Engineer Your Surfaces Towards Higher Profits

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Wear and abrasion of engineering components are taken care of by a wide portfolio of surface modification technologies. Added value comes by way of enhanced performance and aesthetic appeal.

Detroit, Tuesday, 22nd December 1998 ; Ford Motor Co. announced that it voluntarily recalled about 3.5 million of its Taurus and Sable cars from the North American market. The reason: in a little under 1% of these cars, road salt and moisture it is believed, could have caused corrosion in the engine body and transmission supports causing the subframe to drop and making steering difficult. Ford had received seven reports of alleged accidents due to this corrosion problem.

This is not the first instance when manufacturing companies have had to face these kinds of problems. Every year, and across the entire gamut of manufacturing and engineering industry, problems related to component and surface degradation have taken a heavy toll through equipment that fail to withstand the rigours of tough, and operating conditions.

Engineering components when subjected to aggressive environments like high speed, corrosive media, extreme temperatures and cyclic stresses result in surface degradation. The common problems faced are:

- Wear: degradation due to the relative motion between two mating parts, like in crank shafts, position rings in a cylinder, gear drives, bearings etc.
- Abrasion: Gradual deterioration/degradation of the surface due to the impingement of coarser particles continuously. For example, impeller casing of centrifugal slurry pump when subjected to attack by coarser slurry particles. The damage caused by these phenomena becomes very critical at times like in the case of the hydro turbine blades in power plants situated in the Himalayan regions, that disappear after some years.
- Corrosion: Surface degradation due to corrosive media like acid, water, moisture seawater and its environment etc.

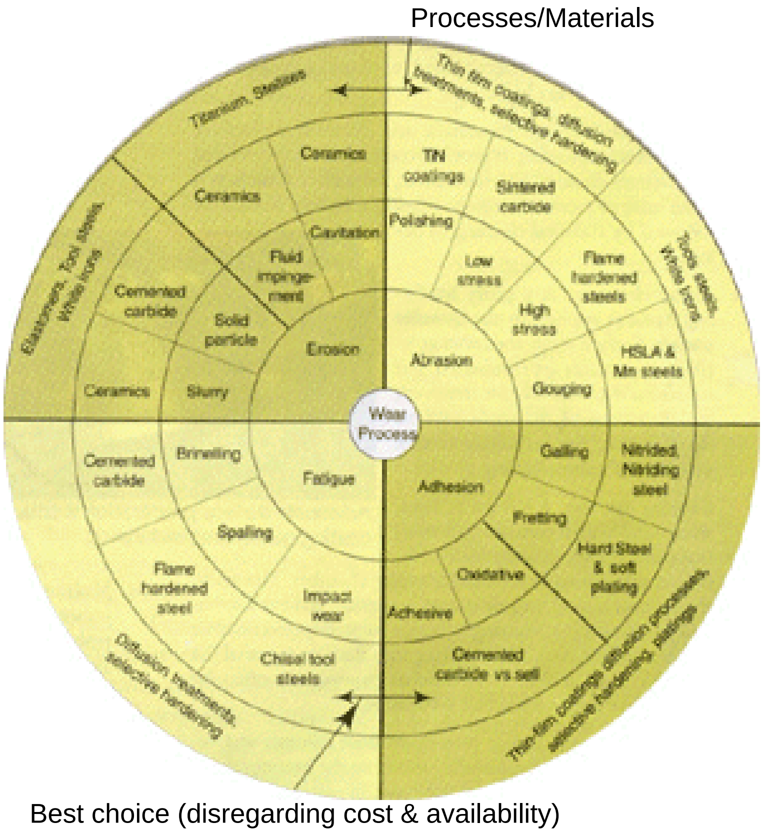
The recognition that a vast majority of engineering components fail catastrophically in service through the above mentioned surface related phenomena, led to the development of a broad interdisciplinary subject of ‘Subject Engineering’ (SE). SE could best be defined as The design of surface and substrate together as a system, to give a cost effective performance enhancement of which neither is capable of its own.

Adding value through SE

Today, there is a growing realisation that the Surface Modification approach can not only solve component degradation problems but can provide added value as well. This could be in the form of significant improvement in productivity (due to less frequent repairs and consequent down time) like ceramic coating of textile disc – cones subjected to intense wear through the rubbing of synthetic yarn at thousand of cycles per minute or extending tool life in a wide variety of engineering goods. Advanced coating also helps in achieving much higher performance like those on gas turbine blades which enable the engine to run at supersonic speeds. More recently, decorative coatings are being used to "value-add" the aesthetic appeal and that too very economically, like combination of titanium nitride and gold of just a few microns thickness to impart the glittering golden hue, which does not 'wear off' over the years.

Modifications to the component surface could be metallurgical, mechanical, chemical or physical. Surface engineering is an enabling technology applicable to a wide range of industrial sector activities. It enables the design and manufacture of metallic, ceramic, polymeric and composite systems with unique combinations of bulk and surface properties obtainable in neither the substrate nor the surface material alone.

Wear Modes & Material Solutions



The end purpose of a surface modification process could be manifold. Typically, these include minimising corrosion, reducing frictional energy losses, reducing wear, acting as a diffusion barrier, providing thermal insulation, blocking radiations of a certain type (wavelength), electrically insulating or simply, improving the aesthetic properties of the surface. Surface modification however, is largely done when the main concern is damage to the surface of the component or machine part. The potential causes of such damage in most engineering applications are due to one or more of the following agents: Chemicals such as acids, alkalis, salts and solvents, thermal, direct flames, oxidizing gases etc., atmospheric agents and finally, mechanical reasons such as abrasion, vibration, galling and the like.

The newer surface engineering techniques along with the traditional ones have a profound influence on several engineering properties. These include tribological, mechanical, chemical, thermal, electronic and super-conducting, optical, magnetic and indeed, aesthetic. Surface engineering technologies span five orders of magnitude of thickness and three orders of magnitude in hardness. The thickness of engineered surface can vary from several millimetres for weld over lays to a few nanometers for physical vapor deposition (PVD) and chemical vapor deposition (CVD) coatings or ion implantation. Example of coating hardness range from 250-300 Hv for spray coatings, 3500 Hv for Titanium Nitride PVD coatings and upto 10,000 Hv for diamond coatings.

The SE Process

Three interrelated activities could best describe surface engineering:

- Optimisation of the surface/substrate properties and performance in terms of corrosion, adhesion, wear and other physico-mechanical traits.
- Coatings technology including the traditional techniques of painting, electroplating, weld surfacing, plasma and hypervelocity spraying, thermal and thermochemical treatments such as nitriding and carburising, newer combinations of laser surfacing, physical vapor deposition (PVD), chemical vapour deposition (CVD), ion implantation and ion mixing.
- Characterisation and evaluation of surfaces and interfaces in terms of composition and morphology and their mechanical, electrical and optical properties.

Surface engineering processes can be classified into two main groups namely, surface preparation processes that help clean and prepare the component surfaces and surface treatment processes that give the desired properties to the material.

An Overview of Surface Preparation Techniques

By taking time to adequately prepare the surface, both coating quality and endurance will be optimised. The selection of appropriate cleaning and surface preparation techniques is dependent on the nature of the surface and the intended coating or surface treatment technique. The different methods to prepare surface are:

- **Manual cleaning**: Different tools are used to wipe away rust, oxide scale and foreign materials from the surface. It is often not completely effective and, to obtain a good finish, the costs can be very high.

- **Mechanical cleaning**: Pneumatic and electrical devices are used to clean the surface. It provides considerable improvement over manual cleaning but, used alone, the surface condition is often unfit to provide adequate coating adhesion. It must be followed by chemical cleaning as below.
- **Flame cleaning**: A slightly oxidising flame is applied to the metallic surface. Surface water and other volatile continimators are eliminated, but tenacious deposits are not removed, and distortion of the surface might occur. Alone, this technique cannot provide sufficient cleaning.
- **Blasting dry/wet**: A stream of sand, wire, metal or glass particles (grit/shot) is applied at high velocity under controlled conditions in a closed blasting chamber. Normally, the process is used only to clean the surface, achieve a specified roughness (i.e. 'blasting', repair some imperfections or prevent fatigue cracks propogating into the base material (ie. 'shot peening'). In case of thermal spraying, it is often the only surface preparation that is required.
- **Grease removing**: This is performed with solvents and detergents and eliminates contaminants from the base surface. It is used before applying the coating and, in combination with the other surface preparation methods, helps to ensure coating adhesion.
- **Alkaline bath**: A combination of ingredients such as surfactants, saponifiers, emulsifiers, stabilisers, etc. They are physically and chemically active and reduce interfacial surface tension. Electrolytic bath: It is a modification of an alkaline bath. An electrical current produces gassing on the surface, which then helps to remove contamination.
- **Acid surface preparation**: This is acid cleaning or pickling. Usually, sulphuric acid is used, together with an oxidising inhibitor to stop rust formation and to minimise the formation of toxic vapours. Afterwards, the part must be washed with a hot water solution of neutralising characteristics to eliminate acid residues. It is especially important to control concentration, temperature and immersion time of the process. There are multiple variations of this treatment, with different acids, oxidising inhibitors and immersion times to achieve a specific condition.
- **Molten salt cleaning**: A salt bath is used in order to remove scale. Processes can be classified as oxidising, electrolytic, and reducing. If complete scale removal is required, an acid pickling must be applied after the salt bath process.
- **Ultrasonic cleaning**: High frequency sound waves pass through a cleaning agent, creating minute gas bubbles which enhance the cleaning process by a mechanism of cavitation. It is probably the most efficient cleaning process. Because of the high capital investment required, it is often uneconomical.

Preparing surfaces

Substrate surface preparation is an integral part of any coating deposition process. Surface preparation aids in easier and better treatment through removal of unwanted impurities, reduces interfacial surface tension, removes scaling as well as condition the surface for better adhesion bonding. Adequate care and detailing can ensure durable treatment that will improve component and machine life. Inadequate surface preparation is often the single greatest cause for failure of surface treatments. Various techniques are available for the preparation stage. These can be selected depending on the nature of the surface and the chosen or desired technique for treatment. Preparation of surfaces is in itself a major branch of engineering and it would be near impossible to adequately delve on this subject in an article such as this.

Treating the surface

Treating surfaces can be done in a variety of ways and techniques depending on the end result desired. However, broad categories of practice currently:

Modifying without altering the substrate's chemistry – In this case the existing metallurgy of the component surface is changed within the surface regions either by thermal or mechanical means to increase hardness.

Changing the surface layers by altering the alloy chemistry – Here, new elements are diffused into the surface usually at elevated temperatures so that the outer layers are changed in a composition and properties compared to those of the bulk.

Adding layers of material to the surface –This category incorporates a wide variety of coating processes where a material different from the bulk is laid on the base substrate. Unlike the first two categories, there will exist a clear boundary at the substrate/coating interface and the adhesion of the coating is the major issue.

There are different methods and approaches ranging from 'low end' to very 'hi-tech' technologies. A few of them which are proven and commercially practised are:

Surface hardening treatments like carburising, carbon nitriding, induction hardening, nitriding (gas/ion) nitro carburising etc. improve surface hardness, providing case hardening so that the material withstands heavy loads and improves fatigue resistance. Common applications include cam shafts, crank shafts, rocker arms, cylinder liners, punches and dies, steel and CI bushings etc. The broad indicative price of such a treatment is around Rs.20/kg, for carburising to Rs.150/kg. for Ion Nitriding.

Chrome Plating Process: To impart wear and corrosion resistance to components and a bright decorative surface finish. Major applications include automotive cylinder liners, rolls in steel mills, printing and paper mills, dies and rolls used for wire drawing, exhaust pipes. The cost depends on the size of the components as the investments increase substantially with the size. Costs in the upper end are approx. Rs.8,000 to Rs.10,000 per sq.m. The typical life enhancement factor is 3 to 5 times more than the uncoated components.

Physical Vapour Deposition (PVD) & Chemical Vapour Deposition (CVD): To apply a thin film, very hard coating such as TiN, TiAlN, TiC, TiCN, Alumina on cutting tools and dies to enhance component life. Common applications include HSS and Carbide cutting tools used for turning, milling, drilling, reaming etc. Die casting dies, Decorative coating for cutlery, jewellery, watches. The cost ranges from Rs.20 for a turning insert to several thousand rupees for gear shaper cutters. The coating imparts 30% to 500% improvement in life, substantial increase in machining speeds, and hence productivity and better surface finish of the component.

Cleaning of Turbine Blades Using a CVD Technique (Siclean™)

Land based turbines are increasingly being used with more aggressive conditions in the hot or exhaust section of the engine. Consequently, the material can suffer from considerable attack from contaminants in the fuel such as NaCl, Na_2SO_4 and V205 or from high temperature oxidation. Over recent years a variety of protective coatings have been developed for hot sections and these include Vacuum Plasma Sprayed (VPS) MCrAIY's, where M = Co, Ni or Fe, stabilised zirconium dioxide thermal barriers and CVD coatings.

During an engine outage it is necessary to remove these old consumed coatings and apply a new coating in its place. This was found to be problematic as unless the corrosion products were effectively removed from the substrate, then the new coating would have poor adhesion. Detachment of the new coating could then occur resulting in a poor life for the refurbished blade. Removal of consumed MCrAIY coating is particularly difficult to be carried out with mineral acids, as the surface layer of the coating is depleted of aluminium and is essentially rich in nickel. Consequently a method was developed that was based on a CVD technique.

The Sinclean™ Technique

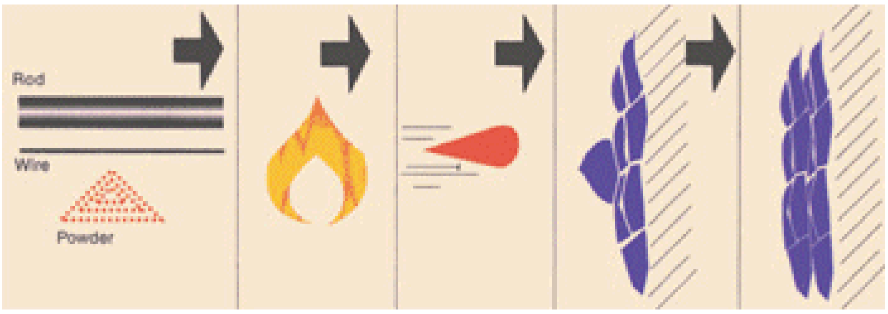
The surface of the used blade was first blasted using a Al203 grit to remove any substantial surface oxides. The surface was then subjected to a CVD process whereby aluminium is deposited and diffused into the surface of the blade to a depth of 200 – 300 m m. The surface is thereby transformed from a metallic into an intermetallic aluminide.

This aluminide coating is seen to encapsulate the corrosion products, (i.e. oxide, sulphide and nitride particles) in the surface of the superalloy. The coating, (nickel aluminide for a nickel superalloy), changes the surface properties of the nickel alloy significantly. First, it is now very susceptible to acid attack and second, it is brittle and friable and consequently it can be easily removed using a combination of blasting and acid pickling. The resulting surface is clean and ideal for depositing an overlay such as a VPS MCrAIY layer. The box below shows a typical turbine vane after service and illustrates the Siclean™ processat various stages.

Another important advantage of the Siclean™ process makes use of a benefit of CVD mentioned earlier. One standard method of removing corrosive products from the surface of a used turbine blade is to carry out hand finishing with belt grinders. It is extremely difficult to remove uniformly the corroded surface of a turbine blade, especially around awkward contours, such as a trailing edge of a turbine blade. However, the CVD process produces a uniform depth of aluminide over the whole surface of the turbine blade and consequently the layer that is removed is also uniform and therefore independent of operator skill or part geometry.

Thermal Spraying: The process helps to reclaim worn out material, provides corrosion resistance to steel structures, improves wear resistance and product quality and hence improves product performance. Applications are components used in pumps, compressors and paper mill machinery, rolls that come in contact with the yarn in the manufacture of synthetic fibres, steel mill components. Lower end processes like combustion spray, wire arc spray are used for coating (by Al, Zn) of bridges, cooling towers and structures used in corrosive environments.

Sequence of events during thermal spray coating



Coating Material in any form	Melts in a high temperature zone	Molten particles accelerate in gas stream	Flatten on substrate	Cool and coalesce

Costs very widely depending on the process used and material that is coated; lowest being combustion spraying of metallic powder (Rs.9000 per sq.m) and higher being for carbide coatings with advanced coating technique such as super D-gun. For the upper end processes like spraying of carbide coating, the costs are Rs.30,000 to Rs.50,000 per sq.m. but the performance is greater than 10 times that of chromic plating !

The investment costs for setting up some of the above facilities vary widely from a few lakhs to over a crore of rupees depending on the capacities, level of instrumentation etc. In the past, most of the equipment and consumables were imported but now quite a few manufacturers are gearing to set up indigenous facilities.

Emerging Technologies

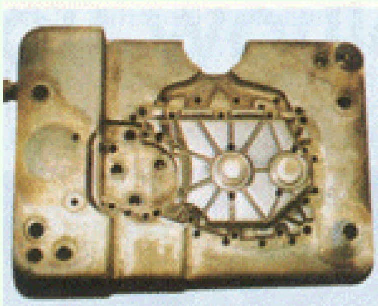
Surface engineering technologies are growing rapidly both in terms of finding better solutions and in the variety and complexity of techniques. From simple age-old techniques such as coatings and electrochemical treatments to the use of lasers and electric arcs and advanced simulation on expert systems, modern surface engineering technologies are able to provide better treatment solutions in a wider range of applications. For example in the area of corrosion control -– perhaps the single most frequent degradation phenomena – Smart overlay coatings, are a key development. Similarly, new tribotechnical coatings can be used for both external and internal surfaces without limitation in terms of surface complexity or size of parts. These coatings are claimed to withstand aggressive environments with 3.1 pH, long exposures to gas stream and temperatures between as high as 4000-6000 degrees Celcius ! Some of the other key technologies that have widespread applications are profiled here:

Plasma Ion Nitriding (PIN)

This is a high precision, vacuum based thermochemical diffusion treatment to increase the surface hardness of the material. PIN scores many critical advantages over conventional nitriding, namely lower processing temperatures, almost zero contamination, faster treatment cycles, lower costs and replacement of costlier materials etc.

Understanding Plasma Ion Nitriding

Plasma Ion Nitriding (PIN) is a high precision vacuum-based thermo-chemical diffusion treatment, utilising gas-mixtures duly ionised and thus, turned into their 'plasma' state, a highly activated state.



Plasma nitrided Aluminium pressure die casting for two-wheeler gear box

How does it work?

The process involves the use of vacuum initially for establishing a clean atmosphere and subsequently heating the workpiece under low gas pressure condition, up to a suitable temperature. This may vary from 340 to 570 degree Celcius, according to the material being nitrided.

Nitriding takes places through following two mechanisms:

- Through diffusion, since highly activated N+ species penetrates faster as compared to conventional nitriding.
- Through a thermo-chemical reaction forming actual nitrides of iron and varying alloying elements.

PIN, in general, is capable of generating deeper 'cases' i.e. the total size of both these layers. Thermo-chemically formed 'compound zone' may be 2 to 15 microns, whilst the diffusion zone may be from 150 to 750 microns (or more) depending upon the metallurgy of the workpiece and processing parameters. Plasma-nitrided surfaces are generally smoother, and apart from the abrasion resistance, PIN also increases the abrasion resistance and the unique ability to withstand high temperatures.

PIN v/s conventional nitriding

The most popular conventional nitriding processes are liquid nitriding or salt both nitriding and, gas nitriding or ammonia nitriding (or gas diffusion nitriding). PIN scores over these conventional process in the following areas:

- Lower processing temperatures: This factor signifies lower dimensional distortion and more control on the formation of undesirable metallurgical phase.
- Almost zero contamination: With the use of vacuum, chemical contamination due to the presence of atmospheric oxygen, moisture of hydrocarbon etc. is eliminated.
- Faster treatment cycles: PIN cycles may be as short as 15-20 minutes or 6 to 8 hours on an average compared to the 80 to 100 hours required by gas nitriding.
- Total control over the nitrided case: All conventional nitriding processes call for an additional lapping/grinding operation to remove the brittle ‘white layer’. In comparison, PIN is the only nitriding process, which offers total control over the composition of the nitrided case.
- Lower Costs: Due to shorter treatment cycles, greater reproducibility and an almost zero rejection rate due to tight process control, PIN works out much cheaper. PIN can act as a final hardening cum finishing operation, thereby reducing manufacturing costs and can replace costlier materials used conventionally.
- Augmenting the metallurgy: In high wear rate components such as mining, earthmoving or construction equipment. PIN can raise surface hardness from 65-68 HRC obtained traditionally to 72 plus HRC at a small extra cost.

Typical applications

Toolings for the most severe applications: Pressure die casting, plastic/ceramic processing, glass blow moulding, etc. where hot molten metal/liquids cause excessive wear by erosion and abrasion.
Toolings/allied components for mechanical deformation: Forging, sheet metal processing (pressing, folding, nibbling, cutting, punching, stamping, slitting, forming), spinning, rolling, piercing, blanking, impact extrusion, wire drawing etc.
Toolings/components meant for hot processing: Hot forging, hot processing, temperature steps up the abrasive and erosive wears.
Toolings/components for powder/slurry processing: Dies and punches for pharmaceutical tabletting, powder metallurgical pressing before sintering, ceramic powder pressing before sintering, food processing, cattle-feed processing, sugar processing, pulp and paper processing etc.
Automotive components: crankshafts, camshafts, cams, valves, valve-seats, gudgeon pins, piston rods, bushes, gears, synchroniser rings, timing gears, sprockets, steering pivot, cross joint etc.
Textile machinery parts: Levers, actuators, yarn processing rolls, wire-guides, and healds, friction-discs, wet processing rolls, guides etc.

Plasma Spraying

Plasma Spraying uses an electric arc maintained in a nozzle as the source of heat. This arc hears a stream of inert gas generally. Argon, Nitrogen, Helium or Hydrogen attaining temperature higher than 20,000^{0}C. Typical advantages of the process is that the composition, configuration and properties of the Plasma spray layers can be varied over a wide range and thus optimised to a particular application. Also the thickness can be varied and suitable layers can be applied, thereby saving expensive material.

The common spray materials are cemets, ceramics/carbides, alloys etc. The Plasma spray coating proves effective in imparting wear protection, corrosion protection, thermal insulation, salvaging of worn components and surfaces with special properties also.

Typical application include synchro ring, pivot ball pin, vibrator blades, carburising basket etc. A case study done on a Gas turbine flame tube reveals that Plasma spraying of Ni-Cr bond coat and Ceria-stabilised zirconia top coat has increased life of the component by 75%.

Diamond like Nanocomposite coatings (DLN):

The basic coating technology provides coating which are intrinsically hard and impervious, strongly adhere to virtually any material and have an extremely low coefficient of friction, stable in oxygen-free atmosphere upto 1200^{0}C. the typical characteristics of DLN coatings are adhesion, stability, differential thermal expansion, corrosion resistance, high micro hardness, low co-efficient of friction, excellent optical electric and electronic properties. Typical applications of DLN coatings include Wear protection of sliding machine components in the chemical, pharmaceutical, food and plastics processing industry, Non-stick coatings on surgical instruments, release coatings for electro-mechanical contacts with controlled electrical conductivity and wear resistance.

Diamond-like Carbon Coatings (DLC)

The unique properties of DLC coatings make them an ideal material for a wide gamut of applications. The coatings have excellent electric and thermal insulation, are highly transparent in UV&IR, visible regions, have lowest friction co-efficient etc. They find application in protective coating for lenses/sun glasses, protection against UV radiation, salt water corrosion and sand abrasion. The coated tools aid the dry machining of aluminium engine blocks. This coating is able to extend the life of a drill or die thousand of times.

SE in Indian Industry

An initial TIFAC study on the potential of Surface Modification Technologies in India indicated a possible market size of nearly Rs.300 crore. Spurred by the encouraging response from the industry and significant research carried out at several R& D labs in this fast emerging area, a detailed literature and market survey along with industry interaction was undertaken. TIFAC piloted the nation-wide effort through experts on Surface engineering working in five nodal centres of excellence namely, DMRL (Hyderabad), IPR (Ahmedabad), NAL (Bangalore), RRL (Bhopal) and the IISc. (Bangalore).

In order to facilitate technology development in the country, the S&T departments of the Government of Indian have initiated several innovative mechanisms to provide partial financial assistance for setting up units.

Home Grown Technology (HGT) a TIFAC initiative promotes commercialisation of indigenous technologies developed in R&D labs which have good market potential. HGT encourages projects with Technology Developing Assistance (TDA) which is upto 50% of the approved project cost. The TDA is in the form of soft loan and is extended to companies and/or R&D labs returnable to TIFAC, after successful completion and commercialisation of the project.

Another funding mechanism from DST is Technology Development Board (TDB) which provides soft loans to industrial concerns and other agencies attempting development and commercial application of indigenous technology or adapting imported technology to wider domestic applications. In addition, the Department of Scientific and Industrial Research (DSIR) has other funding mechanisms like other funding mechanisms like PATSER which give funds as grant-in-aid for development and upscaling of engineering applications, prototypes etc.

Conclusion

The wide spectrum of surface engineering technologies outlined in this article are available to Indian industry and it is imperative to achieve a synergy between different stake-holders so as to exploit the full advantage of developments in this area.

Rich dividends would accrue in the form of value-added products and through achieving higher productivities would lead to an attractive bottomline, to increased profits as well as make Indian engineering components competitive for export markets.

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