

DHFの 溶射と熱処理

THERMAL SPRAYING & HEATING



第一高周波工業株式会社
DAI-ICHI HIGH FREQUENCY CO., LTD.



Additional Benefits — Additional Years of Service Life

DHFの溶射 — 熱処理

DHF's S&F (Sprayed and Fused) lining - Synergy of unique thermal spraying and heat-treatment technologies

- 溶射と高周波誘導加熱を組み合わせた耐摩耗、耐食性に優れた皮膜形成法です。特に高温で使用されるごみ焼却炉のボイラーチューブに有効です。

It is the unique process combining thermal spraying with high frequency induction heating to form the lining with excellent wear and corrosion resistances.

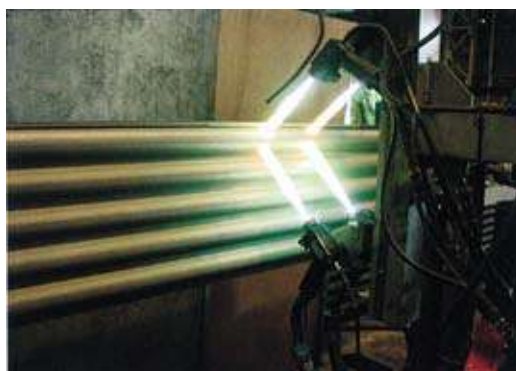
Specifically, it is quite effective to improve service life of boiler tubes used at waste to energy (WtE) incinerators, which operate at high temperature and under severe condition.

- Ni-Cr合金主体なので、塩素系や硫酸系の腐食ガスに対しても優れた耐食性を有します。

And the DHF's S&F lining is made of Ni-Cr rich alloy, so that it has an excellent resistance against corrosive gases such as hydrochloric and sulfuric acids.

- 本製品は、実機で性能が実証され、多くのお客様の要望を満たした商品と確信しています。

Its excellent performance has been fully proved by the actual applications to facilities so that we are fully convinced to satisfy customers by meeting their requirements.



▲ 水壁パネルの溶射施工写真

Thermal spraying on a tube panel of the water wall



▲ 水壁パネル溶射品の高周波曲げ加工写真

Bending a tube panel of the water wall with the lining at a high frequency heating process

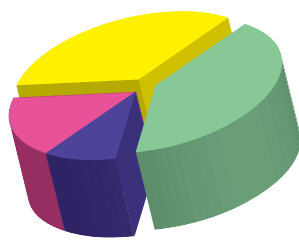
DHF溶射 — 採用の拡大化

DHF's S&F lining - Expanding to the world market

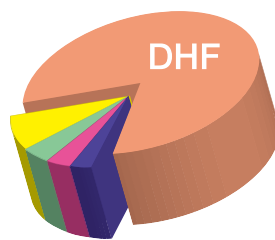
- DHF溶射は日本や台湾のごみ焼却炉を手始めとして近年世界的に採用が広まってきています。これはボイラーチューブそのものの寿命がのび、かつインコネルの肉盛と比較して価格が安いことなどが2002年よりシェアを飛躍的に拡大している理由となっています。

Since DHF started commercial production of the lining to introduce to the markets in Japan and Taiwan in 2002, demand for the lining has been steadily increasing mainly in the field of the WtE incinerators.

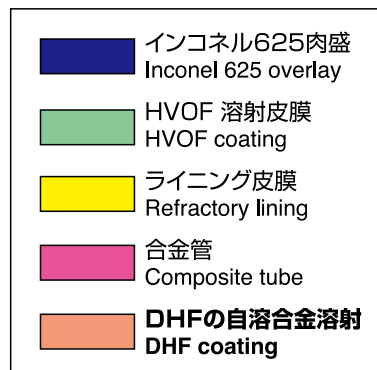
As a result, the market share of the lining in the field of the boiler tube application has been increasing due to its longer service life and more competitive price than the conventional lining made of the Inconel alloy deposit formed by welding method.



in 2002



Now



▲ 台湾のごみ焼却炉BTのコーティングシェアの動向

DHF's S&F lining - Increasing its market share in the field of application to boiler tubes at WtE incinerators in Taiwan



Additional Benefits — Additional Years of Service Life

● DHF溶射の高信頼性と寿命

DHF's S&F lining - High reliability and long lifetime

- 自溶合金皮膜は、溶射後再溶融処理（フュージング）により母管と皮膜が拡散結合します。このため、非常に結合力が強く耐剥離性が非常に高い皮膜となるばかりでなく、高周波再溶融処理することで、さらに皮膜が緻密になり、かつ母管への貫通気孔がなくなることで相交わって母管の防食に関して一層効果が大きくなります。

The lining is made by fusing (melting) the layer formed on the surface of the base (boiler tube) material by thermal spraying self-fluxing alloy, which results in diffusion bonding between the lining and the base material. Therefore, its bonding strength is so high that it secures no spalling of the lining from the base material.

Furthermore, the fusing process ensures the dense lining by eliminating pinhole-like defects which might entirely penetrate the lining from its top surface to the bottom interface with the base material. Therefore the lining performs excellent corrosion resistance.

- 本皮膜の膨張係数が母管よりもやや大きいため、高温域での使用では皮膜に圧縮応力が掛かるようになります。このため、温度変化に伴う熱応力による皮膜の疲労破壊は生じにくくなります。

The thermal expansion coefficient of the lining is higher than the boiler tube material's so that compressive stress is always loaded on the lining during the usage at high temperature. Therefore, the fatigue breakdown of the lining, which might be caused by repeated tensile stress originated by cyclic temperature changes during the usage, never occurs.

- 本皮膜の熱伝導度は、インコネル625と同等です。しかしインコネル肉盛とくらべて膜厚が薄いので熱伝導量は多くなります。

Thermal conductivity of the lining is comparable with the Inconel 625 alloy, which is used as a conventional material to overlay on the boiler tube.

But the lining's heat transfer coefficient is much higher than the Inconel 625 alloy because of its thin thickness, which results in higher heat transfer capacity of the boiler tubes compared with the Inconel 625 alloy.

- 再溶融処理時の加熱時間が短く、且つ母材への熱影響が溶接肉盛よりも少ないため、母材の持つ機械的性質を維持出来ます。

The fusing process requires shorter heating time and lower maximum temperature than those of the welding-overlay method so that the heating effect to the mechanical strength of the base material can be minimized.



▲ ごみ焼却炉（処理能力:450トン）で3年後の皮膜の状態写真。表面は滑らかでかつ、金属光沢を維持している。

Boiler tubes with the lining at the WtE incinerator (Incineration capacity; 450 tons/day) after 3 years running.

The lining surfaces of the tubes shows smooth and metallic luster demonstrating no corrosion of them.



▲ 皮膜のマイクロ組織
Ni-Crのマトリックス中にCrB、CrCが析出している。

Micro structure of the lining. Hard CrB and CrC particles are uniformly precipitated and dispersed in the matrix of Ni-Cr alloy.



Additional Benefits — Additional Years of Service Life

DHF溶射のユニークなソリューションのご提供 DHF's S&F lining-Further Advantages

- 高周波誘導加熱と鋼管曲げ技術をベースに自溶合金皮膜を高品質なものとして提供しています。

Furthermore, DHF is able to supply the high quality bent pipes and panels coated with the lining fabricated by the unique and proprietary steel pipe bending process, which employs DHF's induction heating technology.

- お客様の用途やご要望に合わせて、直管、曲げ管、直パネル、曲げパネル、スーパーヒーター管など、幅広い商品をそろえています。

As a result, DHF is able to prepare a wide variety of the products, such as straight/bent tubes, straight/bent tube-panels, and super heater pipes ensuring to fully meet the customers' requests and requirements.

- また、お客様の用途に合わせた膜厚を提供します。

Also, the lining is flexible about thickness so that it can be optimized to maximize its performance according to customer's application.

- 弊社、自溶合金皮膜は、耐摩耗と耐食性に優れた皮膜です。

The lining has excellent wear and corrosion resistance.

Characteristics Comparison

	HVOF溶射 HVOF coating	溶接肉盛 Weld Overlay	DHF溶射 DHF
皮膜材質 coating material	Ni-Cr	インコネル625 inconel 625	Ni自溶合金 Ni-Cr-Fe
希釈化 dilution with substrate	無し no	有 yes (Fe:10-20%)	無し no
皮膜厚み allowable thickness	0.25mm	>2mm	0.3~3mm
熱影響 adverse effect on thermal transfer	少ない minor	有 notable	少ない minor
熱による歪 tube distortion by thermal stress	少ない minor	有 notable	少ない minor
耐食性 corrosion resistance	良い good	良い good	良い good
耐摩耗性 erosion resistance	問題あり medium	問題あり medium	良い good
密着力 bonding strength	70Mpa	450Mpa	400Mpa
皮膜硬さ (HRC) coating hardness(HRc)	45	<40	>55
表面状態 surface condition	良好 even	良くない uneven	良好 even
膜厚の調整 thickness monitoring	容易 easy	やや困難 grind necessary	容易 easy
剥離 peeling off	可能性あり possible	無い impossible	無い impossible
コスト cost	溶接肉盛の半分 \$/2	\$	溶接肉盛の半分 \$/2



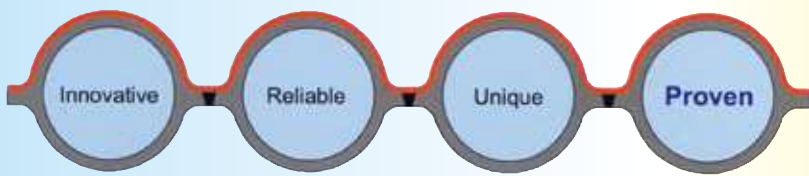
▲ 直管パネルの高周波フュージング

Fusing a straight tube panel by the high frequency induction heating



▲ 高周波曲げ処理された溶射パネル

Bent tube panels processed by the high frequency induction heating and bending



Additional Benefits — Additional Years of Service Life

DHF溶射—実証例

DHF's S&F lining-Verification example

- 国内の流動層式石炭燃焼ボイラーのスーパーヒーターに使用して、耐エロージョン性が著しく向上しました。(1993年に施工)

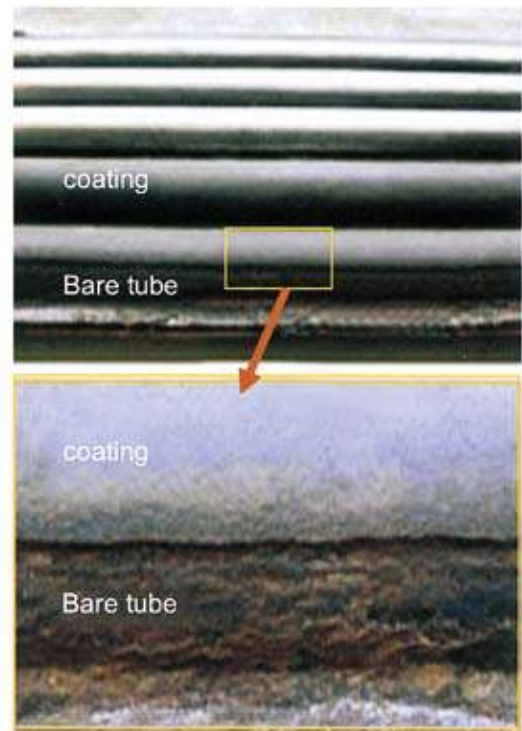
Erosion resistance of the super heater in the fluid bed type coal firing boiler improved remarkably after introducing the lining pipes in Japan in 1993.

- 台湾のごみ焼却炉では、腐食性が高い燃焼ガス環境においても耐食性を十分に発揮しました。特に台湾でのゴミ焼却は、一般ゴミと産業廃棄物を同時に焼却するため高濃度の腐食性ガスが発生する環境にあります。

The lining product used as boiler tube panels at the WtE incinerator in Taiwan, which generates extremely corrosive combustion gases, showed excellent corrosion resistance. Specifically, it demonstrates the lining's incomparable performance. Because the concentration of corrosive combustion gases generated at the WtE incinerator in Taiwan are extremely high due to burning both public garbage and industrial waste simultaneously.

- ごみ焼却炉における煤煙喚起近傍のスーパーヒーターは腐食性燃焼ガスの乱気流により腐食と摩耗が著しいにも拘わらず、本処理皮膜管は摩耗が極めて少ない結果を得ています。

The lining boiler tubes of the WtE super heater around soot blower, where corrosion and erosion are extremely severe due to turbulent flow of combustion gas, shows almost no abrasion.



- ▲ 台湾ごみ焼却炉の使用3年後のチューブ状態写真。無処理の母管は塩化物などにより損耗が激しいが本皮膜は腐食していない。

The both boiler tubes with and without the lining after 3 years of usage at the Taiwanese WtE incinerator.

The tubes without the lining show severe worn-out due to chloride corrosion, however the tubes with the lining remain intact.

Corrosion Resistance

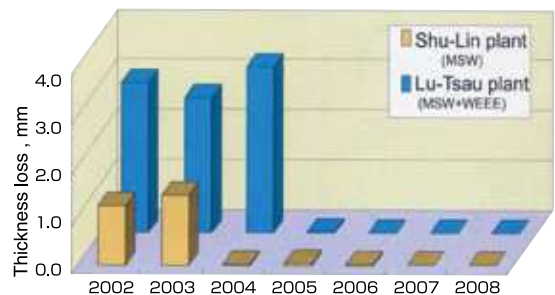
優れた耐食性

産業廃棄物を含めたごみ焼却炉で、耐食性が実証されました。右図に示すように、皮膜層の厚み追跡調査から、導入以来、腐食による減厚が見られず、客先より高い評価を頂き、更に追加注文を受けました。

Excellent corrosion resistance

The lining's excellent corrosion resistance has been also proved at the WtE incinerator which burns garbage including industrial waste.

As shown in the right figure, no loss of the lining thickness was confirmed at the follow-up inspections after introduction. The customer highly evaluated the lining's performance, which convinced enough to secure additional introductions.



- ▲ 台湾の2プラントで、DHF溶射がボイラー管防食に効果を示す表。

Eliminate corrosion of boiler tubes by introducing DHF panels in two plants in Taiwan.



Additional Benefits — Additional Years of Service Life

● DHF溶射の更なる利点

DHF's S&F lining - Additional merits

- DHF溶射の皮膜層は、インコネル肉盛りよりも薄く、表面も滑らかで腐食が少ないといった特長があります。このため、ボイラーの熱伝導率が良く、スーパーヒーターの熱交換チューブとして適しています。

The heat exchange efficiency of the boiler tube with the lining is much higher than those of Inconel alloy layer deposited with welding. Because the lining thickness is much lower, and its surface is smoother, and cleaner than the Inconel's due to no corrosion.

As a result, corrosion of the super heater tube can be constrained due to lowering combustion gas temperature.

- このことは、右図にしめす台湾のごみ焼却炉の運転実績で証明されます。

主ボイラーの燃焼室の水壁パネル245m²をDHF溶射(自溶合金処理)パネルに置き換えた結果、スーパーヒーター入り口部の燃焼ガス温度が安定し、ボイラーの水蒸気温度も低下しないため、著しく熱交換率が向上しました。

It is proven in the right figure which shows the operation results of the WtE incinerator in Taiwan.

Because gas temperature at the super heater entrance dropped without dropping the steam temperature after replacing the section of a 245 m² of the water wall panel in the primary boiler chamber with the lining, the heat exchange efficiency improved remarkably.

- DHF溶射をごみ焼却炉に導入した時の経済効果予測

下記の表に、φ76.2X6000mmの皮膜有り無しの効果予測を示します。

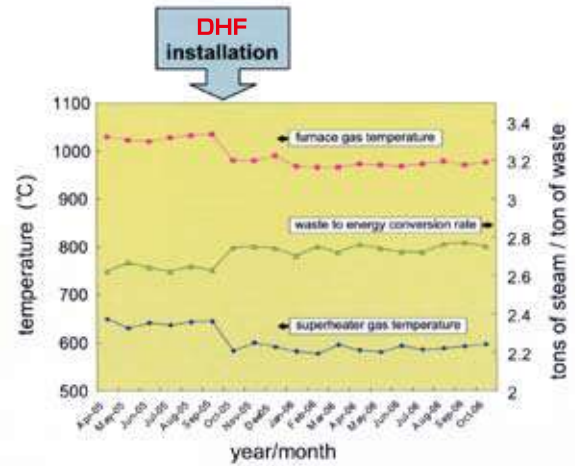
各々16年間使用した時のトータルコストを比較すると本皮膜を適用することで経済効果があると推定できます。(皮膜は0.8mmとし、皮膜摩耗速度を0.05mm/年と仮定して算出)

DHF's S&F lining - Benefit estimation of introducing the lining into the WtE incinerator

A comparison of the total running cost of each 76.2 dia. x 6000 mm long tube unit with and without the lining shows in the bellow table.

It compares the total running cost of each 16 year-operation. It is evaluates under the condition that the lining thickness is 0.8 mm, and its abrasion rate is 0.05 mm/a year.

Substantial cost reduction can be achieved by introducing the lining.



- ▲ ボイラー燃焼室の水壁パネルの245m²をDHF溶射(自溶合金皮膜処理)パネルに交換したことで熱交換率の向上結果。

The improvement of the heat exchange rate at the WtE station which resulted from replacing a 245m² section of the original water wall panel in the primary boiler chamber with the lining ones.

炭素鋼管 Carbon steel	ボイラー管寿命年数 Tubes in different lifetime in the boiler	2年 2 years	4年 4 years	6年 6 years
	16年での交換回数 Replacement frequency in 16 years	8	4	2.6
	トータル維持費 Total maintenance cost in 16 years (USD)	4480ドル 4480\$	2240ドル 2240\$	1460ドル 1460\$
DHF溶射	皮膜寿命 Lifetime of coating	16年 16 years		
	16年の総投資額 Total Investment in 16 years (USD)	1300ドル 1300\$		

ボイラーチューブ抜管装置

Induction Heating(IH) Shrinker for Boiler Extubation

高周波加熱弛緩装置

High Frequency Induction Heating Tube Shrinker

技術の第一高周波が、水管・煙管ボイラや、熱交換機、復水器等の管孔に拡張により取り付けられたチューブの弛緩抜き取り作業を画期的に改善しました。誘導加熱を使用した新工法は、火気を一切使わない為、作業環境が改善され誰でも確実に作業出来ます。

DHF, gained the reputation as the IH technology pioneer, developed a unique equipment, called "the IH tube shrinker", which revolutionary improves the extubating operation of both water-and fire-tube boilers, heat exchangers, and water condensers, in which tubes are joined to the holes of the end plate mechanically. By introducing the IH tube shrinker, the extubating work requires no burner flame to heat which results in tremendous improvement of working environment as well as work efficiency.

● 特徴 Features

① 時間短縮 High Working Efficiency	誘導加熱により短時間にチューブを昇温する為、作業時間が大幅に短縮されます。 It requires a very short time to heat by the IH shrinker so that working hours are substantially reduced.
② 品質向上 High and Consistent Quality	管孔に傷が付きません。又管孔の収縮や胴体の変形が殆ど有りません。 It causes neither damage nor shrinkage of the end plate holes as well as no distortion of the body barrel.
③ 安全性 High Safety	焰を使用しないため狭益部での酸欠の危険性がありません。 There is no risk to expose workers to the oxygen deficiency atmosphere in the small work space by using burner flame.
④ 操作性 High User Friendliness	処理条件に再現性が有りますので、熟練者が不要です。 High consistent working quality is secured with any average skilled operators.
⑤ 作業環境 Good Working Environment	排熱・輻射熱・騒音・粉塵の発生がなく、クリーンです。 Relatively clean working environment is secured due to neither hot exhaust gas nor blowing dust caused by using burner flame.



● 弛緩の原理 Mechanism of extubation by heating and relaxation method

チューブを約1000℃に加熱すると、1%程度熱膨張します。しかし、チューブ外径は管板の内径により拘束されているため膨張出来ず、この1%分だけ圧縮降伏します。チューブ温度が常温に下がると、チューブ外径はこの1%分だけ収縮され、弛緩が完了します。

In general, tube expands its size when it is heated to about 1000 degrees C.

And the tube outside diameter contacted with the plate hole surface area can not expand due to being tied down with the plate hole so that such area yields by the compression force to result in plastic deformation. And after the tube is cooled down to the room temperature, it shrinks its size by 1% from the original size which causes a gap between the tube outer and the end plate hole diameters to result in relaxation of them.

DHF溶射 現地工事

DHF's On — site Thermal Spraying Job Service

自溶合金溶射と高周波フュージング

Self-fluxing alloy thermal spraying and IH fusing

水壁パネルの局所の溶射と高周波再溶融処理

Spraying and induction fusing of the water wall panel



溶射施工

Thermal spraying

高周波溶融処理

IH fusing

DHFの溶射ロール

Thermal Sprayed Roll

【サーメット溶射ロール】 Cermet sprayed roll

当社では二種類のHVOF溶射ガン(高速フレイム溶射ガン)を保有し、ニーズにあった炭化物系サーメット溶射皮膜を形成しております。

用途に応じた面粗度調整が可能で、耐摩耗・スリップ防止用等に広く使用されております。

現在溶射可能形状は、最大径φ1500、重量5000Kgとなっております。

DHF has two types of HVOF (High Velocity Oxy-Fuel) thermal spray (the high-speed flame spraying gun) system to form various carbide type cermets coatings to meet customer's requirement.

DHF can supply the roll, of which surface roughness is adjusted to the best use for applications, as well as wear resistance, and so on.

Size capacity of roll to be processed: Max. dia. 1500 mm, Max. weight:5000Kg.

製品名 Grade	DHF-W1200	DHF-W1700	DHS-W250	DHS-HT2500
成分系 Coating	WC-Co	WC-Co	WC-NiCr	Cr3C2-NiCr
溶射方法 Spray method	HVOF	HVOF	HVOF	HVOF
硬さ(HVO.3) Hardness	1000~1400	800~1000	1000~1100	800~1000
気孔率(%) Porosity	<0.5	<0.5	<0.5	<0.5
密着強度(kgf/mm ²) Adhesion strength	>8	>8	>8	>8
熱膨張係数(10 ⁻⁶ /°C) Coefficient of thermal expansion	7~8.5	7~8.5	8~9	8~9
使用限界温度(°C) Max use temperature	550	550	700	850
特徴 characteristics	高耐摩耗性 Anti Heavy Wear	耐摩耗性 Anti Wear	耐摩耗性 耐食性 Anti Wear & Corrosion	耐摩耗性 耐食性 Anti Wear & Corrosion



HVOF spray Process



As sprayed

【自溶合金溶射ロール】 Self-fluxing alloy coated roll

自溶合金溶射はニッケルやコバルトを主成分とした、耐食性溶射材です。溶射後に再溶融処理（フュージング）を施すことで、粒子は溶融結合し、基材との界面においても合金層が形成されます。

そのため、貫通気孔はなくなり、母材との結合も強固となります。

当社では、溶射後の再溶融処理（フュージング）において誘導加熱を利用することで、安定した処理が可能となり、皮膜性状が均一となります。

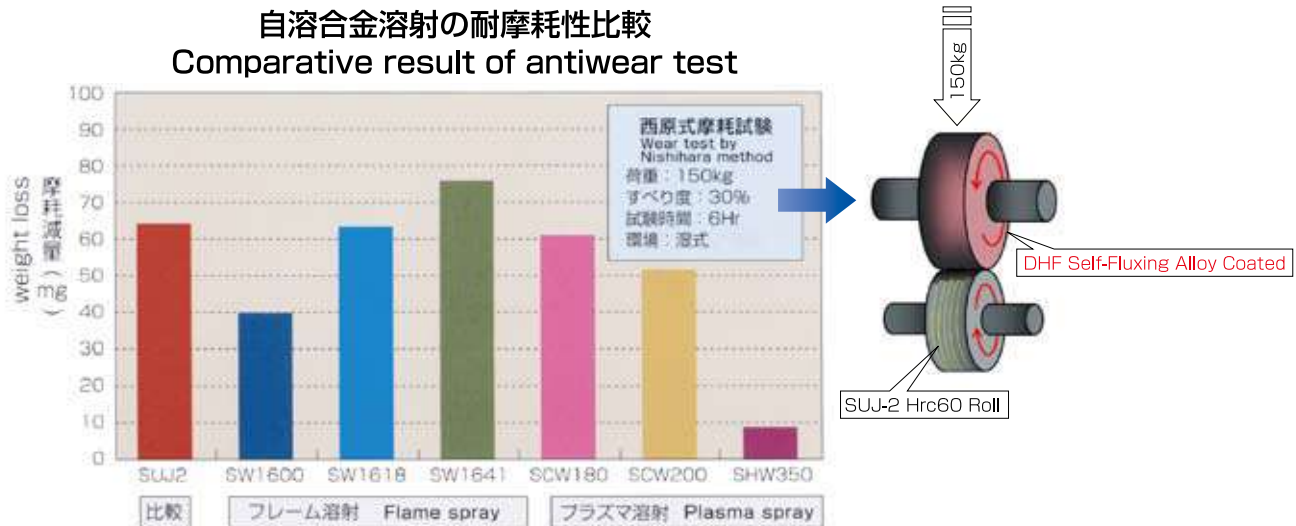
また、高温処理が容易に行えるため、従来フュージングが困難な特殊溶射品材の製作も可能となります。

製作可能形状は、最大径φ750mm（実績ベース）、重量5トン以下となります。

Ni or Co-base self-fluxing alloy is the hardfacing material, having low melting temp, which has corrosion and wear resistance. In case of applying it in the form of powder, it has two processes, thermal spraying and fusing. By fusing as-sprayed coating, more pinhole or defect free and dense coating layer is formed as well as strong bonding with blank material due to alloying at the interface between them by fusion process. DHF developed own fusing process, which uses high frequency induction heating instead of gas flame as heating source, and realizes a high uniform and consistent quality coating. Also, it becomes possible to process a high melting temp. Production size capacity: Max. dia. 750, Max. weight:5000Kg

製品名 Grade	SW1600	SW1618	SW1641	SCW180	SCW200	SHW350
系統 alloy base	ニッケル基 nickel			コバルト基 cobalt		WC入りニッケル基 nickelwc
成分 chemical composition	SFNi4相当 JIS SFNi4	高Mo High Mo	高クローム High Cr	SFCo相当 JIS SFCo	高W High W	SFWC2相当 JIS SFWC2
溶射 spray method	フレイム Flame	フレイム,プラズマ Flame, Plasma	フレイム,プラズマ Flame, Plasma	フレイム Flame	フレイム Flame	フレイム,プラズマ Flame, Plasma
皮膜硬度(HV0.5) coating hardness	700-800	700-800	500-600	600-700	800-900	900-1000
特徴 characteristics	耐食・耐摩耗 Anti Corrosion & Wear	高耐食 Anti Heavy Corrosion	高耐食 Anti Heavy Corrosion	耐食 Anti Corrosion	耐食・耐摩耗 Anti Corrosion & Wear	高耐摩耗 Anti Heavy Wear

自溶合金溶射の耐摩耗性比較
Comparative result of antiwear test



Plasma spray



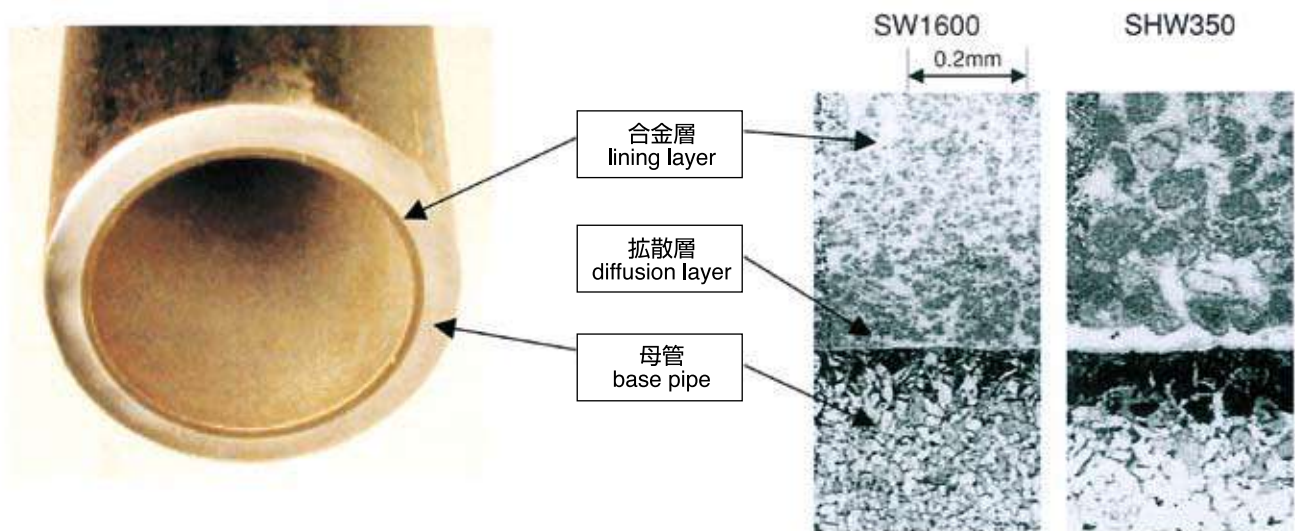
IH fusing

金属複合管 DML Bimetal Pipe “DML”

金属複合管DMLは、鋼管内面に高耐摩耗・耐腐食合金を拡散接合させた金属複合管です。高い密着力を備え、耐エロージョンはもとより衝撃などによる合金層の破壊、剥離がなく、従来の表面処理品と比べ高い評価を受けています。石炭火力、石油化学、製鉄、ごみ焼却などの飛灰、微粉炭、ペレタイザー、触媒などの配管に使用されています。

DML is the steel base pipe, of which inner surface is coated with a high wear and corrosion resistance Ni-base alloy layer, which is strongly bonded with the back steel resulted from diffusion bonding. And due to its high bonding strength between the lining and the back steel compared with those made by conventional coating methods, there is no concern about cracking or peeling off due to mechanical impact or vibration.

It is widely used for piping at pneumatic conveying systems of fly ash, pulverized coal, pellets, catalysis, etc. in electric power, petrochemical, and steel industries as well as incineration stations.



金属複合管DMLの特長 Features of DML

- 拡散接合により接合が強く、剥離の可能性が少ない
- 用途により合金層の厚みが選定可能
(最大3mm厚まで可能)
- 従来の異材の内張管に比べ安価で高品質
- High bonding strength and no peeling off of the lining due to diffusion bonding.
- Wide range of the lining thickness to ensure its optimum application.
(The maximum lining thickness:3mm).
- Competitive price compared with the conventional bimetal or non-metal inner coated pipes.

DML製造可能範囲

DML's size specification

合金層の厚さ Lining thickness	最大膜厚3mm (標準1.5mm) ≤ 3 mm (Regular : 1.5mm)
パイプサイズ Diameter.	40A~300A
パイプ肉厚 Wall thickness	25mm以下 ≤ 25 mm
炭素鋼鋼管 Carbon steel	sch40~sch160
ステンレス鋼管 Stainless steel	sch20~sch160
パイプ長さ Length	3000mm以下 ≤ 3,000 mm
曲管(バンド)曲げR Bending R (Radius)	4DR以上 (標準4.5DR) ≥ 4D(Regular4.5D)* *D ; diameter

上記仕様範囲外については別途ご相談願います。

In case of exceeding the above specification limits, please let us know.

溶射とは・・・!?

What's Thermal Spray !?.

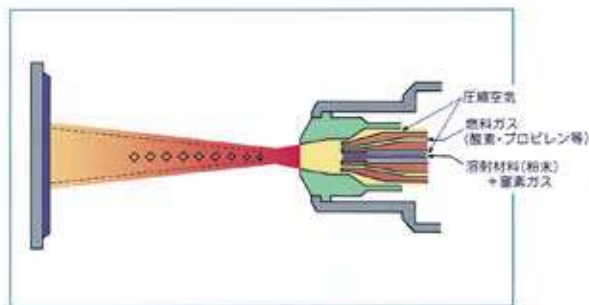
各種材料を適当な加熱源を用いて熔融もしくは半熔融状態とし、これらをしかるべき母材の表面に吹き付ける事で粒子が積層して皮膜化する加工方法を溶射と称する。

溶射粒子は熔融もしくは半熔融の状態では母材に衝突する為、母材表面の凹凸に沿って付着・凝固する事で収縮力が付着力に変わる(アンカー効果)。これ以外の密着力として瞬間的な固相拡散による結合力や原子間結合(ファンデルワールスフォース)等が考えられるが実体は定かでない。場合によっては溶射後に加熱再熔融処理、封孔処理等を行い実用に供している。

It is one of the surface processing methods to form a coating layer of various kinds of materials onto the substrate (base material) by spraying its droplets, which are fully or partially melted by going through a high temperature flame generated from one of energy sources.

By deforming and shrinking after colliding with and freezing on the patterned indented surface of the substrate, the sprayed droplets can adhere and pile-up on the substrate to form a coating layer by the force generated by so called as, "the anchor effect".

In addition to the above, some types of bonding forces between the coating and substrate are thought to exist, such as the force originated by the solid phase diffusion between them, the attractive force among atoms (Van der Waals force). And in case of some applications, the fusion process, which melts the sprayed coating, follows in order to improve the coating quality by removing defects such as, pinholes, voids, oxides, non metallic compounds, and so on.



高周波誘導加熱とは・・・!?

What's High Frequency Induction Heating !?.

図1の様に永久磁石をコイルの中に入れ、磁束の変化が起きる様に永久磁石を上下させるとコイルに誘導電流が流れる。このような現象を電磁誘導と呼ぶ。

このコイルの中に金属の様な導電体を挿入し、図2の様にコイルに交流電流を流すと周波数に応じた磁束の変化(交番磁束)が発生し、この磁束が導電体を貫通し、誘導電流(渦電流)が流れる。この誘導電流と導電体の抵抗によりジュール熱が発生し導電体が発熱する。このような加熱を誘導加熱と称している。

この時、交流電流は導体の表面に集中して流れ、内部へ行く程指数関数的に減衰していく事が知られている。この誘導電流が表面の電流の0.368倍に減少する地点までの深さを電流浸透深さと呼び、この値は次の式により求める事が出来る。とされている。

$$\text{電流浸透深さ } \delta (\text{cm}) = 5.03 \times (\rho / \mu \cdot f)^{1/2}$$

ρ : 被加熱物の抵抗率 ($\mu\Omega \cdot \text{cm}$)

μ : 被加熱物の比透磁率

f: 周波数(Hz)

As shown in the Fig.1, the induced electric current flows through the coil in case of putting a permanent magnet into the coil and letting it go up and down to change its magnetic flux. Such a phenomenon is called electromagnetic induction.

On the other hand, as shown in the Fig. 2, the induced electric current (called eddy current) also flows within the rod, which has electric conductivity like metal, in case of flowing alternating current through the coil, which generates and change the magnetic flux periodically (called alternating magnetic flux), which penetrates the rod, according to its frequency.

This eddy current generates Jules heat due to the electric resistance of the rod (conductor), which results in the heating up its own rod. This kind of heating method is called induction heating.

The alternating current tends to flow mainly on the surface of the conductor, and its intensity attenuates exponentially with the depth from the surface of the rod (conductor).

The depth, at which the alternating eddy current flow decreases to 36.8 % of those of the surface, is called as the electric current penetrating depth, and which can be calculated by using the following equation.

$$\text{Electric current penetrating depth } \delta (\text{cm}) = 5.03 \times (\rho / \mu \cdot f)^{1/2}$$

ρ : Electric resistivity of heating workpiece ($\mu \Omega \cdot \text{cm}$)

μ : Relative magnetic permeability of heating workpiece

f : Frequency (Hz)

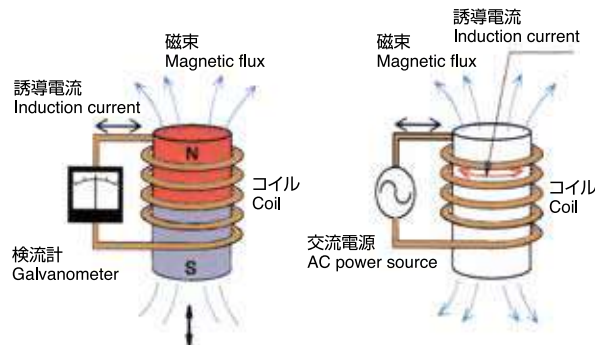


図1
Fig.. 1

図2
Fig.. 2



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