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The body can be viewed from the next page.

Development of New Coloured Polyurethane Elastomer-Coated Heavy-Duty Steel*

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New coloured polyurethane elastomer coated steel structures with top coating of acrylic urethane have been developed for marine and harbor environments. Polyurethane elastomer coatings contain a little aliphatic isocyanates, which have colour-change resistance, together with aromatic isocyanates and chelate agents, which restrain the advent of diquinone imide structures formed by a photocatalysed autoxidation process. Acrylic urethane as a top coating consists of aliphatic isocyanates and aliphatic acrylic polyols and colour pigments. Surface treatment and the polyurethane elastomer coating layer have good adhesion, good mechanical properties and anticorrosion properties. The top layer of acrylic urethane has good weathering properties. This new coloured polyurethane elastomer coated steel can be used for marine and harbor structures to meet both an added safety for ship sailing and environmental colour harmony.

1 Introduction

Because of their excellent strength characteristics and workability, steel pipe piles, steel sheet pipe piles, and steel sheet piles are used in large quantities as materials for marine, harbor, and river structures and as civil engineering and construction materials in dredging and revetment project. In some of these steel structure facilities in the marine and harbor environment[1], however, the service life is shortened by corrosion, making corrosion protection an important problem, both in terms of durability and safety[2-4].

Application of a thick organic coating (film thickness: 0.5 to 1.0 mm) such as tar epoxy, over a zinc-rich primer, cathodic protection, and the combined application of these two measures have been adopted for anticorrosion purposes because of their relatively low cost[5]. However, organic coatings are damaged by collision with flotages and are delaminated and deteriorated by seawater; their service life is a maximum of ten years. Furthermore, cathodic protection, although effective in seawater and underground, is ineffective in the splash zone where a very severe corrosive environment exists.

In addition to these measures, fiber-reinforced plastic coverings, cement mortar, and metal coating, have been used[4]; these, however, tend to require a high initial investment.

Both organic coating and cathodic protection require maintenance to ensure durability. For this reason, maintenance-free organic coating heavy-duty steels which can be produced at low cost have been desired. Recent long-term seaside exposure tests conducted by Japanese Association for Steel Pipe Piles, as well as other tests, confirmed that thick plastic linings of polyethylene and

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polyurethane elastomer have excellent anticorrosion properties[6-8].

Consequently, Kawasaki Steel developed and began marketing **KPP pile** (Kawasaki plastic-coated pipe pile), **KP sheet pile** (Kawasaki precoated sheet pile), and **KP sheet pipe pile** (Kawasaki precoated sheet pipe pile) as civil engineering and construction materials for marine, harbor, and river structures between 1984 and 1985. KPP pile is a polyethylene-coated steel pile and KP sheet pile and KP sheet pipe pile are coated with a polyurethane elastomer.

Demand for these organic coated heavy-duty steel products has increased rapidly, but these polyethylene- and polyurethane elastomer-coated heavy-duty steel piles were available only in black because carbon black was added to prevent film degradation and chalking by ultraviolet rays. In recent years, however, coloured coatings have been required for marine, harbor, and river structures where markings are used to improve navigational safety, as well as for such aesthetic reasons as maintaining harmony with the natural environment[7].

In response, Kawasaki Steel has developed a new coloured polyurethane elastomer-coated steel with a top coat of acrylic urethane. This steel offers excellent resistance to weathering, and is applicable to all civil engineering and construction materials for steel pipe piles, steel sheet pipe piles, and steel sheet piles. This report presents the concepts behind the development of this coated steel, and the properties of the coating.

2 Basic Concept of Development of Coloured Coated Steel

2.1 Compatibility of Colouring and Weathering Resistance

A polyethylene resin usually absorbs ultraviolet rays from sunlight. This causes the phenomenon of chalking, the generation of white powder at the coating surface by the degradation mechanism of photo-catalyzed autoxidation[9] shown in the following reaction formulae:

Initiation	$RH \xrightarrow[h\nu]{} R\cdot + H\cdot$
Propagation	$R\cdot + O_2 \rightarrow ROO\cdot$
	$ROO\cdot + RH \rightarrow ROOH + R\cdot$
Chain branching	$ROOH \rightarrow RO\cdot + \cdot OH$
	$2ROOH \rightarrow ROO\cdot + RO\cdot + H_2O$
	$RO\cdot + RH \rightarrow ROH + R\cdot$
	$HO\cdot + RH \rightarrow R\cdot + H_2O$
Termination	$RO_2\cdot + RO_2\cdot \rightarrow$ radical destruction

Chalking substantially decreases weathering resistance; therefore, carbon black is added as a pigment to the

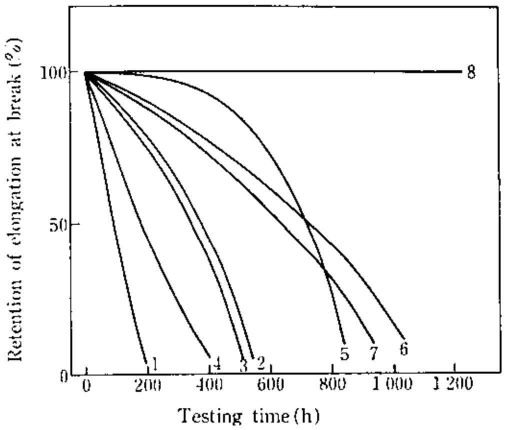
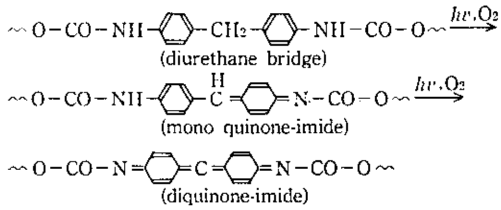


Fig. 1 Effect of pigments on high density polyethylene tested by weatherometer (1, natural; 2, TiO_2 anatase; 3, TiO_2 rutile; 4, phthalocyanine blue; 5, cadmium yellow; 6, cadmium red; 7, phthalocyanine green; 8, carbon black)

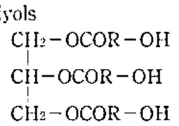
polyethylene coating of KPP pile, as shown in **Fig. 1**, as a preventive measure. By this method, a service life of 40 to 50 years can be obtained. Polyols, the main agent in polyurethane, cause chalking to a certain extent by degradation due to photo-catalyzed autoxidation. The aromatic isocyanate component of the curing compound generates diquinone-imide chromophore structure by the following mechanism, and causes the phenomenon of yellowing[10], thus also lessening weathering resistance:



In polyurethane resins, both yellowing and the degradation resulting from photo-catalyzed autoxidation occur only in the surface layer in the thickness range of several microns, while the interior of the film does not deteriorate. Therefore, the mechanical properties of the film are not impaired and durability of 40 to 50 years can be ensured. However, the colouring of polyurethane resin itself results in yellowing and chalking, impairing the appearance of such coated steels. For this reason, no great progress has been made in the colouring of polyurethane resins itself. The above-mentioned deterioration in weathering resistance is improved in the polyurethane elastomer coating used in KP sheet pile and KP sheet pipe pile: Castor oil, which is relatively impervious to water absorption, and polyols are used as the main agents, crude MDIs (diphenylmethane diisocyanates, which are aromatic isocyanates) are used as curing agents, and fillers, carbon black, an oxidation inhibitor, and an ultraviolet light absorber are added to produce a black polyurethane elastomer coating material with high strength and excellent durability for use in heavy-duty corrosion-resistant coated steels.

The presently used black polyurethane elastomer coating material has the following molecular structure, providing the properties required of heavy-duty corrosion-proof coatings (be described below):

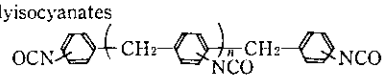
Polyols



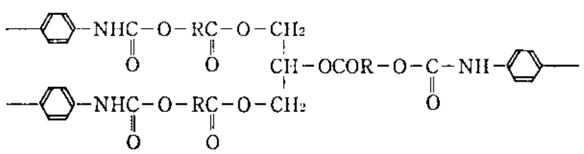
and other polyols

Caster oil

Polyisocyanates



Crude MDI (diphenylmethane-4, 4′-diisocyanate)



Results of fundamental research on the colouring of coating materials showed that with polyethylene it is presently difficult to improve weathering resistance, even if color pigments are used, and that polyurethane coatings offer greater possibilities. The following three measures[11-13] were taken to develop a coloured heavy-duty corrosion-proof coating excellent in weathering resistance, in which yellowing and chalking of the polyurethane elastomer coatings would be prevented[14-16]:

(1) A curing agent containing small amounts of aliphatic isocyanates, which do not yellow, was used in place of the conventional curing agent composed of 100% aromatic isocyanates.
(2) A chelating agent effective in preventing the formation of diquinone-imide chromophore was added.
(3) An acrylic urethane resin composed of aliphatic isocyanates and aliphatic acrylic polyols, and resistant to yellowing and the degradation resulting from photo-catalyzed autoxidation, was applied as a top coat to the polyurethane coating.

When non-yellowing aliphatic isocyanates are contained in the curing agent of the polyurethane elastomer coating material, the film softens, the resin does not cure easily, it is difficult to obtain the thick film required in heavy-duty corrosion-proof coatings, and adhesion to the steel surface and anticorrosion properties deteriorate sharply, as is apparent from **Table 1**.

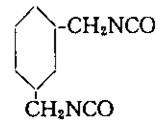
Therefore, an aromatic isocyanate-based curing agent was used, with aliphatic isocyanates excellent in weathering resistance added to such a degree that the curing reaction, adhesion, and anticorrosion properties would

Table 1 Effect of aromatic and aliphatic isocyanates on coating properties of polyurethanes

	Aromatic isocyanate*/ aliphatic isocyanate**				
	0/100	30/70	70/30	90/10	100/0
Elongation (%)	186	146	92	67	54
Tensile strength (kgf/cm²)	93	128	176	202	216
Hardness (Shore D scale)	29	39	54	60	63
Adhesive strength (kgf/cm²)	63	74	90	108	110
Impact strength (kgf·m)	3.5	3.3	3.2	3.1	3.0
Hot salt water resistance*** (mm)	>25	12	4	0	0
Salt spray test*** (mm)	>25	8	2	0	0
Cathodic peeling resistance*** (mm)	>35	20	3	0	0
Electric resistance**** (Ωm^2)	5.4×10^7	2.5×10^8	1.1×10^9	8.6×10^9	9.2×10^9
Weathering resistance***** (ΔE)	2.6	3.8	5.3	7.6	11.5

* Aromatic isocyanates: Crude MDI (diphenylmethane-4.4′-diisocyanate)

** Aliphatic isocyanates: Bis (isocyanate ethyl) cyclohexane



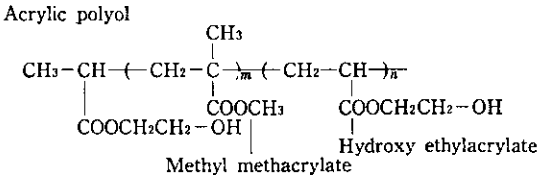
*** Delamination length of coating layer after 30-day test

**** Electric resistance after 30-day immersion test in a 3% NaCl solution at 60°C

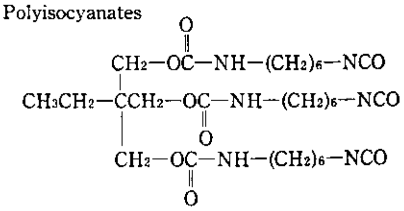
***** Colour difference after 2 000-h test by weatherometer

not be impaired. Furthermore, a chelating agent which would prevent the formation of diquinone-imide chromophores was mixed with the curing agent in order to prevent yellowing of the coating layer. A top coat of acrylic urethane resin was further applied to the weatherproof coating thus obtained; This double-layer coating ensures complete weathering resistance. **Table 2** gives a comparison of the compositions of the newly developed coloured polyurethane elastomer coating (coloured PUE coating) and the conventional black polyurethane elastomer coating (black PUE coating). The molecular structures of the acrylic urethane resin used as the top coat are shown below:

Acrylic polyol



Polyisocyanates



Hexamethylene diisocyanates adducts

Table 2 Compositions of polyurethane elastomer coatings of the conventional black type and new coloured type

Items	Black coating	New coloured-coating (Double layer)	
		Under coating	Top coating
Polyols	Caster oil and other polyols 41% Additives 44% Carbon black 3% Aromatic hydrocarbons 12%	Caster oil and other polyols 61% Additives and other chelate agents 39% Pigments 3~15%*	Acrylic polyol 77% Additives and pigments 23%
Polyisocyanates	Crude MDI	Crude MDI	Hexamethylene diisocyanates adducts
Mixing ratio** by weight	4	3	4
Density at 25°C (g/cm^3)	1.40	1.28	1.32

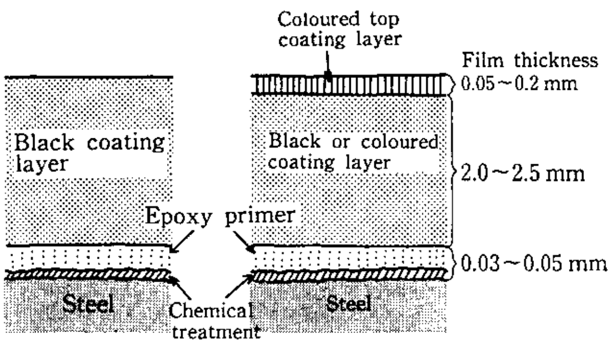
* Amounts of pigments vary by colours

** Polyols/polyisocyanates

Table 3 Effect of surface treatment on heavy duty coating properties

Surface treatment		Mechanical properties		Anti-corrosion properties				Total evaluation
		Adhesion	Impact	Hot salt water resistance	Salt spray test	Cathodic peeling resistance	Electric resistance	
Chemical treatment		○	○	○	○	○	○	○
Chemical treatment and epoxy primer		○	○	◎	◎	◎	○	◎
Epoxy primer composing chromate pigments		○	○	△	△	△	○	△
Zinc rich primer	Inorganic	×	△	△	×	×	△	×
	Organic	○	△	△	×	×	△	×
Primer	Epoxy	○	○	△	△	△	○	△
	Urethane	○	○	△	△	△	○	△
No surface treatment		△	△	×	×	×	△	×

◎ Excellent, ○ Good, △ Fair, × Poor



(a) Black coating (b) New coloured coating

Fig. 2 Comparison of polyurethane elastomer coated steel structures between the black type and new coloured type

The coating layer system of the coloured PUE-coated steel and that of the black PUE-coated steel are compared in **Fig. 2**. The film thickness of each layer is about 50 to 200 μm for the acrylic urethane top coating layer, 2.0 to 2.5 mm for the polyurethane elastomer coating layer, and about 30 to 50 μm for the surface treatment layer. Various top coat colours, such as blue, yellow, green, brown, and gray can be produced by adding colour pigments to the acrylic urethane resin of the top coat.

2.2 Surface Treatment

In general, the corrosion prevention capacity of coated steels is determined by the quality of the adhesive interface between the steel base and the coating material, which in turn depends on the quality of the surface treatment given. Even if an excellent coating material is used, corrosion resistance will be lessened if the surface treatment is poor.

The coating system most frequently used to protect marine structures from corrosion has conventionally been composed of a thick film of zinc-rich primer applied as a surface treatment, over which an epoxy resin or tar epoxy coating is applied. The total film thickness of the coating system is 0.5 to 1.0 mm, and service life is a maximum of only about 10 years[8]. Various surface treatment methods for heavy-duty corrosion-resistant coated steels, including the application of a zinc-rich primer, were examined to clarify the cause of this short service life, with the results of this examination are shown in **Table 3**. Zinc-rich primer clearly has poor adhesion with the coating in the area in contact with water and is inferior in water resistance. This tends to cause the coating to peel off, especially when the coated edges are exposed as they are in deformed steel products such as steel sheet pipe piles and steel sheet piles. It was also found that zinc-rich primer has poor impact properties due to its poor adhesion with the coating film and shows low impact resistance. In actual use, the mechanical action of waves and impact with vessels and waterborne debris result in damage to the coating film. As shown in Table 3, therefore, a two-layer system composed of a chemical treatment layer and an epoxy primer layer was adopted as the surface treatment method which would ensures the best mechanical and anticorrosion properties in heavy-duty corrosion-proof coated materials.

2.3 Required Coating Properties

The environmental degradation factors and coating

Table 4 Environmental degradation factors and coating properties needed for heavy duty coating steel structures

Environment	Environmental degradation factors	Coating properties
Atmospheric zone Splash and tidal zones Submerged zone	Ultraviolet radiation Temperature Oxygen Salt fog Impact (Wave and floating materials) Water Temperature Dissolved salts Dissolved oxygen	Weathering resistance Thermal degradation resistance Photo-oxidation resistance Adhesion durability Impact resistance Anti-corrosion
Buried zone	Bacterias pH Water Dissolved oxygen	Adhesion durability Anti-corrosion

Table 5 Coating properties needed for heavy duty coating steel structures for long term use

1. Adhesion strength (Pull off method)	above 40 kgf/cm^2 at room temperature
2. Impact strength (ASTM G 14)	above 3.0 kgf·m at room temperature
3. Hot salf water resistance (30-day immersion in a 3%NaCl at 60°C)	No peeling from edge
4. Salt Spray test resistance (30-day test in a 5%NaCl fog at 35°C)	No peeling from edge
5. Cathodic peeling resistance (30-day test in a 3%KCl at −1.5 V vs. SCE at room temperature)	No peeling from an initial hole
6. Weathering resistance (8 000-h test by weatherometer)	Colour difference <5
7. Life expectancy of heat resistance by torsional braid analysis	above 40 years at 80°C

properties required for heavy-duty corrosion-resistant steels are summarized in **Table 4**. Laboratory coating property tests conducted and target values of film properties are listed in **Table 5**. In the Table, Items 1 and 2 are mechanical properties, and Items 3 to 5 are anticorrosion properties; Item 6 indicates weathering resistance, and Item 7 oxidation resistance. It was judged that a service life can be as long as 40 to 50 years could be expected if all seven items were satisfied.

3 Coating Properties of Coloured Polyurethane Elastomer-Coated Heavy-Duty Steel

3.1 Mechanical Properties

The tensile strength and elongation of the coloured PUE coating are shown in **Fig. 3**. The tensile strength and elongation of the coloured PUE coating with an acrylic urethane resin top coat are slightly superior to those of the black PUE coating. The top-coat double-layer coating method is not detrimental to coating properties. As shown in **Table 6**, the adhesion strength of the coloured PUE coating when applied to a steel base material, as measured by the pull-off method, is more than 100 kgf/cm^2 at room temperature. This figure is sufficiently higher than the adhesion strength of tar epoxy resin, 40 kgf/cm^2. Although adhesion strength

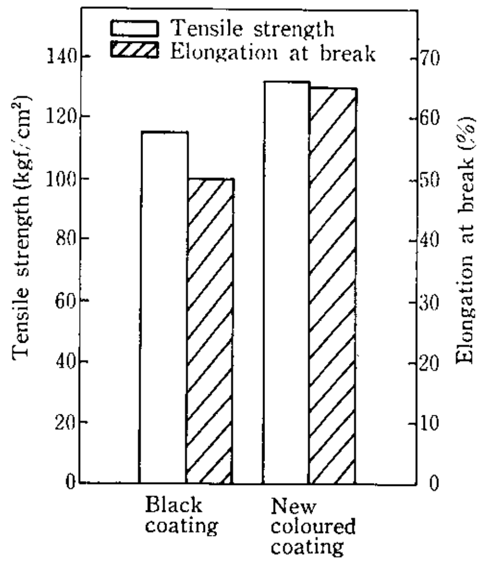


Fig. 3 Tensile properties of polyurethane elastomer coating film (pull speed 50 mm/min, test temperature 23°C, film thickness 2.5 mm)

Table 6 Mechanical properties* of polyurethane elastomer coatings coated on steel plates

	Film thickness (mm)	Adhesion** strength (kgf/cm^2)	Impact strength (kgf·m)	Hardness (Shore D scale)
Black coating	2.2	115	3.5	68
New coloured coating	2.2	120	3.8	68

* Test temperature: 23°C
** Pull speed: 5 mm/min

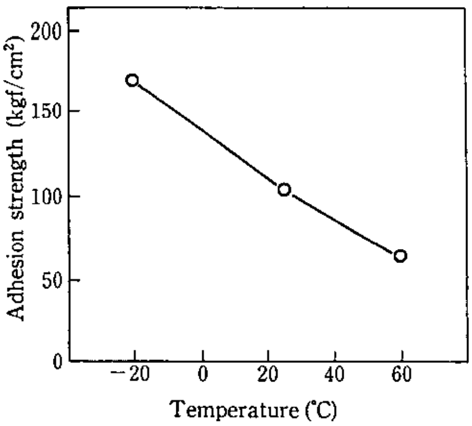


Fig. 4 Temperature dependence of adhesion strength of the new coloured polyurethane elastomer coaing coated on a steel plate (pull speed 5 mm/min)

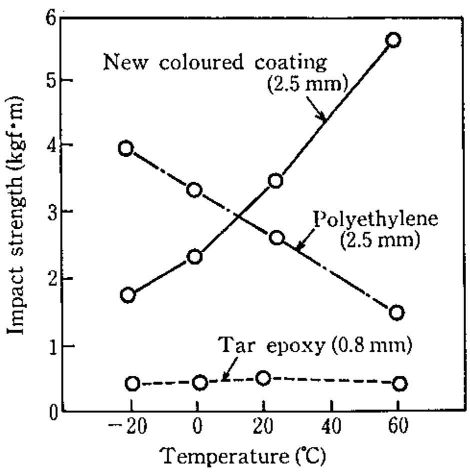


Fig. 5 Temperature dependence of impact strength of the new coloured polyurethane elastomer coating coated on a steel plate

decreases with increasing temperature (**Fig. 4**), the coloured PUE coating shows a high value of 70 kgf/cm^2 even at 60°C. The impact strength of the coloured PUE coating when applied to a steel base (in accordance with ASTM G14) is more than 3.0 kgf · m at a film thickness of 2.5 mm (Table 6); this value is higher than the 2.5 kgf · m of polyethylene coating and 0.5 kgf · m of tar epoxy resin coating (film thickness: 0.8 mm). It may be said, therefore, that when applied to steel plate the coloured PUE coating is superior to any other organic coating. Although the impact strength of coloured PUE coating increases with increasing temperature, a value of about 1.8 kgf · m is obtained even at −20°C, indicating an excellent impact property (**Fig. 5**). As is apparent from the foregoing, the coating of this coloured PUE-coated steel has mechanical properties suitable for

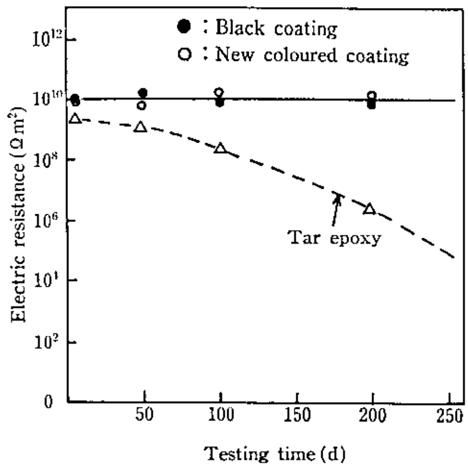


Fig. 6 Time dependence of electric resistance of the new coloured polyurethane elastomer coated steel plate in a 3% NaCl solution at 60°C

heavy-duty corrosion-proof applications over a range of service temperatures from −20°C to 60°C.

3.2 Anticorrosion Properties

The hot salt water test, salt spray test and cathodic peeling test were conducted on coloured PUE-coated steel materials. Peeling of the coated edges did not occur in any of the tests. The surface treatment selected, which involves chemical treatment and application of an epoxy primer to produce a two-layer system, yielded covalent bonding, which has the greatest bonding strength at the interface between the steel base and the coated layer[17)], and not the van der Waals bonding or hydrogen bonding which is frequently destroyed by environmental factors such as water.

In addition, electric resistance, which is one of the indexes for evaluating the anticorrosion properties of coated steels, was measured at 60°C. It was found that the coloured PUE coating has an electric resistance higher than 10^6 Ωm^2. This is on the same order as that of the black PUE coating and indicates sufficient corrosion resistance, by far higher than that of a tar epoxy coating (**Fig. 6**).

3.3 Weathering Resistance

An accelerated weathering test was conducted using a weatherometer: 200 h of irradiation by the weatherometer corresponds to almost one year's average sunlight illuminance in Japan[18)]. The weathering resistance of coloured PUE-coated steels was evaluated by measuring colour difference, film thickness reduction, and impact strength.

3.3.1 Colour difference

Colour differences in the coloured coatings were

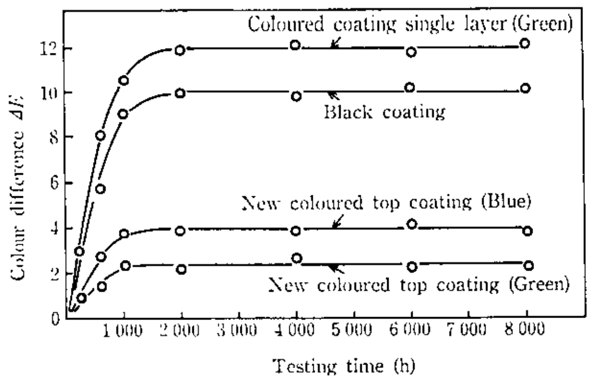


Fig. 7 Colour difference ΔE of "black" and "new coloured" polyurethane elastomer coatings after accelerated weathering test by weatherometer

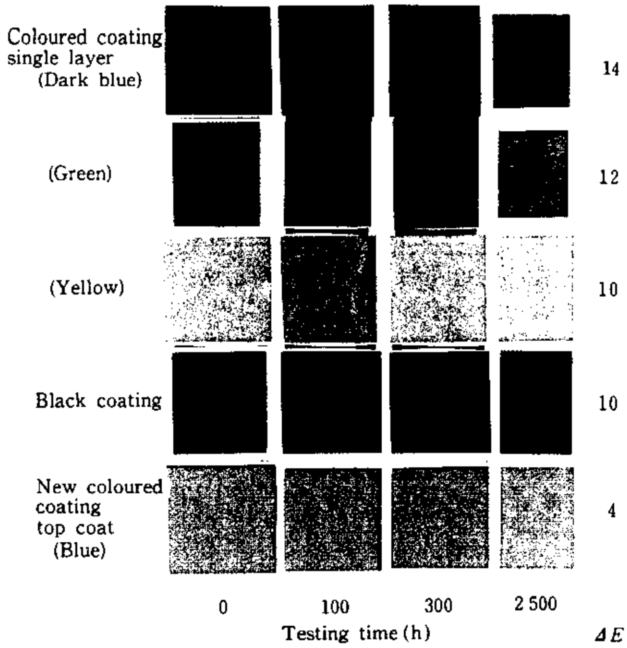


Photo 1 Appearance of "black" and "new coloured" polyurethane elastomer coatings after accelerated weathering test by weatherometer

evaluated using the following equation after measurement with a colorimeter (Suga Shikenki SM-3). Results of the evaluation are shown in **Fig. 7**.

$$\Delta E = \sqrt{(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2} \cdots (1)$$

where ΔE: Colour difference
L: Luminosity after test
L_0: Luminosity before test
a, b: Chromaticity after test
a_0, b_0: Chromaticity before test

The weathering resistance of a single-layer coloured PUE coating containing a chelating agent and small amounts of aliphatic isocyanates is slightly inferior to that of the black PUE coating. However, colour tone change with time is small in the two-layer coloured PUE coating with an acrylic urethane resin top coat. This coating is expected to have weathering resistance equivalent to the 40 to 50 years of service required of heavy-duty corrosion-resistant coated steel products.

Photo 1 shows changes with time in the appearance of the coating surface after the weatherometer test for the single-layer PUE coating, two-layer coloured PUE coating with an acrylic urethane top coat, and black PUE coating. The change in the appearance of the two-layer coloured PUE coating is very small compared to those of the other two coatings, demonstrating the excellent weathering resistance of this coating.

3.3.2 Film thickness reduction

The time dependence of film thickness reduction due to chalking of the coloured PUE coating is shown in **Fig. 8**. The film thickness reduction is very small in the two-layer coloured PUE coating, demonstrating its superiority.

3.3.3 Impact strength

The change in the impact strength of the coloured PUE coating after the accelerated weathering test is shown in **Fig. 9**. As with the black PUE coating, the impact strength of the coloured PUE coating scarcely changes. This suggests that chalking of the PUE coating occurs only in a limited surface layer and does not propagate in the depth direction.

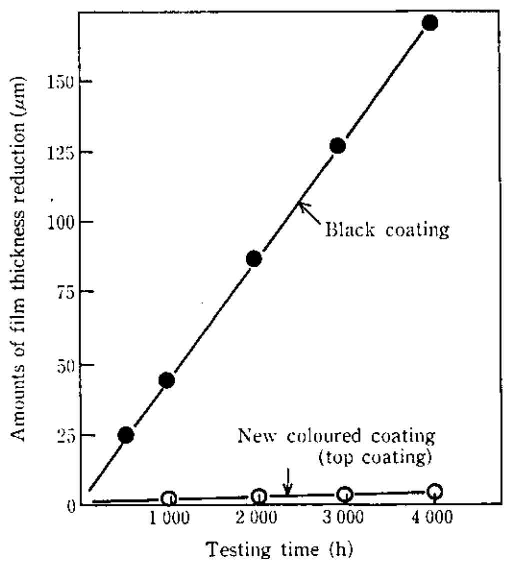


Fig. 8 Amounts of film thickness reduction of "black" and "new coloured" polyurethane elastomer coating after accelerated weathering test by weatherometer

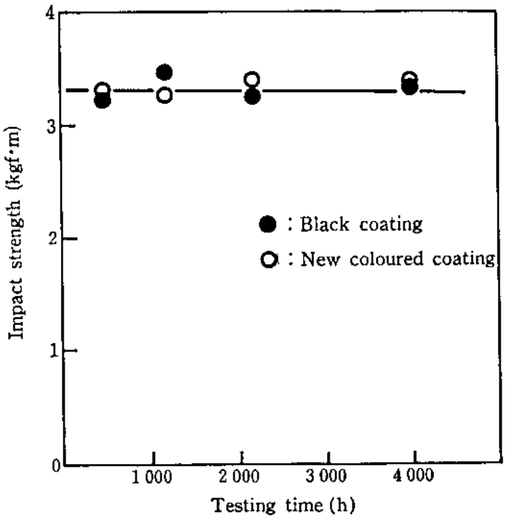


Fig. 9 Impact strength of "black" and "new coloured" polyurethane elastomer coatings coated on steel plates after accelerated weathering test by weatherometer

3.4 Oxidation Resistance

The oxidation resistance of coloured PUE-coated steels was evaluated using a torsional braid tester, by supposing long-term exposure to air. The accelerated test was conducted at temperatures higher than actual service temperatures, and the effect of degradation due to oxidation at actual service temperatures on heat resistant service life was estimated. The point when the logarithmic decrement shows its maximal value corresponds to the point when mechanical properties such as impact strength, adhesion strength, and bending properties change most markedly[19]. In view of this fact, the maximal value of logarithmic decrement in Eq. (2) was taken as an index of the oxidation resistance of coatings.

$$\Delta = \frac{1}{n} \ln\left(\frac{m_0}{m_n}\right) \cdots\cdots\cdots\cdots (2)$$

where Δ: Logarithmic decrement
m_0: Amplitude of the first wave smaller than the set amplitude value M_0
m_n: Amplitude of the first wave smaller than the second set amplitude value M_n

The heat life of coatings at service temperature and activation energy were estimated in consideration of the fact that the maximal value of logarithmic decrement at each temperature is determined by Arrhenius' equation, as shown in Eq. (3). Results of the estimation are shown in **Fig. 10**.

$$\ln t_e = A + \frac{\Delta H}{RT} \cdots\cdots\cdots\cdots (3)$$

where t_e: Time of maximal logarithmic decrement

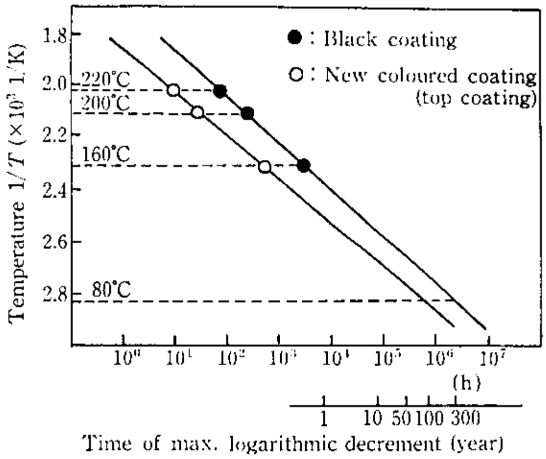


Fig. 10 Life expectancy of new coloured polyurethane elastomer coating by torsional braid analysis

A: Constant
ΔH: Activation energy
R: Gas constant
T: Test temperature (K)

The heat life of the acrylic urethane resin used as the top coat is slightly shorter than that of the black PUE resin. However, the oxidation service life of the coloured PUE coating material with a top coat of acrylic urethane is sufficient for long-term use, since the maximum service temperature for heavy-duty anticorrosion appplications is about 60°C. The activation energy determined from Eq. (3) is 27.9 kcal/mol for the acrylic urethane resin and 26.1 kcal/mol for the black PUE resin. These values are in good agreement with the activation energy in the oxidation of polyurethane resin[20] and it is therefore considered appropriate that the maximal value of logarithmic decrement be used in this method as an index.

4 Manufacture of Coloured Polyurethane Elastomer-Coated Steel

The manufacturing process for coloured polyurethane elastomer-coated steel is shown in **Fig. 11**. After shot blasting, a steel base material is subjected to chemical treatment and an epoxy primer is applied to a thickness of 30 to 50 μm by airless spray coating. PUE coating is then applied to a thickness of 2.0 to 2.5 mm using a special airless spray gun. A top coat of acrylic urethane is applied to a film thickness of 50 to 200 μm by airless spray coating. Coloured PUE-coated steel sheet piles are shown in **Photo 2**. Top coatings of blue, brown, green, red, and yellow, shown in **Photo 3**, can be manufactured.

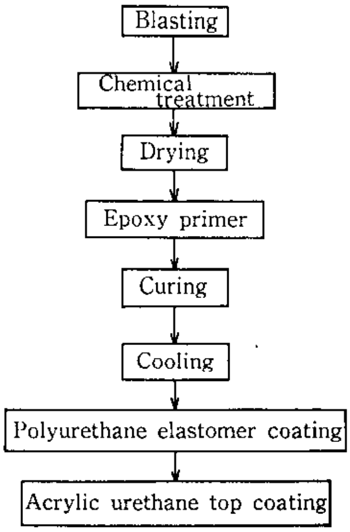


Fig. 11 Manufacturing process of new coloured polyurethane elastomer coated steel structures

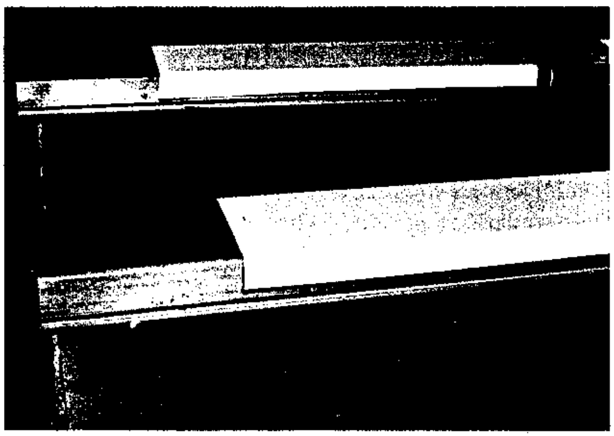
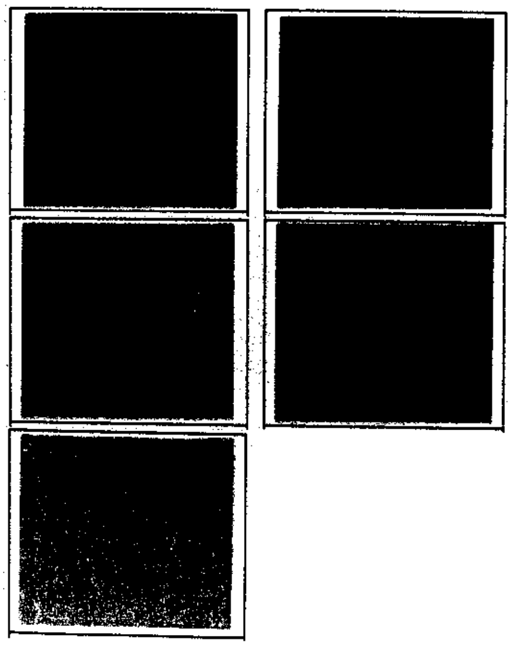


Photo 2 New coloured polyurethane elastomer coated steel sheet piles (Upper, green; lower, blue)



Upper: Blue Brown
Middle: Green Red
Lower: Yellow

Photo 3 Appearance of new coloured-acrylic urethane top coating

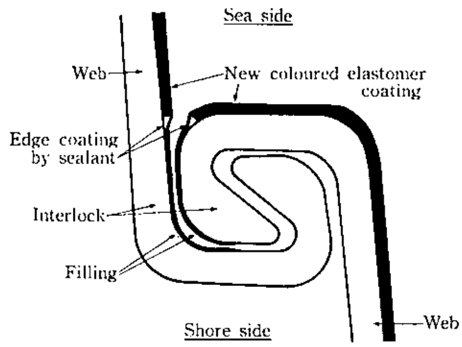


Fig. 12 Coating method at interlock parts of new coloured polyurethane elastomer coated steel sheet piles

5 Application of Coating to Interlock Parts; Field Repair

5.1 Application of Coating to Interlock Parts

In steel sheet piles, as an example, the corrosion of the interior of interlock parts is relatively slight because these areas are filled with sand and available oxygen is limited[21]. In coloured PUE-coated sheet piles, a sealant is applied to the edges of the coating, and corrosion resistance inside interlock parts is maintained by applying an asphalt-based filler, as shown in **Fig. 12**, as the most effective anticorrosion precaution.

5.2 Field Repair

5.2.1 Atmospheric zone

When damage to the coating film does not reach the steel surface, a repair agent can be applied to the damaged area, as shown in **Fig. 13**(1), after surface preparation with sandpaper or some other abrasion material. When damage to the coating reaches the steel surface, a surface treatment agent is applied to the steel

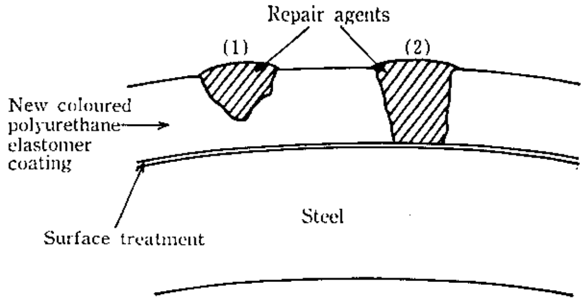


Fig. 13 Repair methods of damaged areas of new coloured polyurethane coated steel structures

surface and a repair agent is then applied after preparation of the steel surface and coating film with an abrasive material.

5.2.2 Underwater zone

Damaged areas of the coating are repaired with an underwater cured epoxy resin after preparation with an abrasive material.

6 Conclusions

Kawasaki Steel developed a coloured polyurethane elastomer-coated heavy-duty steel with far better durability than conventional heavy-duty corrosion-resistant coated steels. In this steel, anticorrosion properties, adhesion, weathering resistance, and mechanical properties are imparted to the surface treatment layer and polyurethane elastomer coating layer, while weathering resistance measures are taken with the acrylic urethane resin top coat. The new steel has the following features:

(1) The coloured coating has vertical tensile strength above 100 kgf/cm^2 and impact strength above 3.0 kgf·m (both values, at room temperature) at a coating film thickness of 2.0 mm. Inter-layer adhesion is not impaired by the use of an acrylic urethane resin as the top coat.

(2) Peeling of the coloured coating did not occur in any of the corrosion tests, which included hot salt water immersion, salt spray and cathodic peeling, because a two-layer system composed of a chemical treatment layer and an epoxy primer layer was adopted for surface treatment.

(3) It is possible to control colour differences of the coloured coating with an acrylic urethane resin top coat to 5 or less after 8 000 h (corresponding to 40 years of weathering) in a weatherometer.

(4) The heat resistant service life of the coloured coating is more than 40 years at 80°C.

With this coloured polyurethane elastomer coating, it is possible to provide, for example, blue, yellow, green, brown, and gray top coat colours by adding colour pigments to the acrylic urethane resin top coat. Thus, with this coating such considerations as appearance, harmony with the environment, and safety markings can be met in a steel applicable to almost all civil engineering and building materials, including steel pipe piles, steel sheet piles, steel sheet pipe piles, and wide flange beams for use in marine, harbor, and river structures.

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