

VITREOUS ENAMELLING

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The vitreous enamelling of metals is analogous to the glazing of pottery in that powdered glass-forming materials, in the form of a liquid suspension (*ie. slip*) or an electrostatic powder, are applied to a formed and prepared article. Subsequent drying and heating in a firing furnace fuses the coating, thereby yielding a continuous and tightly adherent glass layer, on the steel surface.

ENAMEL COATINGS

Enamel coatings have two major applications:

- Decorative Coatings — Opaque white or coloured coats where appearance and protection are equally important. Common examples include stove hobs and doors, domestic baths and architectural panels.
- Protective Coatings — Coatings used where appearance is secondary to protection. Common examples include oven liners and glass lined hot water cylinders.

A ground coat, designed to give good adherence to the steel substrate, is generally used for decorative coatings. For purely protective coatings, a cover coat may be applied over the ground coat or the ground coat may be employed alone.

PRETREATMENT

To provide a substrate which is suitable for coating, the enameller is required to clean or clean and acid etch the steel article prior to enamelling. The pretreatment process employed will depend on the type of enamel to be used.

ENAMELLING STEELS

There are two major technical issues to be considered when choosing the most appropriate steel type for vitreous enamelling purposes:

- Formability — Forming operations in the steel enamelling industry vary from simple bending to severe deep drawing.
- Enamelling Quality — Most importantly, the steel must allow the formation of a defect free, tightly adherent enamel finish as well as resisting distortion during one or more firings.

Fishscale Resistance

Fishscale is a steel related enamel defect which can occur if either the steel structure or enamelling practices are not well controlled. Fishscale occurs after enamel firing when hydrogen in the steel diffuses to the steel-enamel interface and causes small chips or scales to pop loose from the substrate. A number of factors contribute to the tendency of an enamel coating to fishscale:

- the amount of hydrogen picked up by the steel during firing from moisture in the enamel and/or moisture in the furnace atmosphere,
- the degree of adherence between the enamel and the steel (*the higher the adherence the better the fishscale resistance*),
- the structure of the enamel (*a well developed "bubble" structure in the enamel retards fishscale propagation*),
- the ability of the steel to store hydrogen after firing. This characteristic is achieved by creating hydrogen entrapment sites (*ie. voids*) in the steel structure,
- fishscaling typically only occurs on double side enamelled articles.

Steel Type

Carbon is the most troublesome steel constituent in enamelling, for the following reasons:

- at carbon levels greater than approximately 0.03%, a phase change with an accompanying volume change occurs at temperatures in excess of 730°C. The volume change can contribute to distortion during firing.
- carbon can also promote the formation of "carbon boil" type defects, where during firing the enamel reacts with carbon at the steel surface causing large bubbles which break at the enamel surface (*ie. boil*) or cause the dark ground coat to be drawn to the surface causing black specks in white enamels.

BlueScope Steel Limited offers two cold rolled vitreous enamelling steel products, namely CV2S1 and CV4S2:

- CV2S1 – low carbon (0.04 - 0.07% C), skin passed commercial drawing steel guaranteed for general purpose vitreous enamelling with appropriate enamelling practices. CV2S1 is unsuitable for direct-on cover coat and not recommended for decorative finishes, particularly light colours.
- CV4S2 – extra low carbon (0.002 - 0.005% C), titanium stabilised, skin passed extra deep drawing steel guaranteed free from ageing and stretcher strain during forming. CV4S2 is suitable for both protective and decorative enamelling. Care should be taken in the selection of the enamel system used and strict control of all aspects of pretreatment, enamel preparation, application and firing is necessary to achieve the required high level of enamel adherence and appearance. CV4S2 is also suitable for applications requiring low distortion after firing.

It should be noted that these specialised vitreous enamelling products are the only BlueScope Steel cold rolled products not susceptible to fishscale type defects during double side enamelling, i.e. all products which do not include “V” in the product name may fishscale if used in an enamelling application.

CV2S1 and CV4S2 can be ordered either oiled or unoled. The oil used by BlueScope Steel on enamelling steels has been specially selected so that it is easily removed by the enamellers pretreatment process. The typical steel composition and mechanical properties of the two BlueScope Steel vitreous enamelling steel products are presented in Table 1 and Table 2 respectively.

The BlueScope Steel hot rolled product range does not include fishscale resistant steels. For this reason hot rolled products are unsuitable for two side enamelling applications. The susceptibility to fishscale is reduced if the steel is enamelled on one side only, leaving an escape route for entrapped hydrogen via the unenamelled surface.

The hot rolled products most commonly used by the enamelling industry are the low carbon grades such as HA1006. Where higher strength levels are required, higher carbon steels may be suitable depending on the enamel type used and the surface finish required. Table 3 summarises the suitability of a number of BlueScope Steel products for enamelling applications.

Table 1: Typical Steel Composition (%)

Product	C	P	Mn	S	Si	Al	Ti
CV2S1	0.055	0.010	0.25	0.010	0.005	0.040	-
CV4S2	0.003	0.010	0.15	0.010	0.005	0.030	0.010

Table 2: Typical Mechanical Properties (Based on 1.00mm thickness)

Product	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation on 80mm (%)	r ₉₀
CV2S1	190	300	43	1.7
CV4S2	170	290	48	2.3

Table 3: Vitreous Enamelling of BlueScope Steel products.

BlueScope Steel Product	Article Design			Enamel Coverage		Enamel Finish	
	Simple	Complex	Prone to Distort	Single Side	Two Side	Protective	Decorative
CV2S1	✓			✓	✓	✓	
CV4S2		✓	✓	✓	✓	✓	✓
HA1006	✓			✓		✓	
HA3		✓		✓		✓	

Fabrication

Joining methods employed prior to enamelling are limited to spot, seam and continuous filler welding; the latter should be kept away from exposed surfaces to avoid any possibility of differential appearance or defects.

Special aspects of design relate basically to control of distortion during firing and to minimising of stresses in the coating, which can cause crazing during service. The major design characteristics to be considered are proper flanging and stiffening, adequate radii, avoidance of notches (*stress raisers*) and avoidance of large changes in thickness (*uniform heating and cooling*). For further information on this subject refer to Porcelain Enamel Institute Bulletin P-306 "Design and Fabrication of Sheet Steel Parts for Porcelain Enamelling".

It is important that the enameller select water soluble lubricants and drawing compounds which can be easily removed from the substrate during pretreatment.

ENAMELLING DEFECTS

Vitreous enamelling is a complex and critical process. It is therefore apparent that faults in processing or unsatisfactory materials can lead to defective coatings. Table 4 presents the more common steel related enamelling defects and the recommended product for overcoming these defects.

Table 4: Enamelling Defects

DEFECT	STEEL RELATED CAUSES	RECOMMENDED PRODUCT
Fishscale	Inability to "trap" hydrogen within steel structure	CV2S1 CV4S2
Distortion	Phase change (<i>volume change</i>) during heating and cooling	CV4S2 (<i>no phase change</i>)
Carbon Boil	Carbon migrating to surface and reacting with oxygen to form carbon monoxide	CV4S2
Black Specks in White Finishes	Carbon boil may contribute	CV4S2
Frizzing	High rate of reaction between enamel and steel	CV4S2

RECOMMENDED FURTHER READING

Series of PEI Bulletins issued by the Porcelain Enamel Institute, Washington DC, USA:

P-301 Spraying

P-302 Dipping

P-304 Process Controls

P-305 Ball Mill Wet Grinding of Slips

P-306 Design and Fabrication of Sheet Steel Parts

P-307 Preparation of Sheet Steel for Porcelain Enamelling

- Australian Standard 1914 "Glossary of Terms Relating to Vitreous Enamel Coatings".
- Australian Standard 2219 "Methods of Test for Vitreous Enamel Coatings".

The information and advice contained in this Bulletin is of a general nature only, and has not been prepared with your specific needs in mind. You should always obtain specialist advice to ensure that the materials, approach and techniques referred to in this Bulletin meet your specific requirements.

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