Application of Vacuum Coating Process in Metallization of Plastic Surface

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Abstract: The metallization of plastic surface will improve the surface properties of plastic and make it have the unique functions of both plastic and metal. Vacuum coating process is one of the main technologies of modern plastic surface metallization.The principle of plastic vacuum coating technology and its common coating methods were introduced, the particularity of plastic as the substrate material of vacuum coating was analyzed, the application of vacuum coating process in the metallization of plastic surface was expounded, and the current research hotspots were put forward.

1.Introduction

There are many methods to metallize plastic surface, such as electroplating, thermal spraying, vacuum coating, which can achieve the purpose of metallizing plastic surface. Among these methods, vacuum coating method is considered to be one of the most effective means of metallization of plastic surface. It is in the high vacuum state using heating or ion bombardment method to make the metal material from solid state into gas state in molecular or atomic form deposition on the plastic surface to form a thin layer of metal film [1].

2.Plastics vacuum coating process

Vacuum coating commonly used methods include vacuum evaporation coating, magnetron sputtering coating and ion coating, Fig.1 shows the process diagrams of three common vacuum coating methods.[2] Vacuum evaporation coating is heated in a vacuum environment, so that the coating material evaporates in a very short time, and the molecules of the evaporated coating material deposit on the plastic surface to form a coating layer.This method is simple and convenient, easy to operate, fast film forming speed, high efficiency, is the most widely used technology in the film vacuum preparation, but the film and matrix bonding is poor, the process repeatability is not good, can only evaporate low melting point metals such as aluminum.Magnetron sputtering coating is to fill inert gas in vacuum and add high voltage between plastic substrate and metal target. The inert gas is excited by electrons generated by glow discharge to produce plasma. The plasma shoots out atoms of metal target and deposits them on the plastic substrate.Due to sputtering atom energy is 1 ~ 2 orders of magnitude higher than evaporation atomic energy, high-energy sputtering atom deposition in the matrix transformation, can happen even part injection, sputtering film-forming process at the same time, the substrate in plasma was cleaned and activated all the time, so the sputtering deposition and adhesion is better than evaporation coating on the surface of the plastic,The film is dense and uniform. If the workpiece is rotated properly, a more uniform coating can be obtained on the complex surface.Ion coating is the combination of evaporation process and sputtering technology, it is in the coating at the same time using charged ions bombarding the workpiece surface and film layer, so that the coating layer and matrix bonding force is good, not easy to fall off.Because the energy of the metal atoms is lower than that of the steam plating, even the plastic with poor heat resistance can generate a good stability of the metal film on its surface[3].

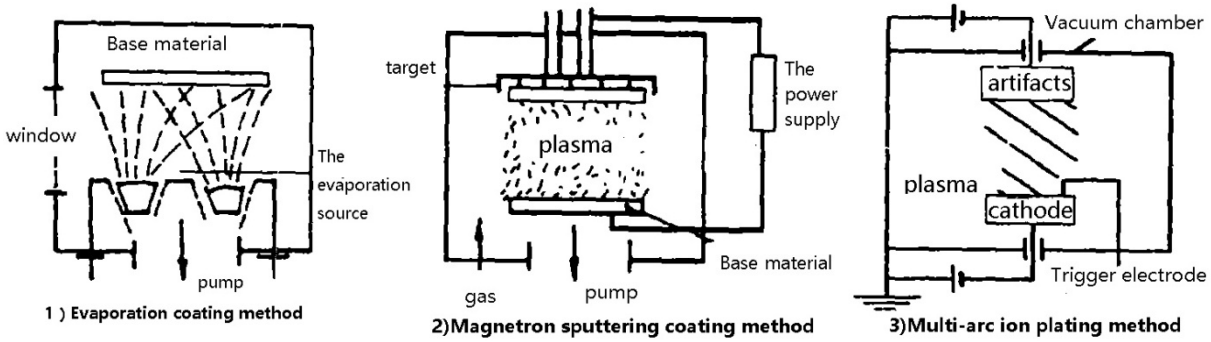

Fig. 1 Three common vacuum coating process diagram[2]

3.The particularity of plastics as coating substrate material

Many different kinds of plastic, not all can be vacuum coating, some with the adhesion strength of the metal layer is very poor, there is no practical value, some physical properties such as the expansion coefficient of metal coating difference is too big difficult to ensure that its use in high temperature environment performance, vacuum coating compared with metal, glass and so on, As the base material, plastics have certain particularity [4].

3.1 Plastics substrate has poor heat resistance, which restricts the deposition temperature

Plastic belongs to polymer organic matter, heat resistance is poor, especially optical plastics, generally in 35 ~ 45℃ temperature for coating.When vacuum coating is used, no matter what method is used, the matrix is affected by heat, such as the radiant heat of evaporation source, the kinetic energy of high energy sputtering atoms impacting the matrix and the condensation energy of atoms of coating material, which will cause the temperature of the matrix to rise.The substrate temperature is controlled within the allowable range to restrict the deposition temperature during vacuum coating.

3.2 Poor adhesion between plastic and metal coating

The adhesion between plastic and metal coating is poor first because the surface energy of plastic is generally low, the surface polarity is poor;Secondly, plastic is easy to carry static electricity, surface easy to absorb dust, plastic parts and soft, poor chemical stability, not easy to get a really clean surface, and plastic surface cleanliness is an important factor affecting the adhesion between plastic and metal coating.Third, even if the plastic surface is kept clean, because the expansion coefficient of plastic and metal is an order of magnitude different, in the film forming process or after film forming, temperature changes will produce thermal stress, stress will make the coating cracking and even fall off.In addition, due to the influence of technology and other factors in the deposition process of metal membrane structure caused by its internal stress, when the internal stress is large, the membrane material deposited on the plastic surface, the internal stress will be transferred to the metal coating, thereby reducing the stability of the coating, and even make the coating cracking and wrinkling.In order to solve the problem of the combination of metal coating and plastic matrix, to ensure that the coating and plastic surface have good adhesion, vacuum coating, the plastic surface is coated with the affinity of the coating metal, or the plastic surface for corona discharge activation treatment.Pan Yongqiang[5] has used plasma bombardment technology to improve the adhesion between plastic substrate and vacuum coating layer. As shown in Figure 2, with the increase of plasma ion energy, the number of reciprocating friction that the film layer can withstand increases rapidly. When the ion energy is about 80 eV, the round trip friction number reaches 25 times, which has reached the national standard. When the ion energy is greater than 100 eV, its increase gradually slows down.

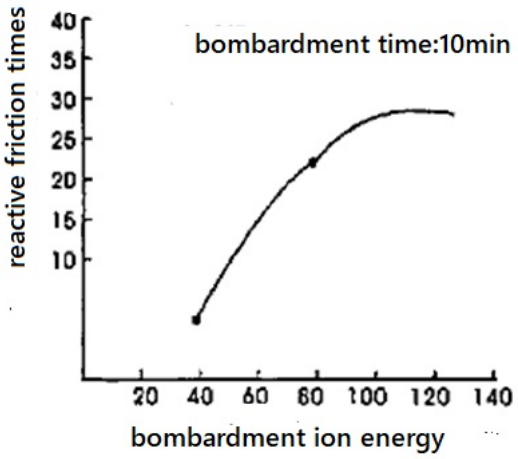

Fig. 2 Relationship between bombardment ion energy and reactive friction times [5]

3.3 Plastics are easy to deflate in vacuum environment

Plastic materials contain air, residual solvent, water, plasticizer, etc., in the vacuum condition of one or more of the above components released, will make the vacuum degree decreased, prolong the vacuum time, affect the whole coating effect, serious and even make the vacuum coating operation difficult to carry out.And different types, different manufacturers of plastic materials, the gas content is not consistent, even if the same kind of plastic, its exhaust characteristics in each evaporation may be different, which will give plastic vacuum coating caused great difficulties.In order to obtain the ideal coating layer on the plastic surface, the most commonly used method is to choose the appropriate coating to close the plastic surface, reduce the amount of air release under the vacuum state, or use a double-chamber vacuum device to improve the pumping efficiency.At present, ion bombardment and vacuum heating and baking, the two degassing methods have been widely used.

4.Application of vacuum coated plastics

4. 1 Application of decorative function

The typical application of decorative film is gold and silver wire. The gold and silver wire processed by aluminum plating of polyester film has become an indispensable decorative material for textiles and is very popular in daily necessities, handicrafts, stage art supplies and other aspects of the application.In addition, decorative plastic coating is also widely used in instruments, machinery, automobiles, toys, lamps and household appliances and other fields, has a high economic value and practicability.Such as in the plate production, Japan is useful magnetron sputtering Ni, Cr instead of wet electroplating, in the convex plastic signs on the plating of words, graphics, good decorative effect;Straumal B et al. also used vacuum arc deposition to coat large areas of plastic surface with decorative coatings of Ti, TiN, TiO and TiN/TiO [6].

4.2 Application of barrier function

In order to improve the circulation cycle and shelf life of goods, the role of commodity packaging is increasingly important, especially for food, medicine, cosmetics, washing products and other goods with high quality requirements, the use of high barrier performance packaging materials is often the most effective means.The commonly used high barrier packaging film is usually plated with a layer of aluminum on the plastic film by vacuum evaporation or vacuum sputtering.Recently, people not only require commodity packaging film with heat resistance and high barrier, but also require good transparency and excellent microwavability.One of the methods to make high barrier transparent film is to vacuum plating SiO_x on the plastic film. The inorganic layer of silicon oxide film is dense, which has high barrier, high temperature resistance, transparency, microwave transmission performance is good, and it has the effect of keeping fresh and fragrance similar to glass container.In addition to SiOx, there are Al_2O_3, MgO, TiO_2, Gd_2O_3, Y_2O_3 and so on.

4. 3 Application of electromagnetic function

Now, electronic instruments toward "light, thin, short, small" and multifunctional, high performance and low cost direction. Plastic chassis, plastic parts or panels are widely used in electronic instruments. External electromagnetic waves can easily penetrate the shell or panel, causing harmful interference to the normal operation of the instrument.The electromagnetic wave produced by the instrument is also very easy to radiate into the surrounding space, affecting the normal work of other electronic instruments.In order to meet the electromagnetic compatibility requirements of this electronic instrument, a metal film is vacuum coated on the plastic surface.After surface metallization treatment, the completely insulated plastic surface has the characteristics of reflecting, absorbing, conducting and attenuated electromagnetic wave like metal, and can play the role of shielding electromagnetic wave interference.The electromagnetic function of the plastic vacuum coating layer is also used in the production of capacitors, electromagnetic shielding packaging film, transparent conductive film with high conductivity, magnetic film, copper-plated flexible printed circuit board, selenium rectifier and so on. For example, in the electric power industry, the film capacitor which is windinged by the plastic vacuum plating film is an important component, and the plastic film such as polyester and biaxial tensile polypropylene after vacuum coating treatment can be used as the electrode of the capacitor.Transparent conductive plastic film with transparent conductivity, used in the production of solar cells and electrochromic devices transparent electrode.Magnetic thin films have been widely used in magnetic recording and magneto-optical storage.

4. 4 Application of light and heat functions

Compared with matrix plastics, metallized mirror plastics not only have a sense of precision, weight and magnificent decoration, but also are superior in mechanical strength, heat resistance, dimensional stability and water absorption.The light and heat function of the plastic vacuum coating can be used to produce the reflective cover of civil mirror, car lamp, flashlight, road sign, glasses, lens, astronomical

telescope, interference filter, regulating film of sunlight and so on.Plastic lenses, for example, are coated with silver and chromium to reflect strong and harmful light.If a thin layer of aluminum is plated on the polyester substrate to form a solar regulating film, it can filter sunlight and save the cost of room cooling in summer.In agriculture, the light and heat function of plastic vacuum coating layer can also be used to produce translucent sun-shading and energy-saving film, which is used as heat preservation and cold-proof film for orchards and farms.At present, the vacuum coating method in addition to plating optical film, electrical film, magnetic film, and a variety of novel, gorgeous decorative film, is to obtain more additional functions in the direction of development.

5. Research hotspots

5. 1 Combination of various vacuum coating process

Vacuum coating process is developing towards the direction of the combination of many processes.For example, Fulton once combined ion-assisted deposition technology with filter cathode arc deposition technology to make optical film on the surface of plastic lens.Souquet has also used sputtering and evaporation to make solid-film lithium batteries.At present, the multi - arc magnetron sputtering multi - function coating equipment is the most effective method for low temperature deposition of plastic surface.

5.2 Combination of vacuum coating process and electroplating process

Plastic vacuum coating, due to the formation of the vacuum coating layer is actually vaporized deposit in gaseous atoms or groups of atoms in metals, plastic surface deposition rate is not high, thin film layer, the thickness of only decades from around 100 nm, not enough to cover the plastic substrate surface roughness and other defects, wear resistance is not good.In order to improve the wear resistance, it is necessary to increase the thickness of the metal film to form a dense and defect-free surface. However, the current vacuum coating technology is still difficult to achieve, and it is not economical, so in practical use, the parts with frequent friction simply using vacuum coating method often can not meet the requirements.Because of electroplating technology has high deposition rate, easy to form a thick and flat metal coating layer (20 ~ 30 microns), you can directly use of the characteristics of metal plating layer, no matter in the aspect of wear-resisting, resistance to aging performance is good, if in the vacuum coating layer surface metal plating a layer of protection, can get excellent metal coating to wear.

5. 3 Development of multilayer composite films

Due to the poor heat resistance of the plastic substrate, there has been little research on the deposition of multilayer composite film on the plastic surface for a long time. In recent years, in order to improve the wear resistance and corrosion resistance of the coating, people began to pay attention to the research on the technology of multilayer composite coating.For example, Zhitomirsky used multi-arc ion plating technology to deposit metal/ceramic composite coatings on polysulfone S2010.Erlat used reactive magnetron sputtering to produce AlOx and AlOxNy composite coatings with high barrier properties on polyethylene.Ni Xingyuan et al. prepared multilayer optical discoloration film on PET film.The successful development of multi - arc magnetron sputtering multi - function coating equipment lays a good foundation for the application and development of multi - layer vacuum ion coating technology.In order to expand the application field of vacuum coating, China has developed a composite ion coating equipment on the basis of multi-arc magnetron sputtering multi-function coating equipment, which can complete the preparation of multilayer membrane and multilayer composite membrane in a vacuum coating room.The results show that the multilayer composite films can be prepared by electron beam evaporation, ion beam sputtering, magnetron sputtering, multi-arc ion plating and molecular beam casting, and can also be prepared by different combinations and layers according to the requirements. The prepared multilayer composite films can not only achieve the

performance that can not be achieved by monolayer films.At the same time, it also has special optical, electromagnetic, mechanical and friction properties [7], which has a broad application prospect.

5. 4 Determine the best process conditions

In the process of plastic surface vacuum coating, any change of technological parameters will lead to the change of the composition, structure and properties of the film.At present, the plastic vacuum coating mainly solves the coating process problems, including adhesion, high temperature oxidation resistance, film surface brightness and deep hole, concave surface, cavity and other complex shape areas of the film adhesion problems.Therefore, changing the preparation process, reducing the temperature of the plastic substrate surface, obtaining the coating with good performance at a lower temperature, analyzing the relationship between the deposition rate and the composition of the film and the process conditions, and determining the optimal process conditions for a good film are one of the research hotspots of plastic vacuum coating at present.

5. 5 strengthen the basic research of plastic surface coating layer

With the development of ultra-high vacuum and electronic technology, the research methods of thin film materials are more and more extensive, especially on the basis of various microphysical phenomena, a series of new analysis methods of thin film structure and composition have been developed.But for now, for the plastic surface vacuum coating technology research are still largely focused on the coating method, process and application research, the fundamental research of the plastic vacuum coating layer is relatively small, this is mainly due to the disorder compared with inorganic macromolecular compounds, the analysis of the surface should be carried out in a high vacuum device be polluted by decomposition of plastic material,The analysis of plastic surface coating layer is restricted.In the plastic substrate surface membrane layer should be enhanced in basic research, including the structure and composition of the coating layer on the surface of a plastic and plastic and metal interaction interface carries on the analysis and research, analysis about the composition, structure and surface properties of the plastic metal deposits, the influence of the analysis of metal deposits in the plastic on the stability and combining with the situation,Therefore, the bonding mechanism of plastic and deposited metal is studied.

5. 6 The evaluation index system of plastic surface metallized functional materials is established

For plastic surface metallized functional materials, it will show a variety of functions in the use process, such as solvent resistance, wear resistance, thermal stability, corrosion resistance, light resistance, thermal and electrical conductivity, etc.At present, there are corresponding national and international standards for the inspection of metal coating by electroplating method and thermal spraying method.Standard respectively on the thickness of the coating, surface hardness and bonding strength, abrasion resistance, porosity and corrosion resistance, tensile strength determination made detailed provisions, However, vacuum coating technology only has corresponding standards for vacuum coating equipment, vacuum pump , lacks systematic and quantitative research on evaluation of plastic surface metallized functional materials.In the future, it is necessary to strengthen the research in this field and establish a complete evaluation index system for plastic surface metallized functional materials.

6. Conclusion

Metallization of plastic surface is a topic of great concern at present. Vacuum coating process can form a bright metal coating layer on the plastic surface. Its application fields are very wide, including optics, magnetism, electronics, machinery, construction and other fields.In the future, we will further strengthen the research work on all aspects of plastic vacuum coating process, so that it will be more and more widely used in plastic surface metallization.

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References
[1] Zhao fan; zhang Shiwei;Jiang Yifeng;Qiao Yongliang;Huang Xianjie. Application of Vacuum Coating Process in Surface Treatment of Plastic Workpieces. Summary of the 15th National Thin Film Technology Symposium.2019, 11.
[2] Bai Xiuqin, Li Jian et al, Application of Vacuum Coating technology in Plastic Surface [J]. Journal of Wuhan University of Technology2005,29(6):947-950.
[3] Kong Jianjun. Effect of process parameters of vacuum coating on film properties. Defense Manufacturing Technology. 2011,10(5).51～53.
[4] Tian Minbo, Liu Deling.Handbook of thin film science and technology.Beijing: China Machine Press, 1991. 871 ~ 893.
[5] Pan Yongqiang, Lu Jinjun, Wan Jingyu.Journal of Applied Optics, 2003, 24(3) : 32 ~ 34.
[6] Straumal B , Vershinin N F, Cant arer o-Saez A, et al. Vacuum ar c depo sitio n of pro tectiv e layers on g lass and polym er substr ates. Thin Solid Films, 2001, 383 (1-2) : 224～226.
[7] Zhao Xinze, Xiao Hanliang, Gao Hongliang.Dry friction properties of elastic metal-plastic composites.Journal of Wuhan University of Technology 2001,25(3):283~ 286.