Nickel-based pigments – the versatile alternatives

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Metallic pigments have, for a number of decades, provided an essential tool in the hands of the formulators and manufacturers of organic based coatings. A number of different metals and alloys have been used for this type of application including aluminium, silver, gold, copper, bronze, stainless steel and nickel. Since many of applications of organic-based metallic coatings are ones that depend on their decorative properties, the pigments are most usually employed in the form of flakes of varying sizes and thicknesses.

The inherent visual properties of the various types of metallic pigments generally determine the applications in which they are used. For example, aluminium flakes exhibit an extremely high level of reflectivity and have a very 'white' hue, which makes them ideal for many applications where very bright coatings are required. Copper and bronze flakes however, which are available in a very wide range of colour shades, are extensively used in printing inks to simulate a 'gold' or 'gilt' appearance. Other types of flake pigment may be specified on the basis of properties other than just appearance, such as resistance to corrosion or chemical attack. For example, stainless steel flakes, whilst not showing such as high level of brightness as aluminium, are frequently used in situations in which their excellent durability in aggressive environments is essential.

Nickel, and nickel-based, pigments may be considered in some ways as the most versatile of the alternative materials available for use in this type of situation and have, as a result, been finding an increasing range of uses in recent years due to the fact that they exhibit, not one but several, highly beneficial properties in a unique combination.

- Good corrosion resistance
- Attractive visual appearance
- High electrical conductivity
- Ferromagnetism

This combination of properties means that there are many situations where nickel pigments are the only ones that can be used and others where they provide the most economically viable alternative.

In more general terms nickel metal and materials derived from it are currently some of the most vital and irreplaceable elements in our technology-based society due to their inherent chemical and physical properties. Since it was discovered over 250 years ago nickel has become an important constituent of a very wide range of materials and industrial processes to the extent that current annual world production is in the region 1,200,000 tonnes. Some of its better-known applications include the production of high performance metallic materials - such as austenitic stainless steels – chromium containing nickel alloys for high temperature applications and corrosion resistant alloys for chemical plant construction, as well as being vitally important in electroplating and battery technology

Much of the versatility and usefulness of nickel-based materials depend upon the unique method by which the pure metal is refined – the gas phase nickel carbonyl process. This depends upon the reaction of elemental nickel with carbon monoxide gas to form volatile nickel tetra-carbonyl.

$$Ni + 4CO \rightarrow Ni(CO)_4$$

Of all the other elements only cobalt and iron behave in a similar way. So, the process provides a very effective method of manufacturing elemental nickel, on a commercial scale, to an extremely high standard of purity.

In terms of small particle production the critical advantage of the nickel carbonyl reaction is that it can be reversed so that high purity, nickel tetra-carbonyl gas can be induced to decompose to yield high purity nickel metal. This decomposition reaction can be controlled so that nickel can be induced to deposit either in a massive form - most usually as spherical pellets - or as fine powder. Even further refinement and control of the decomposition process allows a range of nickel powders to be produced either as filamentary particles (Figure 1) or as spherical ones (Figure 2) which can, due to the high ductility of the particles, be subsequently processed by mechanical means to produce nickel flake pigments (Figure 3).

The outcome is that nickel particulate materials are available in these three quite distinct physical forms - all of which are suitable for use as pigments in organic-based systems.

- Flakes
- Filamentary powders
- Spherical powders

This situation contributes greatly to the versatility of nickel particulates with the consequence that they can be used not only in coating products such as paint and ink but also in filled elastomers, sealants and adhesives.

Uses of nickel-based pigments

Decorative/functional coatings

Decorative grades of nickel flakes are used to produce bright, fully metallic, coatings. They exhibit a subtle visual effect having a ‘yellowish’ tinge, similar to that of silver, as apposed to the very ‘white’ appearance of aluminium-based coatings or the distinctly ‘bluish’ appearance of electrodeposited chromium. These pigments are manufactured specifically for decorative applications by carefully selecting the manufacturing conditions in order to maximise their aesthetic appeal. Recent refinements in the production technology has enabled special ‘pigment’ grades to be developed that provide additional film opacity; this is a distinct advantage in situations where a minimum film thickness is vital.

Flake morphology is the only one used for decorative/ functional coatings since spherical and filamentary particles do not exhibit the required visual properties.

The choice of nickel for a decorative application is not, however, normally made purely on grounds of appearance. In general there is a strong consideration of functional suitability that results in the selection of nickel as opposed to other alternative flake materials. Two benefits are of particular significance.

- Nickel pigments exhibit very high stability in aqueous media, even at pH values above 7, which this makes then eminently suitable for use in water-based coatings. A special grade of decorative nickel flake – completely free of stearate residues – has been especially developed for use in this type of resin system.

- The corrosion resistance of nickel-containing coatings, particularly in alkaline media, allows them to be used without a lacquer topcoat in many applications.

In addition to being suitable for use in solvent and water-based liquid paints nickel flakes can also be incorporated into in powder-coating products to produce the usual range of visual effects. The pigments are robust and show good durability in a range of environments; however, they are susceptible to attack in atmospheres containing appreciable quantities of sulphur dioxide. For application where the powder coated product is to be used in an external atmospheric exposure application without lacquer topcoat, particularly in industrial environments, stainless steel flakes are therefore preferred.

Electrically conductive coatings

The importance of electrically conductive coatings has been increasing steadily during the past two decades. One of the primary reasons has been the requirement to provide shielding for all types of electronics equipment in order to avoid radiofrequency (RFI) and electromagnetic (EMI) interference problems. Almost all electrical and electronics devices are vulnerable to this type of interference which can result in various levels of equipment malfunction from the trivial to the catastrophic. The problem has become so serious that it has been found necessary to enact legislation - in the EU, North America and other industrialised countries - to make shielding of electronics devices from RFI/EMI mandatory.

Although there are a number of alternative coating methods that are suitable for shielding applications paint coatings have retained a prominent position in this market. This has been due not only to the high quality performance of these coatings but also to the simplicity and versatility of the techniques used to apply them. Nickel pigments have become widely used in this technology since the advantages that they exhibit make them eminently suitable. Their inherently high electrical conductivity combined with high resistance to corrosion ensures that the excellent initial shielding performance of the coating systems does not decay with time. In addition, the variety of particle morphologies available to the coating formulator provides a considerable freedom of choice.

Nickel flake materials - such as NOVAMET Conductive Grade HCA-1 - are generally regarded as the most suitable form for use in conductive paint coatings. Since the individual flakes have a thickness of just below 1 micron this allows multiple layers of nickel to align along the plane of a typical (50 µm thick) coating film. This provides interference attenuation in the region of 40 - 50 dB. This is an adequate performance for a vast range of product shielding applications, including modern high-speed computers.

For aerospace or military applications higher attenuation values, in the region of 80 -100 dB may be required in which case silver-coated nickel products are available in both flake and spherical morphology forms. In addition to providing higher levels of shielding attenuation than pure nickel

these materials are inherently ferromagnetic. This is a property that is not exhibited by pure silver pigments and one that can provide beneficial shielding effects in selected frequency ranges.

Filamentary nickel powders - such as NOVAMET Nickel Powder Type 525 - can also be used to produce coatings with levels of electrical conductivity and shielding performance similar to those obtained with HCA-1 conductive nickel flake. This provides an alternative route by which shielding coatings can be manufactured with attenuation performance in the region of 40 – 50 dB. This is an important advantage since individual types of nickel pigment quite often perform differently when incorporated into the various types of organic media used for these coatings. There are therefore circumstances in which filamentary morphology may give better overall performance than flake, and vice versa.

The basic mechanism by which electrical conductivity is achieved in these coatings is by particle-to-particle contact. Consequently spherical nickel powders are generally not used to produce conductive coatings since their close packing characteristic means that a much higher pigment loading is required in order to achieve this type of contact and provide good conductivity. One exception is for coatings that may need to be applied by screen-printing where small particles with a highly uniform size distribution may be a vital requirement.

All three types of conductive nickel pigment can be incorporated into commercially available solvent-based resin systems including acrylic, polyurethane and epoxy. A number of water-based conductive coatings have also been developed but in this case flake morphology seems to provide the best overall result in terms of conductivity, smoothness and appearance.

The pigment loading required to achieve electrical conductivity has, so far, proved too high for the development of a successful conductive powder coating system.

Legislation related to RFI/EMI shielding has now been in place for almost 25 years in the U.S.A. As a result nickel-containing conductive coatings have a long history of use in this technology covering a wide range of electronic devices such as computers, cash machines and mobile phones. Despite the maturity of part of this market new applications are still emerging such as shielding walls of rooms to attenuate harmful signals from overhead power lines and mobile communications base stations.

In addition nickel-containing coating systems can be used, not only for EMC shielding purposes, but also just simply as current carriers where they have a distinct over copper due to their very much better corrosion resistance.

Nickel-containing coatings for magnetic applications

Nickel is one of the three elements – the others being iron and cobalt – that is strongly ferromagnetic at ambient temperatures. Of these three only nickel is readily available in the form of small particles - in a variety of morphologies - suitable for use as pigments. This provides an additional range of applications for nickel-containing coating systems and one in which there has been an increasing level of interest in recent years. A recent study carried out to determine the basic magnetic characteristics of organic resin films containing additions of different types of nickel flake together with two special nickel-alloy flake materials, an 81% Ni: 2% Mo; Bal Fe Permalloy type alloy and a special 97% Ni: 3% Al alloy with a very low Curie point. This work has yielded interesting results.

Magnetic Properties of Nickel-Containing Organic Films

Pigment Material Ratio	Pigment to Binder	Saturation Magnetisation M_s *(10^2emu)*	Remanent Magnetisation M_r *(10^3emu)*	Coercivity Hc (Oe)
Pure Nickel Flakes				
HCA-1	1.33	3.5	8.5	87.4
NiFW	1.33	3.2	16.0	77.5
NiFL	1.33	2.9	14.0	72.7
NiFL	0.67	1.5	7.0	73.5
NiFL	1.33	2.9	14.0	72.7
NiFL	2.00	4.7	24.0	74.3
Key: HCA-1:	Conductive nickel flake			
NiF:	Decorative nickel flake - Leafing Grade - for solvent systems			
NiFW:	Decorative nickel flake – Non-Leafing - for aqueous systems			
Nickel-alloy Flakes				
Ni: 3% Al	1.33	1.5	7.0	36.0
Ni: 3.85% Al	1.33	1.4	8.0	25.8
Permalloy Ni 81:Mo 2:bal Fe	1.33	4.2	7.6	10.4

The results available at this stage are essentially those derived from an initial survey of these properties in order to provide background information on the specific properties that might be expected from organic coatings containing these pigments - information that has not been previously available. Further work is already in progress to extend the scope of the work to attempt to quantify the effect of film thickness, pigment loading and flake type on the magnetic properties.

The flake materials examined in this study of magnetic properties have all been successfully used in coating systems – albeit in non-magnetic applications – for many years. Therefore the technology for incorporating them into paint or ink media, solvent or water based, is widely understood and readily available.

The future of nickel pigments

The future of any product suited to high technology applications is never easy to predict since rapid change is very often the norm in these industry sectors. However, rapidly developing technologies inevitably provide demanding challenges in terms of materials and the way in which they are applied. For producers of specialised coating systems nickel and nickel alloy pigments can often provide a commercially viable solution to many of the problems that face them due to their unique properties, versatility together with regular and reliable availability in the market.

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