conclude this study with successful results that have been achieved during the course of this research.

The research has been done in four main steps.

- Coating formulation and production
- Application by flame spray
- Polymer characterization
- Performance tests

18 / 07 / 2019

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1 INTRODUCTION

1.1 Coating

A coating is a covering, contains a film forming material, which is applied to the surface of an object. This surface usually referred as the substrate, (Coating Types and Selection, CED Engineering, 2019).

In many cases, coatings are applied to improve surface properties of substrates such as appearance, corrosion resistance, adhesion and wettability, wear resistance, scratch resistance, impact resistance, etc. Factors affecting the choice of a coating can be summarized as follows; substrate material compatibility, service environment, life expectancy, component shape and size, cost, (TWI Global, 2019).

1.1.1 Components of coatings

Coatings are very complex materials consisting of many components, each responsible to provide a specific quality to the formulation. However, basically all paints contain five type of components as below, (Lambourne et al., 1999).

- *Pigment*: Pigments are used decoratively as colorant or functional as anticorrosion or magnetic pigment.
- *Binder*: The binder bonds the pigment particles to each other and to the substrate.
- *Additive*: Substances added in small proportion to coating composition to modify or improve properties. These are UV additives, surfactants, antioxidants, dispersing agents, foaming and de-foaming agents
- *Filler*: Fillers mostly used to extend the volume for reducing the price of the coating formulation or to improve technical properties.
- *Solvent*: Solvent mixture consists of several components and dissolves binders without chemical reaction, used in if a liquid paint applications.

1.1.2 Types of Coatings

In physical form point of view coatings can be divided into 2 types, powder and wet coatings (paints). In generic powder coating process, dry powder particles are applied onto the part surface and it is then cured in a specialized oven, where the powder melts and covers the surface. The result is generally a thick, fine and durable finish. In wet paint process, liquid paint is applied onto the part surface usually using a spray, pump or pressurized vessel. The paint is applied until the surface is evenly coated to the desired thickness.

Types of coatings can be shown as in Figure 1.

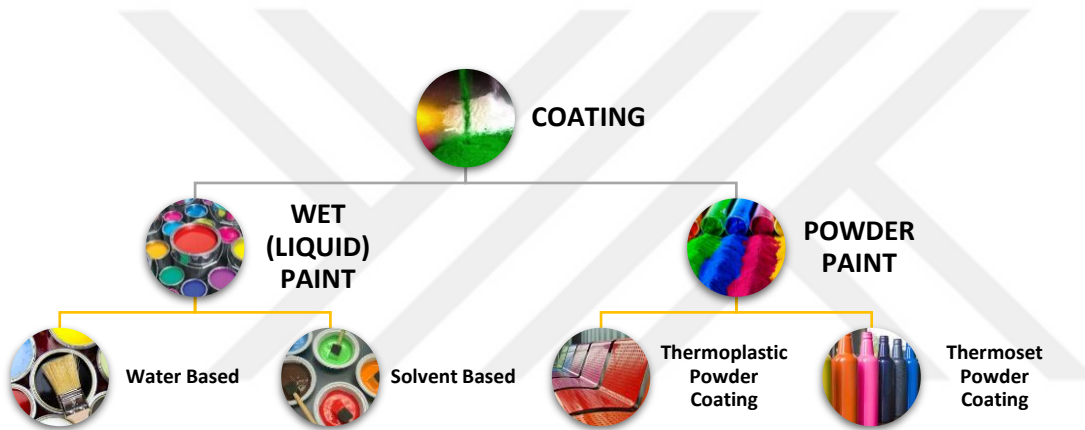


Figure 1 Coating types

1.2 Powder Coatings

Powder coatings have several application areas, which are automotive, architectural, furniture, agriculture, construction and earthmoving equipment (ACE) and general industry.

Powder coatings have many advantages like being economical, long lasting, and durable quality finish for products. Main usage areas are on metals that are in extreme weather conditions, because it has some unique technical properties like superior durability, scratch resistance, gloss retention, and resistance to chalking. In addition to them, powder coatings do not have volatile organic compounds

(VOCs) and solvents, therefore their processes are ecofriendly. Besides these technical benefits, being cost efficient makes powder coatings more desirable.

Main reasons to choose powder coating applications can be summarized as below;

- They are ready to use, there is no need to mix them with other components, such as solvents or catalysts.
- Reduction of fire risk due to static electric, since it doesn't contain any solvent.
- Less air pollution due to no volatile organic compounds.
- They are recoverable.
- Powder processing times are generally shorter than those used for wet paints since, as there is no solvent, no flash off period is required.
- Superior film properties such as adhesion and corrosion resistance are obtained with powders.
- More uniform coating and higher film thickness can be achieved in one application with powder than with conventional paint system.
- Huge range of coatings and effects are available such as matt, satin, gloss, metallic, textures, soft touch etc.

Especially technological developments and environmental restrictions let the powder coating markets demands increased and grow. From market point of view, until 2022, powder coatings market is expected to gather \$12.3 billion and growing at a CAGR (compound annual growing rate) of 5.4% during 2016-2022 as shown in Figure 2.

In 2015, the powder coating applications were one of the major shares and expected to continue on this rise. For these overviews, the powder coatings markets consider their types, usage areas, application methods as well as analyzing the geographical conditions with governmental regulations and policies, (Nathwani, S., 2016).

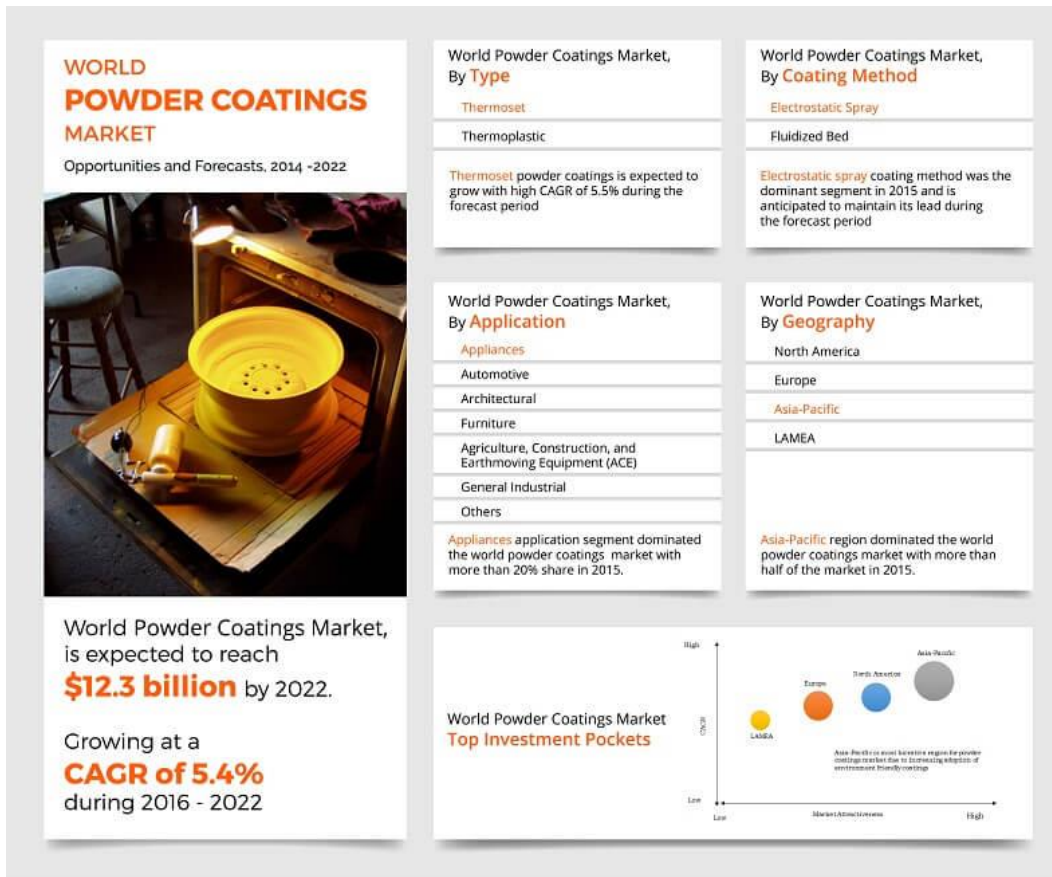


Figure 2 Market overview of powder coatings (Nathwani, S., 2016)

In the matter of their behavior when they exposed to heat, powder coating types can be divided into two groups; thermosets and thermoplastics.

Thermosets are made of polymers that are joined with chemical bonds produce highly cross-linked polymer structure. This highly cross-linked structure provides mechanical and physical strength unlike thermoplastics. However, this advantage can cause disadvantages, which are poor elasticity and elongation of the material. Another drawback of thermosets is no ability to recycle because of cross-linked structure. Thus, they cannot be melted and return to liquid phase. On the other hand, this negative aspect can be useful at a place that material should not melt or deform while heated. (Hayakawa et al., 2004)

A thermoplastic powder coating composition is provided by containing a mixture of two polymers which are compatible and necessary additives for the application and exposed area. Thermoplastics are plastics that can be flexible and

bendable at specific range of temperature and then return to a solid state via cooling. Their molecular structure link to intermolecular forces, which allow being re-bendable and this property, makes thermoplastics different from thermosets. (FitzGerald, et al., 1980)

Chemical structure difference of thermoplastics and thermosets can be shown as in Figure 3.

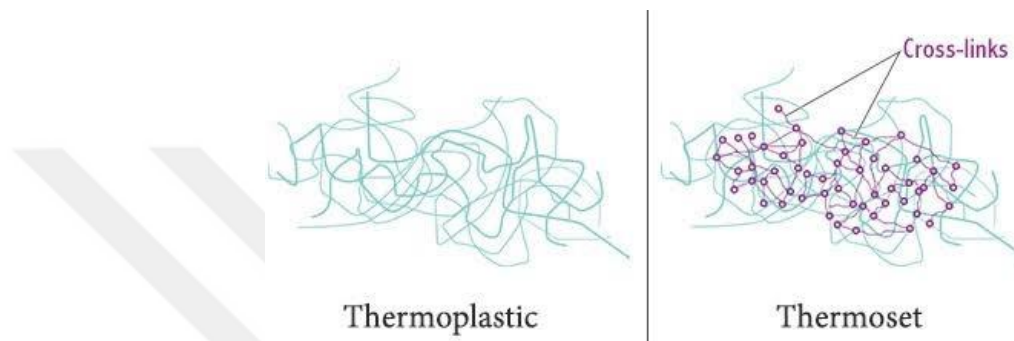


Figure 3 Chemical structure comparison of thermoset and thermoplastic resins (Difference between thermoplastics and thermosets, Science Struck, 2019)

The first powder coatings produced were based on thermoplastic polymers which melt at the application temperature and solidify upon cooling. (Gärtner F. et al., 2006)

Thermoplastic powder coatings can offer some distinguished properties such as excellent solvent resistance, outstanding weathering resistance, and exceptional wear resistance, a relatively good price/performance ratio or high aesthetic appearance.

Currently there is no other surface coating offers higher resistance against corrosion, chemicals and UV radiation.

Thermoplastic and thermoset coatings may have many advantages and disadvantages as listed in Table 1.

Table 1 Advantages and disadvantages of thermoplastic and thermoset powder coatings

Advantages of Thermoplastics	Advantages of Thermosets
<ul style="list-style-type: none"> - Extremely adhesive to metal - Superb corrosion resistance - Highly recyclable - Superb impact resistance - Excellent corrosion resistance - Slip enhancement - Detergent and chemical resistance - Flexibility and elongation of the coating film - Electrical insulation - Chip resistance - Aesthetically-superior finishes 	<ul style="list-style-type: none"> - More resistant against high temperature - Hard and rigid - Thin to thick wall capability - Excellent appearance - High mechanical property - Cost effective - Excellent dimensional stability
Disadvantages of Thermoplastics	Disadvantages of Thermosets
<ul style="list-style-type: none"> - May soften when reheated - May be expensive than thermoset 	<ul style="list-style-type: none"> - Not recycled - Much more difficult to surface finish - Cannot be remolded or reshaped

1.3 Powder Coating Applications

Thermal-spraying of polymers can be traced back to the 1940s, when polyethylene (PE) was first produced, (Brogan, J. A., 2000). Many different methods of application have been developed since then. Most common powder coating applications can be summarized as follows;

- Electrostatic applications
- Fluidized bed applications
- Flame spray applications

1.3.1 Electrostatic applications

This application method uses a spray gun, which applies an electrostatic charge to the powder particles, which are then attracted to the grounded part.

After application of the powder coating, the parts enter a curing oven where, with the addition of heat the powder melts down and forms a coating film on the surface of the substrate.

After the heating process, coated part is removed from the oven and cooled down until it solidifies, (Beetsma J, 2016).

Figure 4 shows an example of an electrostatic spray application of metal parts.



Figure 4 Electrostatic spray application of powder paint on metal objects

1.3.2 Fluidized bed applications

In this application metal parts are heated up and dipped into the coating powder. When powder is in contact with hot metal, it melts and forms a coating film. After the metal is removed from the bed it can be post-heated in order to avoid orange peel on the surface of the coating. To increase the process speed coated part can be dipped into the water for rapid cooling.

Figure 5 presents the fluidized bed application.

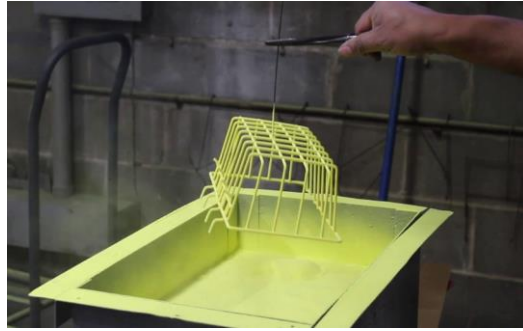


Figure 5 Fluidized bed application of powder paint on metal objects

1.3.3 Flame spray applications

It is an application in which the powder particles sprayed by nozzles, melts while passing through flame that composed around the nozzle. Melted powder particles then stick on metal or concrete surfaces. Coated part is cooled which can be air or water cooled, then the coating film becomes solid, (Fauchais et al., 2014)

If substrate is below room temperature, it is necessary to heat up the part for better adhesion. Heating can be done directly by flame spray gun without spraying powder.

Figure 6 shows flame spray application on steel construction parts.



Figure 6 Flame spray application of powder paint on metal objects

2 EXPERIMENTAL

Experimental part of this research has been constituted of four major parts as follows; formulation and production, polymer characterization, performance test and visual surface analysis.

2.1 Formulation and Production

This process has four steps and these are formulation, compounding, cryogenic grinding and sieving as shown in Figure 7.

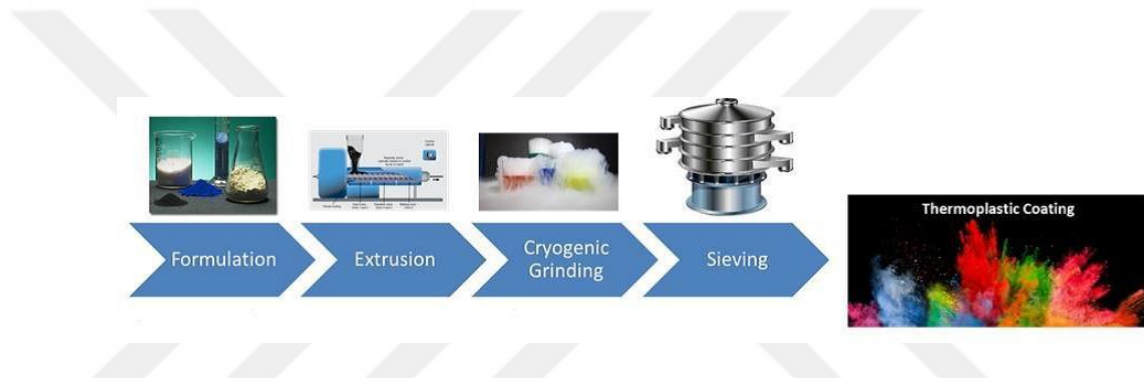


Figure 7 Production process of thermoplastic powder coating

2.1.1 Coating Formulation

In this step the types of raw materials, additives and their amounts in formulations have been determined. The decision to choose the right materials has been made by considering the requirements from the market in parallel to the literature. Then the proper types of copolymers as ethylene acrylic acid and ethylene methacrylic acid polymers were supplied.

2.1.1.1 Polymers

Polyolefins have poor adhesion to metal or other substrates since they are inert materials. Therefore, before polyethylene and polypropylene powder coatings are applied, the substrate must first be primed or adhesion promoters must be added to the powder coating formulations to improve adhesion. Different modifications of polyolefins have been studied in order to improve the adhesive properties. In many cases, these modifications can be a simple blend of polyethylene or polypropylene with polymers containing acid groups as adhesion promoters. (Thermoplastic powder coating, European Coatings, 2019). Acid groups of the polymer etches the metal surface which results as an excellent adhesion property.

In this study, two acid modified copolymers ethylene acrylic acid and ethylene methacrylic acid, have been used and Table 2 shows the properties of these two commercial grade copolymers.

Table 2 Properties of chosen copolymer grades

Properties	Test method	Polymer A*	Polymer B**
Melt Flow Index (MFI)	ASTM D1238	38 g/10 min	450 g/10 min
Density	ASTM D792	0.94 g/cm ³	0.93 g/cm ³

*Polymer A: Ethylene acrylic acid copolymer

** Polymer B: Ethylene methacrylic acid copolymer

2.1.1.2 Additives

In addition to these copolymers, pigments, antioxidants, UV stabilizers, surface additives, dispersion agents and thermal stabilizers are used as additives in the formulations.

Based on the desired physical, chemical and mechanical properties, pre-tests have been performed in the laboratory in order to define the percentages of raw materials, additives and pigments in line with raw material supplier recommendations in technical data sheets of related materials.

Table 3 and 4 shows basic contents of the formulations. Performance of two copolymers, ethylene acrylic acid, Coating A and methacrylic acid, Coating B have been observed in these coating formulations.

Table 3 Formulation of Coating A for ethylene acrylic acid based formulation

Ingredients	%
Polymer A	85
Additives + Pigments	15

Table 4 Formulation of Coating B for ethylene methacrylic acid based formulation

Ingredients	%
Polymer B	85
Additives + Pigments	15

2.1.2 Coating Production

Production process has three main steps, these are extrusion and compounding, cryogenic grinding and sieving.

2.1.2.1 Extrusion and Compounding

Plastic extrusion is a process where parts such as pipes, sealing, tubes and sheet are produced in a mass production.

In this process plastic material (pellet form) put inside a hopper and then fed into the barrel which is heated. All ingredients are mixed inside the barrel with the help of the screw and carried out as molten plastic. In the final part of the extruder, die, molten plastic comes out and then starts to solidify and get in a desired shape, as shown in Figure 8.

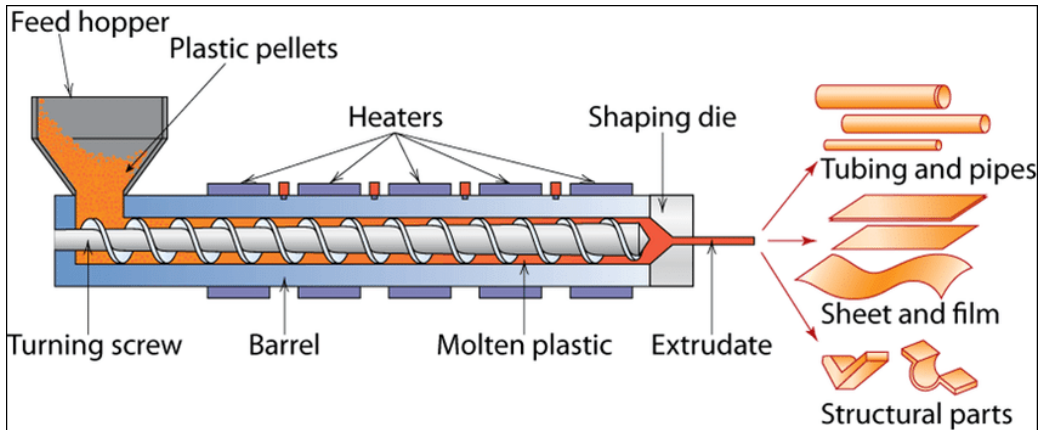


Figure 8 Steps of Extrusion Process (Benk Machine Extrusion Line,2019)

On the other hand, compounding is a method to obtain granules by mixing all ingredients raw materials, additives and pigments. It is similar to the extrusion but the final product is in granular form.

In this research chosen raw materials, additives and pigments are compounded in a laboratory scale extruder to obtain RAL 6005 color shown in Figure 9 and the granules then fed in a cryogenic grinder in order to convert it to powder coating form.



Figure 9 Plastic granules obtained from lab extruder - RAL 6005 color

2.1.2.2 Cryogenic grinding

Cryogenic grinding is a process which is done by freezing the granules and then grinded to reduce their sizes.

Thermoplastics, polymers with lower glass transition temperatures, are difficult materials to pulverize under normal conditions. Since they are very elastic at room temperature, their temperature need to be below their glass transition temperature to grind them. In order to reach those low temperatures, plastic granules are put in liquid nitrogen. When the temperature is low enough, granules are grinded to micron levels and becomes available to be used as powder coating in flame spray applications.

In this process the particle size is usually between 30 μm to 400 μm range. The schematic structure of cryogenic grinding process is presented in Figure 10.

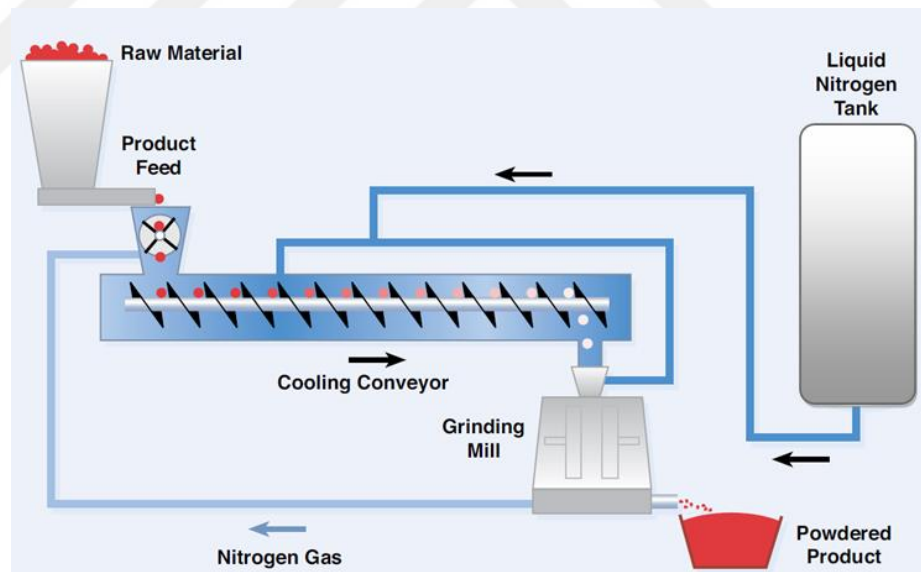


Figure 10 Cryogenic grinding process (Oscar B. et al., 2015)

2.1.2.3 Sieving

One of the most important thing not to have in the application of the powder coatings is dusting. In order to avoid dusting, the powder should not have particles smaller than 60 μm . Since the particle size distribution of the product after cryogenic grinding is large, sieving, as shown in Figure 11, is applied to have desired range.



Figure 11 Sieving equipment (A), Different mesh sizes (B)

Based on the application the mesh size of sieve can change. For the flame spray application this range is around $105 \pm 35 \mu\text{m}$ for $250 \pm 50 \mu\text{m}$ coating film thickness and there should not be any particles with particle size below than 60 μm since they tend to burn while passing through the flame.

Figure 12 shows some examples of wide range particle size distributions which are generally not accepted for such coating applications since big size particles will cause surface disorientation in the coating film.

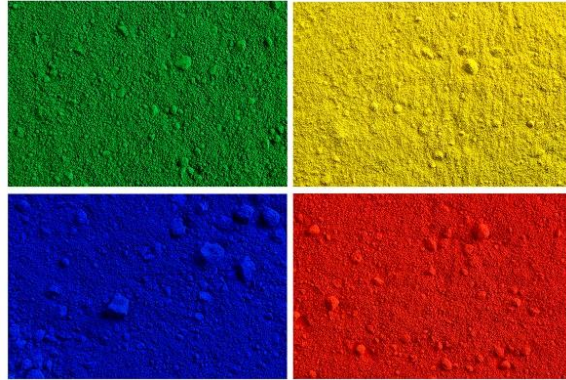


Figure 12 Examples of wide range particle size distribution

2.1.3 Coating Application via Flame Spray

Flame spray application is a technology which allows users to paint on site. There is no need to build big painting systems such as painting cabinets, ovens or fluidized beds. Advantages of flame spray application can be summarized as follows;

- It is suitable to apply in different weather conditions
- Coating and touch-up on site (especially for big and heavy pieces)
- Application in only one step
- No need to big painting systems
- Fast usage of the coated piece after application

Since thermoplastic powder coating do not need to be cross-linked, it can be easily applied on the substrate by melting only as indicated in Figure 13.

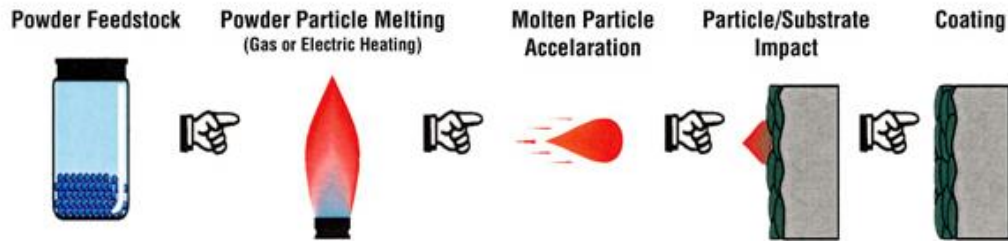


Figure 13 Basics of flame spray application (FST, Thermal Spray Process, 2019)

In flame spray applications, the coating material is applied by flame spray gun as illustrated in Figure 14. There are three inlets in flame spray gun; powder, air and gas. Gas is used to obtain flame and air is used to spray the powder. Powder is passing through the flame where it melts and sprayed on the substrate. Since the polymer is molten it forms a film on the substrate and coating is obtained.

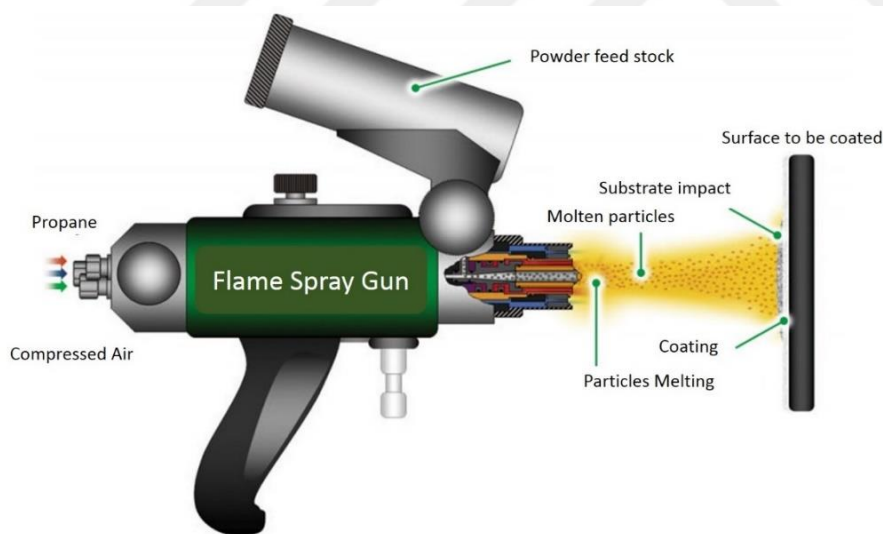


Figure 14 Flame Spray Gun (FST, Flame Powder Spray, 2019)

In this research, flame spray applications of both Coating A and B have been done on standard metal panels with film thickness of $250 \pm 50 \mu\text{m}$ in order to observe the coating performance at standard operating conditions. Below $200 \mu\text{m}$ is generally not recommended for this type of application.

Figure 15 refers to metal sheet panel applications of both formulations, Coating A and B.



Figure 15 Flame Spray Application on a standard metal panels

After the application on the metal sheets thickness of the coating film is measured and visual controls are done to check if there are any surface defects. Typical surface defects are;

- Pinhole
- Orange peel
- Framing effect
- Sagging

2.2 Polymer Characterization

During the new product development, benchmarking or solving product it is essential to characterize polymers.

Polymer characterization has been done to have information about molecular weight, molecular form, morphology and its thermal and mechanical properties. Since the final product is obtained by compounding and applied by flame spray gun in this research, it faces to high temperatures. Therefore, thermal characteristics of the polymer are very important for the performance of the final coating.

In this research thermal characteristic of the polymeric coating formulations have been investigated by DSC (Differential Scanning Calorimetry) and TGA (Thermal Gravimetric Analysis) methods.

2.2.1 DSC (Differential Scanning Calorimetry)

Differential Scanning Calorimetry (DSC) is a technique where heat capacity of the material and the change in the temperature are investigated. A sample, knowing its mass, is heated up or cooled down and the change in the thermal capacity is observed. These changes can be classified as glass transition, phase change, solidifying etc. As a result of these observations some important values can be determined such as glass transition temperature (T_g), melting temperature (T_m) and crystallization temperature (T_c).

In this research, DSC measurements have been performed in order to identify the melting temperature of the products. A small piece form compounded product has been inserted to the DSC instrument and measurements were performed under operating conditions which are shown in Table 5.

Table 5 DSC operating conditions

Standard	ISO 11357-3
Sample Weight (mg)	9.5
Initial Temperature (°C)	23
Final Temperature (°C)	300
Rate (°C/min)	20
Relative Humidity (%)	50

DSC analysis has been performed with Exstar SII DSC 7020 type equipment which is shown in Figure 16.



Figure 16 DSC Equipment - SII DSC 7020

2.2.2 TGA (Thermal Gravimetric Analysis)

Thermal gravimetric analysis (TGA) is a method that sample is heated up and the mass of it is measured by time. This measurement shows the physical cases like phase changes, adsorption, desorption.

TGA is used mainly to check the thermal stability of the polymer. If polymer is thermally stable there will be no change in the mass and TGA graph will be

constant. However, if there will be any changes in mass that shows a degradation in the polymer. Each polymer has a maximum life temperature and above this polymer starts to degrade.

In this research, TGA analysis has been performed in order to determine behavior of coating formulations against thermal conditions and compare their thermal stability. Due to high temperatures they will face during flame spray applications, it is highly important that polymeric structure not to degrade until a certain temperature levels.

In this research, Coating A and B have been compared by TGA method in terms of their thermal stability. Tests has been done on samples whose initial weights are measured and recorded at the beginning of the tests, by increasing the chamber's temperature by constant rate. While temperature is rising, samples start to lose some weights at certain temperatures where thermal degradation occurs. The test has been performed in N₂ environment to avoid any oxidation in the chamber.

Tai Instruments, TA-Q5000 SA type of TGA equipment has been used when performing the analysis for this study and Table 6 shows the testing conditions.

Table 6 TGA operating conditions

Standard	ISO 11358
Sample Weight (mg)	10
Testing Atmosphere	N ₂
Rate (°C/min)	20

2.3 Performance Tests

Coatings are used in order to protect the surface of the part from the environment that it stays. In this research, the thermoplastic powder coating that has been studied, will be used in metallic surfaces such as steel constructions, water tanks and metal plates.

In order to measure the performance of the coating the testing panels are studied. Considering the environments and the conditions that the panels will face and standards that customers ask for are the key parameters to define the tests. In this application the tests will be done on the metal sheets with 200-300 μ m coating thickness and the name of the performance tests are listed below;

- Adhesion (cross cut)
- Salt spray
- UV resistance
- Impact resistance

Table 7 refers the performance targets those are aimed to achieved as a result of this research.

Table 7 Performance targets

Test	Test method	Target
Adhesion (cross cut)	ISO 2409	0
Salt Spray	ISO 9227	1440 hour No corrosion
UV resistance	ASTM D4587	1000 hour No significant change in color visually $\Delta E \leq 3.00$ Gloss retention ≥ 50
Impact resistance	ISO 6272-1	1000mm/kg No loss of adhesion or cracking

2.3.1 Adhesion (Cross-cut)

The cross-cut test is a method of determining the resistance of paints and coatings to separation from substrates by utilizing a tool to cut a right angle lattice pattern into the coating, penetrating all the way to the substrate, (ISO 2409, 2013).

With the help of this method, a quick pass and fail test can be accomplished. When testing a coating system, determination of the resistance to separation from the coated surface can be determined.

Cross-cut adhesion test method is performed on an area of at least 10 x 10 cm, with making a grid incision with a selected cutter or metal blade which can be single blade cutting tools or multi blade cutting tools, all the way down to the substrate. Evenly spaced incisions (8-10 mm) must be created horizontally and vertically to create a lattice pattern on the surface of the test area. Then adhesive tape is applied to cover the cut area and removed as vigorously and the area is observed to determine the result.

In this research, hand-held multi blade cutting tool and 3M 898 type adhesive tape have been used while performing cross-cut test to determine adhesion property. Figure 17 shows the properties of multi-blade cutting tools used in the study where 1 is cutting blade, 2 is guiding edge, 3 is cutting edges and a is direction of cut, (ISO 2409, 2013).

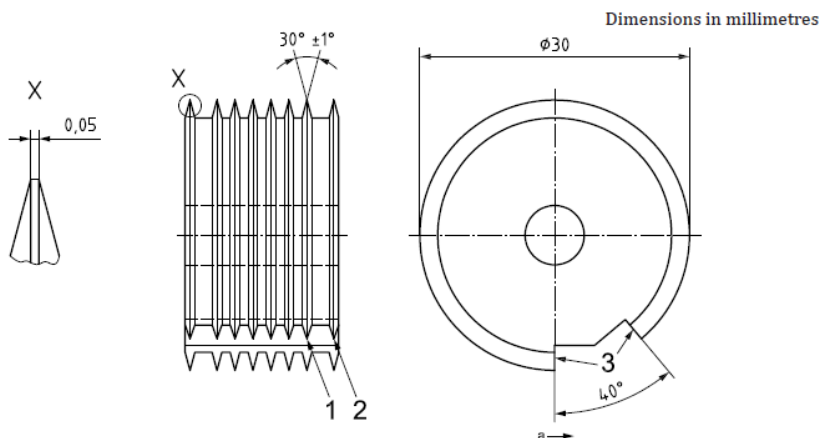
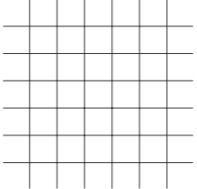
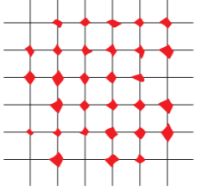
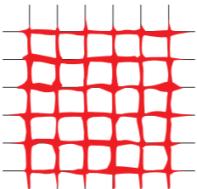
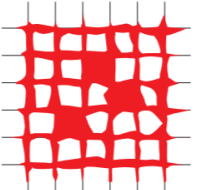




Figure 17 Hand-held multi blade cutting tool (ISO 2409, 2013)

The adhesion results are classified with the following scale in accordance with ISO 2409, 2013 standard shown in Table 8.

Table 8 Cross-cut scales of ISO 2409, 2013

Scale		Remarks
0		The edges of the cuts are completely smooth; none of the squares in the grid have detached.
1		Small flakes of coating have detached at intersections. A cross-cut area of 5 % is affected.
2		Small flakes of coating have detached along edges and at intersections of cuts. A cross-cut area of between 5 %, to 15 %, is affected.
3		The paint has flaked partially or completely along the edges and/or some squares have partially or completely detached. A cross-cut area of between 15 %, to 35 %, is affected.
4		The paint has flaked in large strips along the edges of the cuts and/or some squares have partially or completely detached. A cross-cut area of between 35 %, to 65 %, is affected.
5		Any degree of flaking that cannot fall within classification 4, where the detached paint exceeds 65% of the cross-cut area.

2.3.2 Salt spray

Corrosion degrades the useful properties of materials, especially metals. Rusted areas in the parts can also lead to loss of strength, appearance, and permeability to liquids and gases. Cost of the corrosion is very high in product and infrastructure damage, (Q-Lab, Q-Fog Cyclic Corrosion Tester manual, 2019). In order to avoid these losses, accelerated corrosion tests are performed in just a few days or weeks with special testing equipments that can produce the damage that occurs over months or years outdoors to observe long term behavior of a coating film in corrosive environments.

Salt spray tests are generally suitable for quick analysis of organic and inorganic coatings in terms of their corrosion protection capability. Although the test can be used for quality control purposes, it is possible to make comparison between specimens coated with the similar coatings since salt spray tests are only suitable for the coatings which are sufficiently similar in nature, (ISO 9227, 2017).

As a part of this research, corrosion test has been performed in the fog function of salt spray equipment. During the fog function, the corrosion tester operates as below;

- Corrosive solution from the internal reservoir is pumped to the nozzle
- Compressed air is humidified by passing through the bubble tower on its way to the nozzle
- Nozzle atomizes solution air into a fine, corrosive fog mist
- Chamber heaters maintain the programmed chamber temperature, 35 ± 2 °C.

In this study coated panels have been tested in two different ways, scratched and unscratched. Scratch deformation has been made by Erichsen Type 426 scratcher.

Figure 18 shows the operating mechanism of the fog functioned salt spray test equipment.

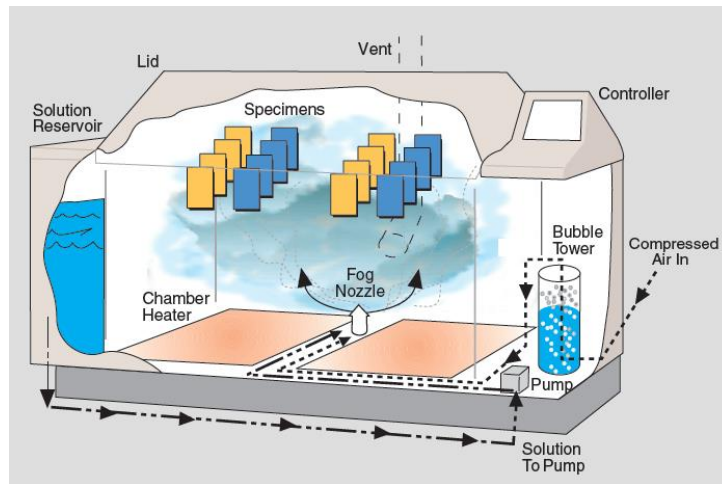


Figure 18 Mechanism of fog functioned salt spray chamber (Q-Fog CCT, 2019)

In this research, Q-Fog Cycling Corrosion Tester (CCT) type equipment has been used with operating parameters as listed in Table 9.

Table 9 Q-Fog CCT operating conditions

Standard	ISO 9227
Exposure Time (h)	1440
NaCl Solution Concentration (%)	5
pH at 25±2 °C	6-7
Solution Temperature (°C)	45
Chamber Cabin Temperature (°C)	35 ± 2
Inlet Air Pressure (bar)	0.7

After unscratched and scratched panel exposed to 1440 hours of salt spray exposure, their corrosion resistance and adhesion performance have been evaluated for C5 corrosion category, shown in Appendix B, which allows coating can be used in industrial areas with high humidity and an aggressive atmosphere.

2.3.3 UV resistance

Polymer degradation is essential when they are exposed to ultraviolet radiation, humidity, high temperatures and temperature fluctuations or combinations of these exposures, (Hamid, 2000). Polymers have wide range of usage areas, so it is important for polymer producers to understand durability and expected life cycle of polymeric products. Resistance against UV exposure is very critical, especially for exterior parts or coatings that will be exposed to outdoor conditions. The structure of paint consists of pigments in a matrix of resin. Polymeric coatings can change the color and the reflectance (gloss) if proper UV additives haven't been used in the formulation. Therefore, UV resistance property of coatings are being tested, (Q-Lab, Q.U.V Accelerated Weathering Tester operation manual 2019).

There are two main testing techniques; Natural Weathering and Accelerated (Artificial) Weathering. Since natural weathering is a slow process, accelerated weathering techniques are widely used when determining UV resistance property of coatings.

In this research, Coating A and Coating B have been exposed to UV light in QUV/SPRAY/SP model of Q-Lab accelerated weathering chamber in Figure 19 that operates according to ASTM D 4587 with conditions listed in Table 10.

Table 10 UV test conditions

Standard	ASTM D 4587
Wavelength (nm)	100-400
Total Exposure Time (h)	1000
Cycle Informations	4 h of UV exposure of 0.89 W/m ² at 60 °C 4 h of humidity exposure of 60-80 % RH at 50 °C



Figure 19 QUV/SPRAY/SP type of Q-Lab accelerated weathering chamber

In order to identify the effect of UV exposure on color and gloss, periodic color and gloss measurements have been recorded in every 150 h of exposure approximately.

2.3.4 Impact resistance

Impact resistance tests are performed to determine the resistance of a coating film and its substrate to the effects of rapid deformation. The impact test can be performed on the coated or on the uncoated side of the test panel depending on the customer specifications. Thus, the indentation can be either an intrusion or an extrusion, (BYK Gardner, 2019). Impact tests are performed as follows,

- The panel is placed on the die with the coated side either up or down depending on the application and then it is fixed by using the clamps.
- The falling weight is raised to the required drop height and it is released.
- After every test the panel is controlled for damage.

In this study, BYK Gardner type of impact test equipment has been used to measure impact resistance performance of Coating A and B. Figure 20 shows the equipment used for this application (top of tube is not shown) and following Table 11 presents the test conditions.



Figure 20 BYK Gardner impact test equipment

Table 11 Impact test conditions

Standard	ISO 6272-1
Height of drop point (mm)	1000
Weight of drop (kg)	1

2.4 Visual Surface Analysis

The appearance of paints can differ in terms of their usage purposes. High-gloss paints are mostly be purchased by automotive manufacturers due to importance of the exterior look of the vehicle. On the other hand architects may purchase a low-gloss paint for house decoration. In line with the requirements from different application areas, coating formulations are designed.

Although appearance of the paints are important, many paint formulations are designed as optimization of the performance and appearance. On the functional coatings point of view final performance of the coating film is more important than how it looks.

As a part of this research, visual surface control has been done during flame spray applications for coating film thickness of $250 \pm 50 \mu\text{m}$. Surface appearances of Coating A and B have been analyzed in terms pinhole, orange peel, framing effect and sagging point of view.

Pinhole occurs due to the collapsed moisture or air which is a pore-like penetration present in coatings film. The presence of pinholes may increase the corrosion rate of coated part due to the holes in the coating film which lead faster moisture penetration to the coated surface.





Orange peel is a coating film characteristic that results with a surface appearance like the skin of an orange. Although there is no side effect of the orange peel look on the functional performance of the coating, it is crucial that the coating film has orange peel degree up to a certain level.

Framing effect can be observed during coating applications even when the paints are still in fluid phase which looks like a picture frame around the edges of the coated part. This effect is mostly depended on the application way of the coating and the behavior of the formulation against application conditions.

Sagging is the tendency of a coating to flow down due to the gravitational force, which results as a thicker down edges on the coated part.

Table 12 refers to examples of surface defects which have been controlled during the applications.

Table 12 Examples of surface defects

Surface Defect	Analyzing method	Image
Pinhole	Visual control	
Orange Peel	Visual control	
Framing effect	Visual control	
Sagging	Visual control	

3 RESULTS AND DISCUSSION

3.1 Polymer Characterization

3.1.1 DSC (Differential Scanning Calorimetry)

Due to the nature of flame spray application method, it is very crucial to identify the melting temperature of the coating formulations to be applied with such method.

As the operating conditions are listed in Table 4, 9.5 g each of two coating samples of ethylene acrylic acid copolymer – Coating A and ethylene methacrylic acrylic acid copolymer – Coating B, was heated from 23 °C to 300 °C and thermal energy change of the sample was recorded. Figure 21 and 22 shows the recorded thermal energy change versus temperature change.

The DSC graph in Figure 21 shows that Coating A formulation has started to change its phase about 92.4 °C. This temperature can be reported as its melting point temperature, T_m .

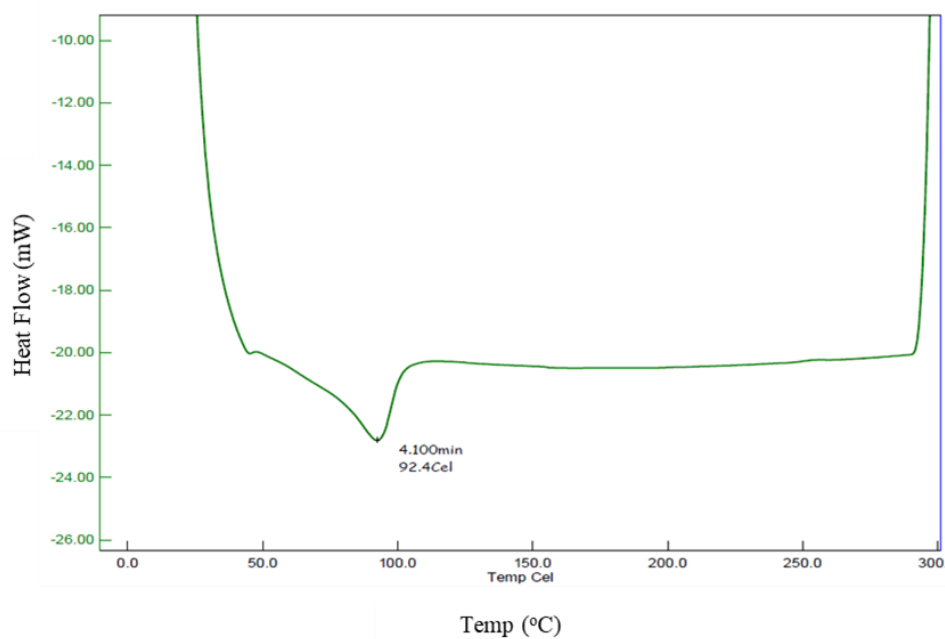


Figure 21 DSC of Coating A

Figure 22 shows that the DSC curve of Coating B - ethylene methacrylic acid copolymer based coating formulation as below.

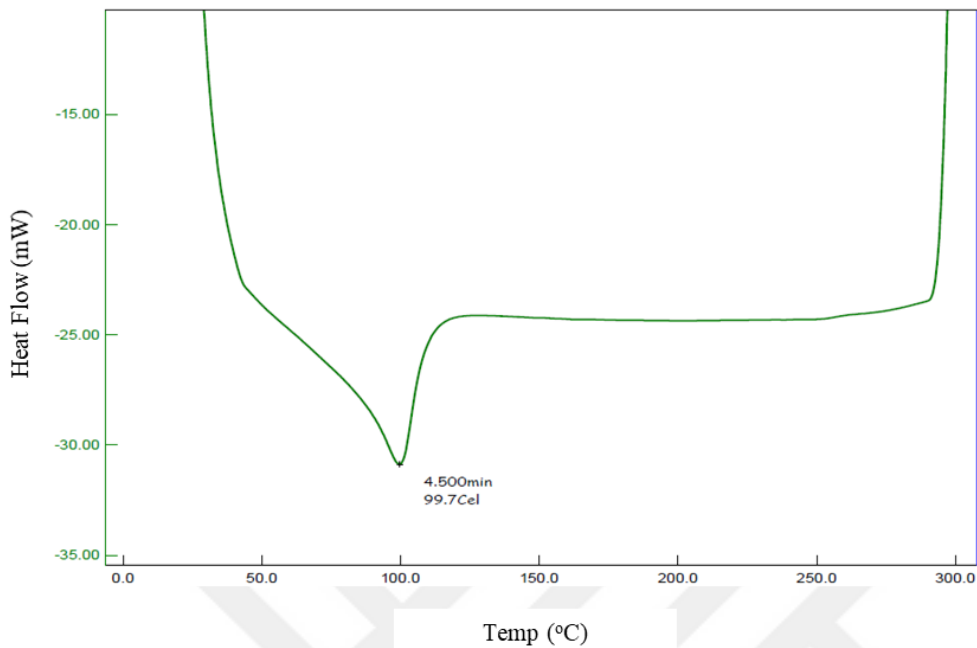


Figure 22 DSC of Coating B

DSC measurement given in Figure 22 shows that the melting temperature of the Coating B formulation has a melting point of 99.7 °C which is relatively higher than Coating A formulation.

DSC analysis of two coatings has shown that the melting point of these two materials are quite close to each other and this level of difference will not cause a dramatic difference during flame spray applications.

On the other hand, after coating application Coating A material can resist up to 92.4 °C while Coating B can resist up to 99.7 °C. This difference is important especially when the maximum working conditions of coating is taken into consideration.

3.1.2 TGA (Thermal Gravimetric Analysis)

As a part of this study thermal gravimetric analysis has been performed for both Coating A and B in order to determine their thermal properties at high temperatures. TGA uses heat to force reactions and physical changes in materials and provides quantitative measurement of mass change in materials associated with thermal degradation.

During the compounding in extrusion and flame spray operations, ingredients of Coating A and B are exposed to high temperatures. Therefore, it is very crucial point to investigate the thermal characteristics of the formulations.

In Figure 23, TGA curve of Coating A is shown. As it can be seen from the curve that the degradation of this formulation starts at 333.98 °C and it loses half of its mass at 466.75 °C. The first peak appeared at about 335 °C, which results as 2% of mass loss, can be attributed as the degradation of the additives. After increasing the temperature further, material starts to degrade more and more. It has been observed that when temperature reached around 465 °C, major part of the material has been started to degrade very rapidly.

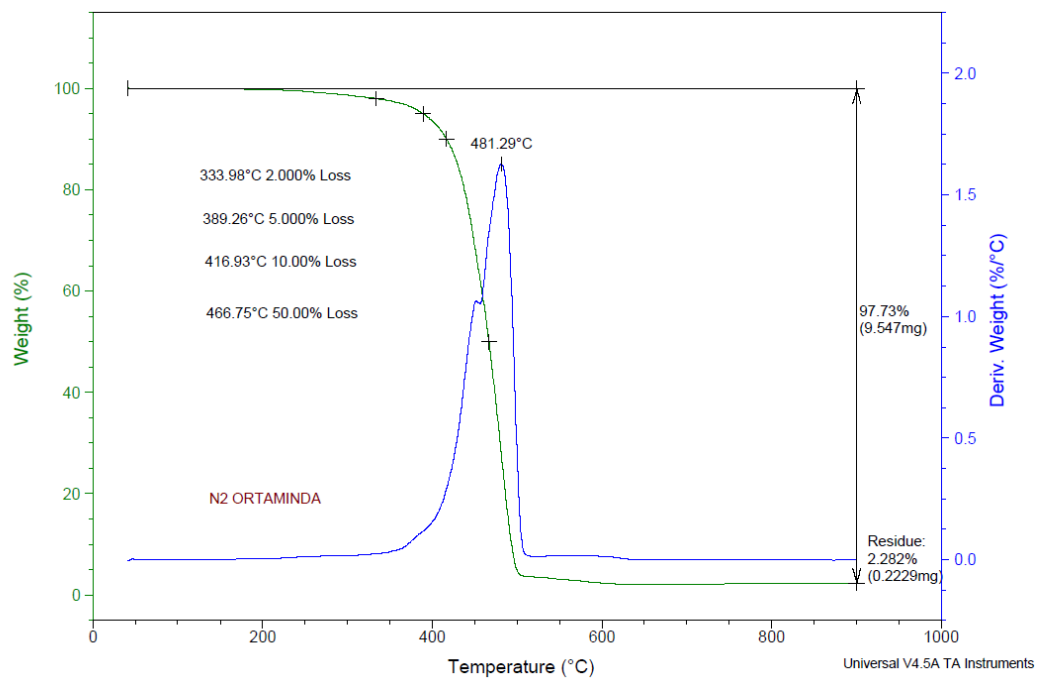


Figure 23 TGA of Coating A

On the other hand, Coating B starts to degrade about 340 °C with 2% of mass loss, as shown in Figure 24, which also can be referred as the degradation of the additives, as discussed for Coating A. The degradation starting points of Coating A and Coating B are 333.98 and 341.47 °C, respectively. This difference can be related to the dissimilarities of additives used in polymerization process of Polymer A and B.

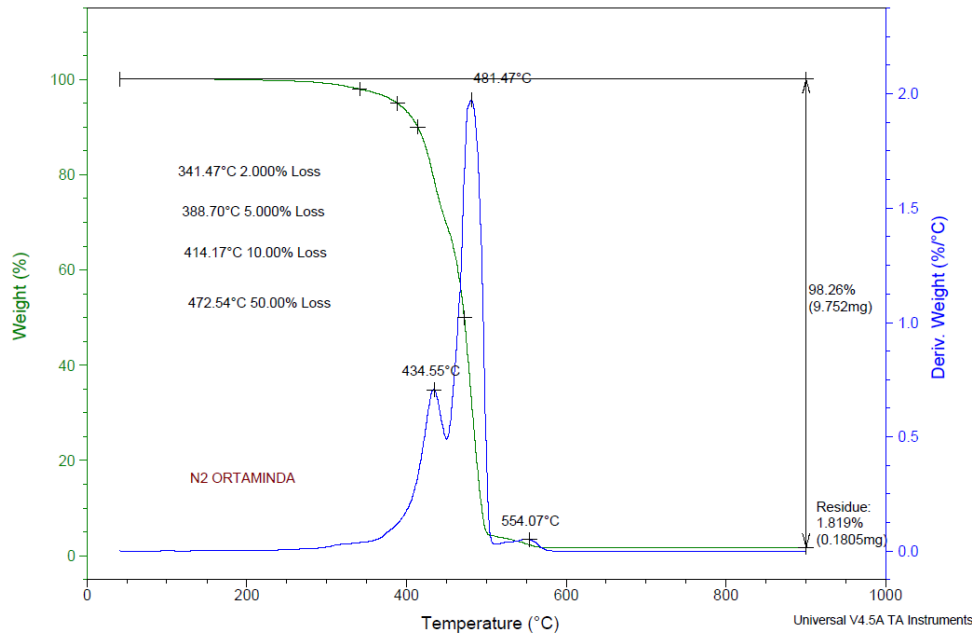


Figure 24 TGA of Coating B

In addition to above discussions, the results have been achieved from TGA about degradation temperatures of coating formulations and polymers, helps us to understand the maximum application temperature for flame spray applications. In other words, when the particles reaches the degradation temperatures, 481.29 and 481.47 °C, for Coating A and B respectively, black spots on the substrate can be observed during flame spray applications due to powder starts to degrade and then burn. This also explains the importance of the sieving and eliminating particles below 60 μm .

3.2 Performance Tests

3.2.1 Adhesion (Cross-cut)

Adhesion resistance of coatings refers to minimum force required to remove the coating film from the substrate it applied on. This property is generally controlled by damaging the coating with specific tools. It is also important to understand the level of adhesion of the coatings since the adhesion is also an indication to corrosion resistance property. The higher the adhesion power results as the higher corrosion resistance and more durable coatings.

In this research, adhesion performance of Coating A and B have been evaluated with cross-cut test according to ISO 2409 standard and favorable results have been achieved with scale of “0”, as shown in Figure 25 for Coating A and Figure 26 for Coating B.

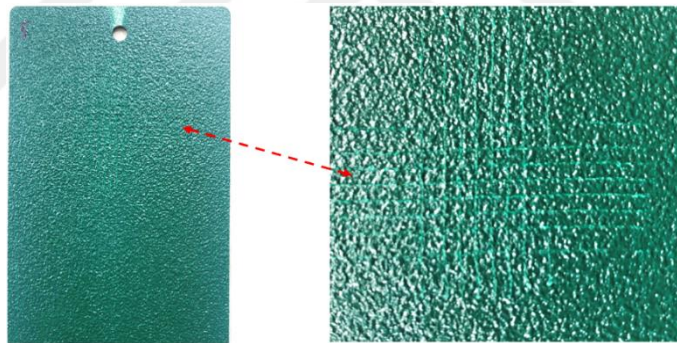


Figure 25 Cross-cut adhesion performance of Coating A

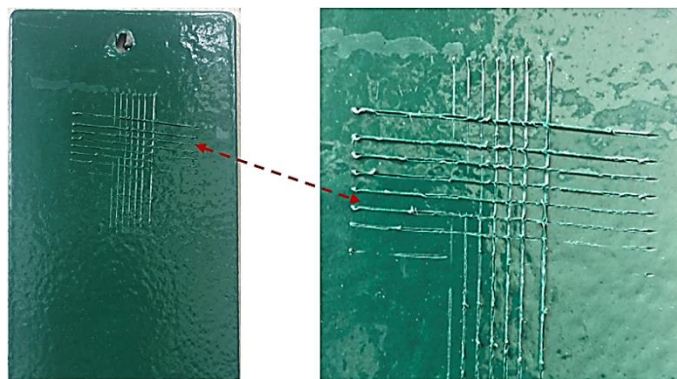


Figure 26 Cross-cut adhesion performance of Coating B

3.2.2 Salt spray

In this study, panels which have been applied by flame spray application with Coating A and B have been tested to investigate their corrosion resistance. The test has been performed in Q-Fog CCT type salt spray chamber according to ISO 9227 with conditions listed in section 2.3.2. In order to evaluate their applicability for corrosivity category of C5, scratched and unscratched panels have been exposed to salt spray solution for 1440 hours.

By the help of excellent adhesion performance of Coating A and B, no adhesion loss have been observed which can be concluded as the corrosion performance of formulations are outstanding. Figure 27 and 28 show that there are no trace of corrosion on the panels.



Figure 27 Salt Spray results of Coating A and B with scratch



Figure 28 Salt Spray results of Coating A and B without scratch

3.2.3 UV Resistance

In this research, Coating A and Coating B have been exposed to UV light in Q-Lab accelerated weathering tester in order to identify their exterior durability against harsh conditions. The test has been performed in line with ASTM D 4587 with conditions listed in Table 11 in Section 2.3.4.

After approximately 1000 h of exposure, panels have been discarded from the chamber and first analysis has been made by visual control in terms of color and gloss change comparison to initial surface.

Figure 29 presents the UV resistance performance of Coating A and B after 1000 hours test period. As it can be observed from the figure Coating A applied panel has a significant gloss and color loss compared to the one that is coated with Coating B.

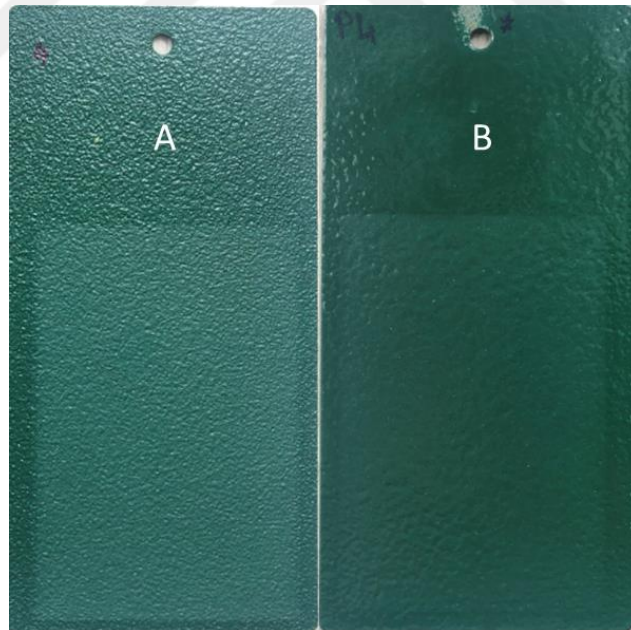


Figure 29 UV Resistance Performance of Coating A and B

Color measurements are done in order to evaluate color loss during UV exposure. Comparisons are done according to Qualicoat standards, as in Appendix A, for RAL 6005 color.

In order to quantify permanent effect of UV exposure on color and gloss, periodic color and gloss measurements have been done in every 150h of exposure approximately and the measurements are recorded. In this part of the research, color and gloss measurements have been performed with X-rite Ci6x type of spectrophotometer.

When color change of RAL 6005 color has been controlled according to Qualicoat standards where ΔE , the measure of change in two given colors, should be smaller than 3.00, gloss retention has also been checked where gloss retentions shouldn't be smaller than 50%.

Table 13 lists the periodic measurements of color and gloss after each 150h of UV exposure in the chamber.

Table 13 Color and Gloss Measurements

		<i>Initial</i>	<i>144h</i>	<i>288h</i>	<i>432h</i>	<i>576h</i>	<i>720h</i>	<i>864h</i>	<i>1.008h</i>
Coating A RAL 6005	L	29.98	30.39	30.94	31.37	31.15	31.06	31.40	32.12
	a	-14.12	-14.16	-13.51	-13.40	-13.93	-12.92	-12.91	-12.77
	b	1.95	1.26	0.76	0.39	0.25	0.16	0.30	0.41
	ΔE	-	0.80	1.65	2.21	2.07	2.41	2.85	3.15
	Gloss	5	4	3	3	3	3	3	2
	<i>Gloss Retention (%)</i>	-	87%	74%	67%	70%	59%	54%	43%
Coating B RAL 6005	L	25.47	25.97	24.69	24.05	24.72	24.35	25.98	26.23
	a	-19.04	-19.29	-19.69	-19.29	-17.86	-18.12	-17.64	-17.03
	b	3.11	3.05	3.01	3.09	2.89	2.78	2.74	2.51
	ΔE	-	0.56	1.02	1.44	1.42	1.49	1.54	2.23
	Gloss	38	36	33	33	30	28	26	23
	<i>Gloss Retention (%)</i>	-	95%	87%	87%	78%	73%	69%	60%

The results show that after 1000 h of exposure, color change performance of Coating B is better than Coating A, with ΔE values of 2.23 and 3.15 respectively. With this color change value, Coating A has not been successful in UV resistance test when it is controlled according to Qualicoat standard. On the other hand, Coating B has good results by having ΔE of 2.23 over 3.00.

Although Coating A has proper color values up to 850 h of exposure, its color value is at the border line at the final 150h round which concluded as negative performance.

When both coatings color performance were controlled around after 450h of exposure, it has been observed that Coating A has already been reached to 2.21 color change while Coating B has 1.44. This can be concluded as the Coating A starts to degrade earlier than Coating B against UV exposure which results as earlier color loss.

Gloss retention of the coating is another important parameter which is controlled after UV kind of exposures. Considering these coatings to be used in exterior parts such as steel constructions etc., it is expected that the coating keeps its gloss value up to min. 50%. After 1000 h of exposure gloss retention of Coating A and Coating B have been resulted as 43% and 60%, respectively. Additional to color change of Coating A, gloss retention performance of this formulation needs further improvement against UV exposures.

Figure 30 shows the graph of UV exposure effect on Coating A and B in terms of color change with increasing exposure time.

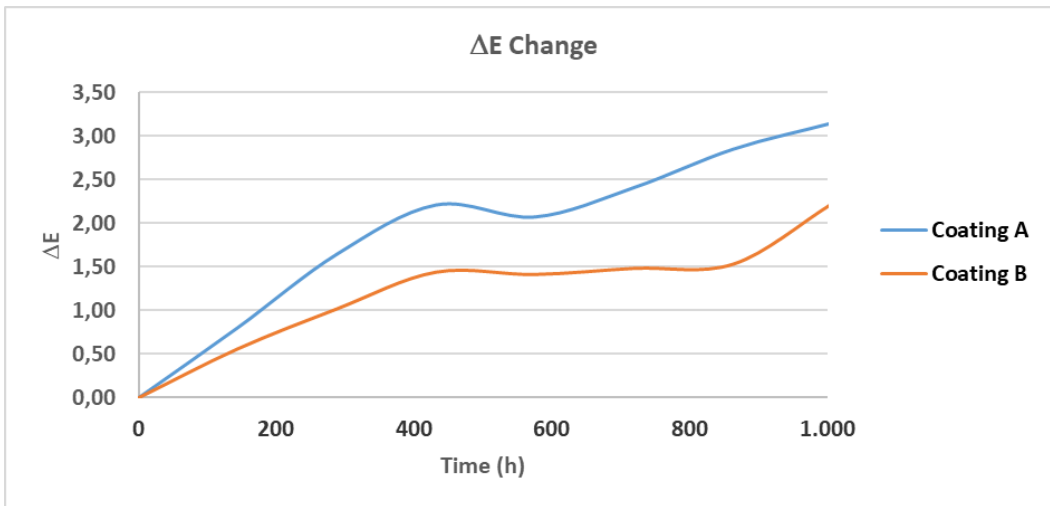


Figure 30 Effect of UV exposure on color of Coating A and B

Figure 31 shows the graph of UV exposure effect on Coating A and B in terms of gloss retention with increasing exposure time.

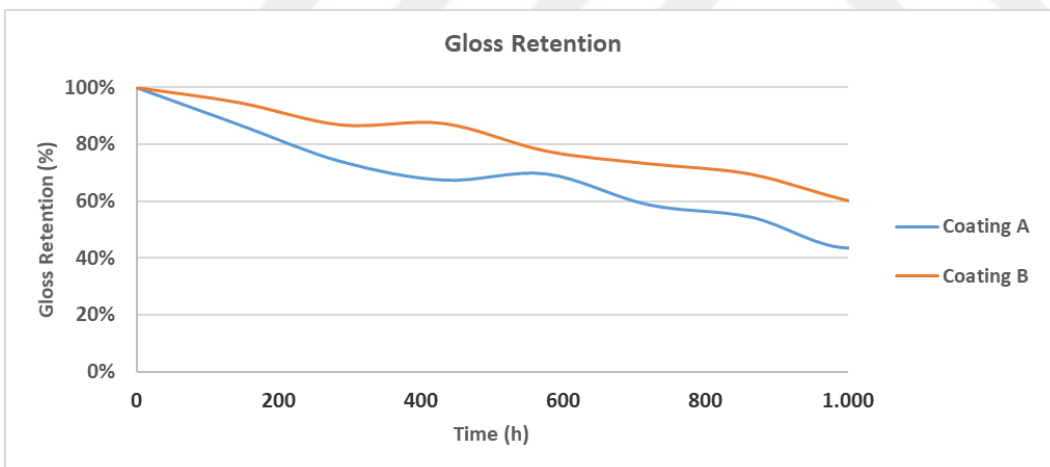


Figure 31 Effect of UV exposure on gloss of Coating A and B

3.2.4 Impact resistance

Impact resistance objective of Coating A and Coating B have been intended as no crack formation and/or coating loss against 1000 mm/kg. These tests have been performed determine the resistance of the coating film to the impacts the may cause rapid deformation. During this study impact has been performed according to ISO 6272-1 on the uncoated side of the test panel in order to observe especially adhesion performance of the coating when exposed to an impact. The tests have been performed on a specific equipment called BYK Gardner.

Figure 32 show the impact resistance test performance results of Coating A and B respectively. As it can be observed form the figure that both formulation have superior results against impact exposures. Neither adhesion nor crack formation observed after the exposure.

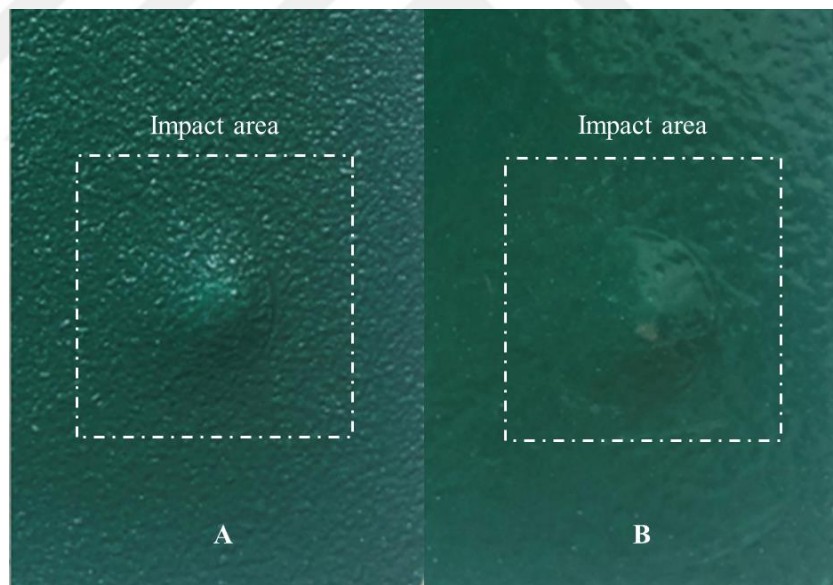


Figure 32 Impact resistance comparison of Coating A and B

This positive result of impact resistance is also important for the handling process of heavy metal parts. During the shipment of such parts, it is inevitable that parts put onto each other and that may cause an impact of the coating even before using the coated parts.

3.3 Visual Surface Analysis

Starting from flame spray applications until dry film formation, surface behavior of Coating A and Coating B have been visually analyzed on the coated panels with film thickness of $250 \pm 50 \mu\text{m}$. Surface appearances of Coating A and B have been analyzed in terms pinhole, orange peel, framing effect and sagging as a part of this research.

In the course of this analysis no pinhole, no significant framing and no sagging have been observed for both Coating A and Coating B.

On the other hand, Coating A has more orange peel look compared with Coating B, which resulted as textured surface, as shown in Figure 33. This visual look can still be fine for application where only function of the coating is required. However, for construction usages this rough surface wouldn't be acceptable.

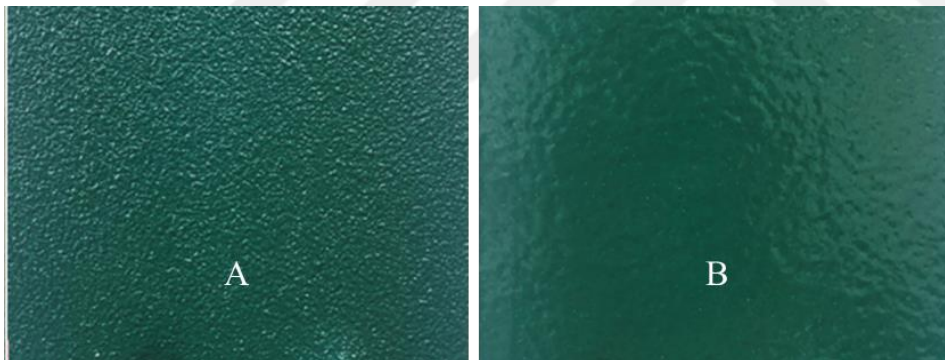


Figure 33 Comparison of Coating A and Coating B in terms of Orange Peel

The main cause of the poor surface appearance of Coating A can be associated with the flowability of the coating which is inflicted by the polymer used in the formulation. In order to validate this cause, additional flowability measurement have been performed for two coating formulations.

Flowability test has been performed as follows;

- Same amount of powder coating samples are placed on a same steel panel
- Panel is then put as flat in a heating oven at 200 °C for 5 minutes.
- After 5 minutes of heating, panel placed in a tool that keeps panel at 45 ° angle for another 5 minutes.
- After waiting 5 minutes at 45 ° angle, flow distance of coatings are measured from the starting point.

Figure 34 shows the flowability of Coating A and B, as 2,9 and 8,2 cm respectively. This results also confirms that Coating B is more suitable than Coating A for flame spray type applications.



Figure 34 Flowability of Coating A and Coating B

4 CONCLUSION

In this research two commercial grade acid modified polyolefins, ethylene acrylic acid copolymer and methacrylic acid copolymer, has been used in order to investigate their effect on the performance of thermoplastic powder coating applied by flame spray.

Two different formulations were prepared by using these two different copolymers and the characterization and performance tests were done. Based on the test results that are shown in Chapter 3 - Results and Discussion, Sections 3.1, 3.2 and 3.3, it can be summarized as follows;

- DSC results have shown that the melting points of these two coatings are very similar which can be considered as their maximum working temperature in hot atmospheres are very much alike.
- TGA results also show that the degradation temperatures of these two coatings are quite similar to each other. By these results it can be said that during the application by flame spray powders' resistance to heat is comparable to each other.
- Adhesion performance is measured by cross cut tests and both coatings had an excellent performance thanks to acidic structures in raw materials.
- Salt spray tests were performed up to 1440 hours for both coating on scratched and unscratched panels. After the tests it has been observed that all panels were in good condition and there was no adhesion loss or any savage corrosion on the panels. Therefore, it can be said that both coatings has an excellent corrosion resistance.
- UV resistance of the coatings were compared and in this case the results show that Coating B has better UV resistance in terms of both color change and gloss retention which means Coating B is more suitable for applications which are exposed to sunlight.

- Impact resistance of both coatings were excellent thanks to their high ethylene content which gives superior flexibility.
- Visual controls show that Coating B had a smoother surface with respect to Coating A.

After considering all of the tests performed it can be said that both Coatings A and B have superior corrosion and UV resistance which are crucial for thermoplastic coatings. In addition, impact resistance and adhesion performance are outstanding thanks to ethylene content. Their melting point can be considered a little bit low with respect to other types of polyolefins but due to their acidic content, which leads to an excellent adhesion performance, it can be acceptable for this kind of applications.

On the other hand, visual controls showed that the surface smoothness of Coating B is much better than Coating A. This phenomena is much related to the difference of the melt flow index (MFI) between two copolymers. Higher MFI allows polymer, Coating B, to flow faster and leads faster smooth film formation. Contrarily, Coating A has lower MFI and the polymer solidifies and forms a textured film.

In conclusion, it can be said that Coating B has better performance than Coating A thanks to its high MFI methacrylic acid copolymer raw material.

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APPENDIX A – QUALICOAT STANDARD TABLE FOR COLOR

A7 - RAL / DELTA E Table

RAL	DELTA E	RAL	DELTA E	RAL	DELTA E	RAL	DELTA E	RAL	DELTA E	RAL	DELTA E	RAL	DELTA E	RAL	DELTA E	RAL	DELTA E
1000	3.0	2000	6.0	3000	6.0	4001	4.0	5000	4.0	6000	5.0	7000	4.0	8000	4.0	9001	2.0
1001	3.0	2001	5.0	3002	6.0	4002	4.0	5001	4.0	6001	5.0	7001	3.0	8001	4.0	9002	2.0
1002	3.0	2002	8.0	3003	4.0	4003	5.0	5002	4.0	6002	4.0	7002	4.0	8003	4.0	9003	2.0
1003	4.0	2003	6.0	3004	4.0	4004	5.0	5003	5.0	6003	5.0	7003	4.0	8004	4.0	9004	5.0
1004	6.0	2004	4.0	3005	4.0	4005	4.0	5004	5.0	6004	5.0	7004	4.0	8007	4.0	9005	5.0
1005	6.0	2008	6.0	3007	4.0	4007	5.0	5005	4.0	6005	3.0	7005	4.0	8008	4.0	9006	2.0
1006	6.0	2009	4.0	3009	4.0	4009	4.0	5007	4.0	6006	4.0	7006	4.0	8011	4.0	9007	2.0
1007	6.0			3011	5.0			5008	5.0	6007	4.0	7008	4.0	8012	4.0	9010	2.0
1011	3.0			3012	2.0			5009	4.0	6008	5.0	7009	4.0	8014	3.0	9011	5.0
1012	3.0			3013	6.0			5010	4.0	6009	4.0	7010	4.0	8015	4.0	9016	2.0
1013	2.0			3014	4.0			5011	5.0	6010	5.0	7011	4.0	8016	4.0	9018	2.0
1014	3.0			3015	3.0			5012	4.0	6011	4.0	7012	4.0	8017	4.0	9022	2.0
1015	2.0			3018	5.0			5013	5.0	6012	4.0	7013	4.0	8019	3.0		
1016	6.0			3017	8.0			5014	4.0	6013	3.0	7015	4.0	8022	5.0		
1017	3.0			3018	5.0			5015	3.0	6014	4.0	7016	3.0	8024	4.0		
1018	6.0			3020	4.0			5017	5.0	6015	4.0	7021	4.0	8025	4.0		
1019	3.0			3022	4.0			5018	5.0	6016	5.0	7022	4.0	8028	3.0		
1020	6.0			3027	6.0			5019	4.0	6017	5.0	7023	3.0				
1021	6.0							5020	5.0	6018	4.0	7024	4.0				
1023	3.0							5021	4.0	6019	2.0	7026	4.0				
1027	3.0							5022	5.0	6020	2.0	7030	2.0				
1028	8.0							5023	4.0	6021	4.0	7031	4.0				
1032	6.0									6024	3.0	7032	2.0				
1034	4.0									6025	5.0	7033	3.0				
1038	2.0									6026	5.0	7034	3.0				
										6027	2.0	7035	2.0				
										6028	5.0	7036	3.0				
										6029	5.0	7037	3.0				
										6033	2.0	7038	2.0				
										6034	2.0	7039	4.0				
												7040	3.0				
												7043	3.0				
												7044	2.0				
												7047	2.0				

APPENDIX B – CATEGORY OF CORROSIVITY AND TEST PROCEDURE

1. Category of Corrosivity

C1: Very Low	Almost no risk
C2: Low	Atmospheres with low levels of contamination. Rural areas.
C3: Medium	Urban and industrial atmospheres, with moderate contamination. Coastal areas with low salinity
C4: High	Industrial areas and coastal areas with moderate salinity.
C5-I: Very High (Industrial)	Industrial areas with high humidity and with an aggressive atmosphere.
C5-M: Very High (Marine)	Coastal and marine areas with high salinity

2. Test procedures for paint systems applied to steel (EN ISO 12944-6)

Corrosivity category as defined in ISO 12944-2	Durability ranges	ISO 2812-1 ¹⁾ (chemical resistance)	ISO 2812-2 (water immersion)	ISO 6270 (water condensation)	ISO 7253 (neutral salt spray)
		h	h	h	h
C2	Low	—	—	48	—
	Medium	—	—	48	—
	High	—	—	120	—
C3	Low	—	—	48	120
	Medium	—	—	120	240
	High	—	—	240	480
C4	Low	—	—	120	240
	Medium	—	—	240	480
	High	—	—	480	720
C5-I	Low	168	—	240	480
	Medium	168	—	480	720
	High	168	—	720	1 440
C5-M	Low	—	—	240	480
	Medium	—	—	480	720
	High	—	—	720	1 440