COSMOS – GUIDE 3

Informative Guide on Paints and Coating Systems

.I. COMPONENTS OF ANTI-CORROSIVE COATING PAINTS

1. **Resin or binder:** They are like the bricks in coatings. It is the main structural component that gives solid paint its hardness, among other properties.
2. **Hardener:** Only thermostable paints use it (see glossary). Normally polyamides or polyamines are used. They are molecules that bind the resin molecules in a three-dimensional way during the paint preparation phase, where the resin is mixed with the hardener.
3. **Solvent:** Important for thermosetting paints. Reactions between the hardener and the resin can only occur if both are present as a liquid (so that they can be mixed and their molecules have a greater degree of freedom). Many resins occur naturally in a solid state; therefore, other molecules (solvent) must be applied whose only function is to dissolve the resin to give it the properties of a liquid. Once the paint has been prepared and applied to the substrate, the solvent is useless and will eventually evaporate.
4. **Pigments:** They are particles, mainly of iron and other components, that will give color to the paint and protect it against corrosion through chemical reactions (cathodic protection) or mechanical reactions: (1) some iron pigments when corroded create layers that prevent the advance of moisture, (2) pigments within the already applied and dried paint can block pathways through which moisture could enter; this is called impermeability.
5. **Additives:** Additives are substances that are added to paint to give it certain useful properties such as, for example: that there are no bubbles, that the impurities of the water (if used as a solvent) do not react with the resin, that the pigments are kept separate during the storage of the paint, that the solvent is less dense, etc.

.II. PHASES OF COATING APPLICATION

1. **Pretreatment:** Every substrate must be pre-treated before applying the first coat of paint (primer). First, the old paint must be removed; either through sandblasting or sanding, so that it does not interfere with the adhesion of the new paint. In addition, sandblasting and sanding allows for the creation of a certain roughness in the substrate that will improve the mechanical adhesion of the first layer of paint. Afterwards, proper cleaning must be carried out with alkaline agents or detergents. These will help remove greasy substances such as oil or animal fat, etc. Likewise, it will help remove accumulated dust or dirt. It is important to not wait too long after cleaning the substrate to apply the primer layer, since by removing the grease or dirt from the metal we are causing it to become very reactive since it will no longer be attached to this grease and will become unstable again. It seeks to join other substances to achieve its stability again. Let us remember that steel or iron is very reactive and unstable (that's why it tends to corrode easily). So by applying the primer we are forcing it to react with the primer molecules and prevent unnecessary corrosion (this benefits us).
2. **Primer Application:** The primer has two main functions: 1) it has an ideal formulation to adhere well to metal surfaces and subsequent layers of paint and 2) it contains a variety of pigments that, when they come into physical contact with the metal, will protect it from corrosion.
3. **Application of paint layers:** On top of the primer layer, intermediate layers are added and then the final layer or enamel is added. These layers serve to increase the level of waterproofing of the entire paint as a whole, carry more pigments that will help in the fight against corrosion and, in the enamel layer, carry the appropriate pigments to give the paint its desired color.

.III. PAINT PREPARATION

1. **Agitation:** In the first instance, the pigments, even if they are separated by the action of some additive used in the preparation, will likely sink to the bottom of the canned paint because they weigh more than the solvent molecules. Therefore, it is necessary to mix the paint well so that the pigments get distributed evenly; the mixing action should not stop when mixing the resin with the hardener. It is very important that mixing is constant and must be done even during the application of the paint. This way we ensure ourselves that for every paint-spray added onto the substrate that there are pigments. There are cases in which after pouring paint on a pipe, for example, there have been areas without color or more corroded than others. This is because fewer pigments reached those areas.
2. **Mix:** The thermosetting resin (epoxy or polyurethane) is mixed with the hardener. It is during mixing that the hardener and resin molecules begin to react and/or join together. You can see that the substance, from being a relatively light liquid, begins to thicken until it becomes like a gel. This means that the hardener-resin bridges are already forming. As the hours pass, the product will become like a rock, completely hard. It is important to know that the reaction between the hardener and the resin is exothermic; this means that it will release a lot of heat (it is a reaction that produces energy). Therefore, it could easily melt a container that is not designed to withstand such a reaction. On the other hand, it is known that energy is good for encouraging reactions, which creates a virtuous circle. The energy released by the first hardener-resin reactions helps the

other reactions occur more quickly (similar to how the energy of the first spark when trying to light a fire helps the fire to occur again and again until reactants run out).

3. **Application:** Application is the process in which liquid resin mixed with hardener is poured onto the substrate. They can be applied using an airless or brush, among others. At this stage it is important to have taken into account the viscosity (see glossary) of the paint. A very thick paint will be difficult to apply. The thicker the paint, the more power the spray machine will need. On the other hand, if it is done with a brush or similar methods, be careful with leveling, since a thick or viscous paint will level worse due to the low mobility of its molecules.
4. **Drying:** Drying is the process in which the solvent evaporates due to the action of ambient heat and only the cured resin remains.

.IV. ABOUT THE COATING ITSELF

Paints can be divided into thermostable or thermoplastic depending on the structure that their molecules form when they solidify. Thermosetting paints are used for industrial coatings because they are hard and resistant.

1. **Thermostable (thermosetting) paint:** Paint whose resin molecules form a three-dimensional structure that is impossible to return to its initial state. They are hard and resistant, precisely due to their three-dimensional structure, since each molecule is linked to other molecules in three dimensions. They need a hardener that binds the resin molecules together during the paint preparation phase.
2. **Thermoplastic paint:** Coatings that do not form three-dimensional structures. They do not need a hardener. They are softer and can return to their initial state if heated, for example.

.V. ABOUT THE DRYING PROCESS

1. **Curing:** Curing is a terminology used when the hardener and resin form their chemical bridges creating a hard and strong three-dimensional structure.

.VI. ABOUT PAINT WHEN IT IS A LIQUID

1. **Viscosity:** It is a property of liquids that refers to the ease with which their molecules flow or move between them. The viscosity of a liquid depends on several factors: the size of the molecules, their intermolecular bonds, their asymmetry, etc. The larger and more asymmetric the molecule, the more difficult it will be to move through a volume. It is like comparing the movement of 2 mechanical shovels with their loaders located in random places trying to move along a highway, in comparison to 2 small and compact cars. In comparison to a liquid, mechanical shovels would be more viscous than cars. Likewise, the stronger the chemical bond between molecules, the stronger the attraction between them and, therefore, the more difficult their relative movement. It would be like having a person holding you tightly when you try to move them relative to them.
2. **Viscosity Types:** Viscosity can be divided into 4 types according to how the liquid to be stirred reacts. There are Newtonian, pseudoplastic, thixotropic and dilatant liquids. Newtonian liquids are

those whose viscosity does not vary despite stirring the liquid: its viscosity remains constant. Pseudoplastics are those that become less thick when shaken, but quickly return to their original viscosity when shaking is stopped. Thixotropics are the ideal liquids as coatings, since they become thinner when shaken and slowly return to their original thickness. This is useful in the application of paint because it allows the liquid to become super easy to discharge by simply shaking it and also allows, due to its slow transition to its original thickness, to move it over the substrate after being applied and make the layer achieve leveling. If it thickened quickly it would create a very rough and uneven layer of paint. Finally, dilatants are those liquids in which the opposite of everything previously said happens: they become thicker when shaken. It is not applicable to paintings.

3. **Shear Stress:** Shear stress is the name given to the agitation that is given to the paint before applying it to the substrate. This serves to make it less thick and to also mix the pigments settled at the bottom of the paint so that they are evenly distributed.
4. **Leveling:** Levelness is how flat the paint is on its surface. Flatness or roughness is evaluated at the level of microns (a very small unit, more perceptible to our touch than our sight since it is one-thousandth part of a millimeter). The degree of leveling depends on many variables and occurs during the liquid phase of the paint until it dries. Among the variables are 1) viscosity, 2) surface tension, 3) cohesive forces.
5. **Surface tension:** It is a property of liquids. It tells us how strongly the molecules below the surface attract (pull down) the molecules on the surface. This property explains why water droplets have a spherical shape. The more surface tension a paint has, the less leveling it will have, since the molecules will not spread homogeneously over the entire surface, but will create shapes on the surface as happens with water droplets.
6. **Cohesive forces:** It is the same as surface tension. Surface tension is a cohesive force reserved only for surface molecules. Cohesive forces are the forces of attraction BETWEEN molecules of the same liquid substance. The opposite case are the adhesion forces, which would be the forces of attraction between molecules of different substances.
7. **Problem between surface tension and painted substrate corners:** In the corners there are only molecules on one side that exert surface tension. Therefore, these molecules will pull on the molecules that are right at the tip of the corner, creating a rounded shape. This will make the corner area less covered in paint and therefore more unprotected. For this reason, more paint is usually added to the corners.

.VII. ON THE ADHERENCE OF THE PAINT TO THE SUBSTRATE

1. **Adherence**: It is the force with which the paint molecules are united to the substrate molecules. They can be joined through chemical or physical bonds such as covalent bonds (the strongest chemical bond produced by the electrons of atoms) or physical bonds (concerning opposite poles that attract each other and produced by opposite electrical charges) or also adhesion can be produced by mechanical mechanisms, such as the overlapping position between the dried paint and the substrate. For example, the serrated shape between the substrate and the paint prevents the paint from easily delaminating. Another form of adhesion occurs when the substrate is so porous that the molecular chains of the paint get into its pores and a type of mechanical adhesion

occurs. It is as if we were putting needles through a fabric and then trying to remove them in orientations other than their axis of penetration. The fabric will act as a kind of block to the effort.

.VIII. ON MOLECULES AND CHEMISTRY

1. **Covalent bond:** It is the strongest bond between atoms that exists. Atoms share their valence electrons and this happens because by sharing them, atoms are more electromagnetically stable.
2. **Physical links:** It is a bond between molecules. It occurs due to the electrical forces of attraction between a difference in charges (+ and -). They are weaker than covalent bonds, but they allow the molecules of a substance to join together.
3. **Electromagnetic stability**: It occurs when a molecule no longer needs to react to feel stable. This happens once all the molecules have reacted until they find their equilibrium state. For example, when the resin and hardener have completely reacted.
4. **Temperature**: In physics, temperature is the average random speed that the molecules of a body have. Although these molecules have speed and are moving, the entire body does not do so because the speeds of each one go in different directions and together cancel each other out. Thus, the more its molecules move, the hotter the object will feel to us.
5. **Second law of thermodynamics**: Hot bodies warm cold bodies and not the other way around. The second law of thermodynamics tells us that the universe tends to become disordered over time. In this case, the molecules of the cold body are relatively still, the hot body arrives with its molecules moving randomly in all directions and these collide with the cold molecules and begin to agitate them. That is, a transfer of energy in the form of heat has occurred. The molecules of the hot body lose their energy of motion and give it to the cold body. Thus the hot body cools down a little, and the cold body becomes warm. Energy is neither created nor destroyed, it is only transferred.
6. **Anode and cathode**: In a REDOX reaction or rather oxidation and reduction: The anode is the part of the reaction where electrons are lost (oxidized) and the cathode is the part that gains electrons (reduced). Example: In metal corrosion the anode is the metal losing electrons and the cathode is the oxygen and water gaining them.

.IX. MECHANICAL PROPERTIES

1. **Elastic deformation**: Elastic deformation is the reversible deformation that a body can experience. That is, its molecular chains are stretched but due to its elastic molecular bonds, they withstand the tension and cause the molecules to return to their original position once they are no longer stretched. Similar to the operation of a spring.
2. **Plastic deformation**: Plastic deformation is the permanent or irreversible deformation that a body can experience. In this case, the molecular chains stretch too much, the molecular bonds cannot withstand so much tension and they begin to deform forever (or may break). Whether it deforms or breaks depends on the degree of tenacity of the body. Bodies that are more tenacious will have molecules that can move more relative to each other, without the need to break apart. This is very useful and helps avoid untimely ruptures when the elastic limit is exceeded. Although, eventually, if you keep stretching it, it will break at some point.

3. **Elastic limit**: The elastic limit is the maximum amount of stress or deformation that a body can undergo without undergoing permanent changes in its shape. Behind this elastic limit, even if the body deforms, it will return to its original shape after the stress has ceased. But beyond that the body will have been permanently deformed.
4. **Hardness**: Hardness is the ability of a body to resist deformation both elastically and plastically. It is also known as resistance to penetration or perforation. This measurement mechanism is precisely used because in penetration the structural participation of the body is avoided and we directly test the resistance of small areas.
5. **Tenacity/Resistance**: Tenacity is the ability of a body to deform plastically until breaking once the elastic limit has been exceeded (only covers the plastic part).
6. **Rigidity**: A body is called rigid when it deforms very little in reversible or elastic terms.
7. **Elasticity**: A body is called elastic when it deforms enough in reversible terms.
8. **Strength:** Strength is a property of bodies that tries to represent how much energy or effort a body can receive until it breaks. It covers both the elastic and plastic parts.

.X. OPTICAL PROPERTIES

1. **Brightness and nuance (light intensity in one direction):** Gloss is the property that some bodies have of reflecting light with high intensity. This means that due to optical phenomena, the molecules of the shiny body do not absorb much of the light energy that reaches them and rather reflect almost all of it. Because we carry so much energy, our eyesight is overwhelmed and we prefer to close our eyes. The glow can be specular or diffuse.
2. **Specular and diffuse reflection (direction of reflected light):** In specular reflection, each ray of light that is reflected outward is parallel, so the figures that our visual perception interprets as containing that light are preserved despite bouncing off the body with specular brightness. This is what is known as a mirror. Bodies with specular reflection are mirrors. On the other hand, a body whose light is reflected in all directions will not be a mirror. Specularity and diffuseness are created 1) through the roughness or smoothness of a surface. If it is very rough, the rays will be reflected in many directions, if it is completely smooth in only one direction. 2) the refractive index of the molecular framework; that is, how much pattern there is in the direction in which light is transmitted through the body's molecules. Because in the end the light that is reflected outside is not the product of a single interaction but of many interactions between the molecules within the body.
3. **Opacity and transparency (ability to reflect light):** Opacity is an optical property of bodies that reflect and absorb much of the light energy that reaches them. That is, the light does not pass through the object; a person behind the object will not be able to see the light reaching them. On the other hand, transparent or translucent objects are objects whose light travels through them and manages to exit through the back. Transparency or opacity depends greatly on the structural pattern of the body and the refractive index and the type of molecules it has. As long as there is more chaos in the structure, the light will come out in many directions and therefore interact with many more molecules, causing the light energy to be transformed and in the end (if it comes out) come out with low intensity. Refraction refers to the change in direction that light waves undergo once they have interacted with molecules. Some molecules will cause some waves or “colors” to

deviate more than others, causing some “colors” to never make it out. This is the case of translucent colored glass, for example. In some other cases no wave can escape. Something similar happens with the sky. The color blue is the only color that manages to leave the atmosphere towards the earth. All other colors are refracted or dispersed in such a way that they lose all their intensity between so many interactions with atmospheric matter. The same thing happens at sunset, but with the reddish-orange color due to the position of the sun. In this case, the orange color is the one that reaches our eyes and the blue reaches the people who are under the sun.

4. **Color:** In physical terms, color is the interpretation that human perception gives to electromagnetic waves according to their frequency and for a certain range of the electromagnetic spectrum. So it can be said that color is nothing more than the frequency of the different electromagnetic waves reflected by a body. For example, if sunlight reaches a body and it absorbs all the “colors” except red (which reflects it), then humans have agreed to say that this object is red; but it is nothing more than the wave that reflected and reached our retina to be processed by our brain.
5. **Reflection and transmission of light:** The reflection of light is the phenomenon by which light reaches a body and it does not absorb it or allows it to pass through, but rather the wave is expelled from where it came from. This can occur when the molecules and the electrons in the molecules do not resonate with light. Since they do not enter into resonance, they do not collide with other neighbors or lose light energy, but rather they only move as we would move in the ocean due to the action of the tide. The tidal energy is so great and our inertia is so low that the tidal energy is minimally affected and simply passes through us. This is an example of light wave transmission and is characteristic of transparent or translucent bodies. In the case of reflection, we could imagine that instead of a human being moved by the tide, there is a firm hydraulic dam. In that case the energy of the tidal wave cannot move the rigid and resistant molecules of the material of which the dam is made and by action-reaction, the energy returns to where it came from. Something similar happens with light reflection.
6. **Light absorption:** In this type of interaction, light interacts with matter so synchronically that matter absorbs the light's energy and reaches high-energy states; so much energy that it ends up colliding with neighboring molecules and transforming the light wave into heat or random movement. The waves are lost, but the energy is not: the body temperature increases. This is the reason why black bodies heat up faster than white ones. The white light from the sun reaches the black pigment of the fabric and absorbs all its energy and converts it into heat. On the other hand, the white fabric reflects all the light. It all depends on the pigments in the fabric. These are the ones responsible for absorbing certain wavelengths. We could compare the interaction of molecules with light in this case as that of a swing that is pushed forward at just the right moment so that each push reaches a greater height in its movement. It is a resonant interaction.
7. **Light refraction:** Light refraction is the change in direction that light waves experience when they pass through a material. The speed of light changes depending on the material through which they move. It is well known that light is an electromagnetic wave and does not need a medium to exist or transit. Light can move through a vacuum, as it does in outer space. However, when it passes through a medium, such as water, air or a specific body, it interacts with the molecules of this body and each interaction makes it “lose time” and therefore move slower in terms of distance per unit of time. In addition, we know that sunlight is made up of many waves, each with a certain

frequency. Molecules react differently for each of these waves. With some waves the interaction will take longer; with others less. Then the light beam will disperse into its components and the colors will split. This is the phenomenon that occurs with the formation of the rainbow. After the rain has fallen, once the sun has risen, the light disperses in the humidity of the atmosphere and depending on the direction in which we look we will see one of the 7 colors of the rainbow.

.XI. AGAINST CORROSION

1. **Cathodic protection by anodic sacrifice:** Cathodic protection by anodic sacrifice is the technology used with paint coating systems to prevent the metal to which it is applied from corroding. This protection is achieved because the metallic pigments contained in the paint system oxidize faster than the metal. For example, zinc oxidizes faster than iron and the electrons lost from zinc prefer to go to oxidized iron rather than to water and oxygen. The end result is that the electrons from the zinc are transferred to the metal that we want to protect by preventing it from oxidizing. This protection is guaranteed until the zinc pigments are completely corroded and cease to exist.
2. **Waterproofing:** Waterproofing is known as the condition in which the pores of a body are blocked or minimized. Every body contains pores, no matter how microscopic they may be. According to our visual perception, we see everything smooth, but atomically there are large spaces between the molecules; and molecules from outside the body, such as gases or liquids, could enter through those pores. So waterproofing consists of trying to cover those pores so that moisture does not reach the metal. No matter how much we apply paint to a metal, if it is a single layer or its molecular structure is very porous, corrosive atmospheric particles will enter through its pores until they reach the metal. This is how it happens, although it seems counterintuitive to our mind. By applying many layers, through probability, we are causing previously open paths to close and thus there are fewer channels through which moisture can enter.