THE USE OF ELECTROLESS NICKEL AND COMPOSITES FOR MOLD AND DIE APPLICATIONS

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ABSTRACT

The mold industry is one market that is increasingly recognizing the benefits of electroless nickel coatings. Historically, mold tool manufacturers have used hard chrome to protect molds from corrosion and wear and to build up dimensional tolerances. However, hard chrome, by it very nature, can not meet all the requirements demanded of a coating for plastic injection, rubber and glass mold applications. Electroless nickel is now being used as a replacement for hard chrome in many applications due to its unique combination of physical and performance properties.

In this paper we will outline the properties of electroless nickel that make it attractive to the mold industry. Included will be a detailed review of specific electroless nickel coatings including electroless nickel PTFE, electroless nickel silicon carbide, and low and high phosphorous technologies. The use of these electroless nickel coatings will be contrasted with hard chrome, nitriding and dry film lubricants. We will attempt to explain through practical applications which coatings may be suitable for which applications.

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INTRODUCTION

The mold industry is one market where electroless nickel is increasingly being specified as a value-added coating. Historically, mold tool manufacturers have used hard chrome to protect molds from corrosion and wear and to build up dimensional tolerances. Although beneficial for many applications, hard chrome, by its very nature, can not meet all the requirements of this industry, including those for plastic injection, rubber and glass mold applications. Electroless nickel is now used as a replacement for hard chrome in many areas due to its unique combination of physical and performance properties.

Electroless nickels are plating processes that autocatalytically deposit nickel alloyed with up to 12% by weight phosphorus. Since the process requires no electrical current (as used in electrolytic deposition of chromium or nickel) the result is a very uniform coating that has a dense, essentially amorphous structure as plated. Blind holes, threads, channels, recesses or internal areas receive the same amount of plate as sharp corners, edges or flat surfaces. Therefore, total "as plated" thickness can often be reduced and close tolerances (within 0.05 to 0.10 mil) maintained. Although electroless nickel can be machined, machining to size is frequently eliminated due to the as-plated uniformity of the electroless nickel coating.

Electroless nickel coatings provide a range of corrosion protection from good to excellent depending on the process selected. Coating thickness, substrate condition and surface preparation procedures are also important factors which determine both coating porosity and the ultimate resistance to corrosive attack. The protective properties of electroless nickel are partially attributable to its dense essentially amorphous structure which can be free from porosity. This is in contrast to the micro-cracked structure of hard chrome deposits which are generally more porous in nature. Electroless nickel deposits tend to form adherent passive nickel oxide films on the surface, particularly at elevated temperatures, which further add to their overall protective properties.

There are several different types of electroless nickel coatings including low phosphorus, mid-phosphorus, high phosphorus, electroless nickel PTFE, and electroless nickel silicon carbide. Each of these types of electroless nickel coatings is designed to provide unique physical and performance characteristics. To realize the benefits from the coating it is important to select the proper type of electroless nickel coating for each individual application.

GLASS MOLDS

The glass mold industry is an energy intensive (gas) industry and is production oriented with high yield objectives. The majority of molds are constructed of either stainless steel or steel and later tooled to engineering specifications. The coating of choice for most mold applications has historically been hard chrome. However, due to the extreme adverse conditions that these molds are subjected to, electroless nickel has started to be evaluated as a viable alternative.

In a typical glass molding operation molds will often be pre-heated to 900 to 1000 °F prior to receiving the molten glass. The mold coating must enhance the ability of the mold to release the product without experiencing coating adhesion problems. Molds will be removed from service and replaced if residual glass in critical areas of molds are found. The temperature of the molten glass will be 1000 to 1200 °F when the globule comes in contact with the surface. The coating must be able to expand and contract in this harsh environment without cracking, so selecting a coating with some ductility is important.

Because of the abrasive characteristics of silica, the coating on molds must be able to withstand the impact of the molten glass hitting the mold as well as glass splinters that may occur when the product cools down. Usually radii or curvatures which must release the glass upon opening are the first areas to experience wear. In the extreme conditions described above, a low phosphorus (2 to 4% by weight) electroless nickel coating with its high as plated hardness (HV_{100} 625-675), excellent erosion resistance and high melting temperature is an ideal coating choice.

PLASTIC MOLDS

The plastics industry has used coatings in injection, transfer, and compression molding applications for many years. Chrome, again, has been the coating of choice, but electroless nickel, particularly high phosphorus(10 to 12% by weight) and electroless nickel PTFE composite have become increasingly popular in recent years.

There are many causes of wear in a plastic mold that can contribute to greatly reduced mold life in service. Abrasive wear can occur on compression molds which use mineral or glass-filled materials that can exhibit a scouring action on the mold surface. In transfer and injection molding of thermosetting materials, wear is often detected in the high flow areas such as in the sprues, runners, gates and portions of the cavities and cores that are directly opposite the gates. In injection molds for thermoplastics, wear most commonly appears on the surface opposite the gate.

Most often damage results from continuing to run the mold after flashing occurs. However, there are often other sources of damage such as when water contacts unplated surfaces and corrosion ensues. Water forms in the molds from condensation, seepage through porous metals, leaky pipe fittings and "O" rings. Where chillers are used for mold temperature control, condensation of moisture on the mold surfaces can sometimes occur even while they are in full operation. Careless handling of hoses and feed lines during hook-up leaves water on the mold surface. Corrosion is progressive and even if the molds are stored after being sprayed with an anti-oxidant, a few drops of water or condensation can cause tremendous and costly damage.

Not all damage to molds is confined to molding surfaces. Rust and salt deposits form inside of the heating or cooling channels in spite of the use of well designed treatment systems. Electroless nickel solutions can be pumped through water lines and the resultant coating can form a barrier coat against corrosion. This has been shown to be a cost effective way to minimize corrosion in these areas.

Another source of damage can include attack from acids after exposure to corrosive materials which may form when some thermoplastics are decomposed by over-heating. Overheating can occur in the plasticizing cylinder, the hot runner system or in the mold cavities as the result of too small gates, or inadequate venting or cooling systems. During the molding of PVC, a small amount of hydrochloric acid is formed which is extremely corrosive to the mold cavity. Electroless nickel, by its very nature, is an excellent corrosion barrier for most mineral acids, whereas chrome is attacked by these materials. Stainless steels can also be susceptible to attack by chlorine or fluorine containing plastics which can lead to pitting or stress corrosion cracking.

The main benefits of using electroless nickel coatings in the plastic mold industry are summarized below:

- Enhance release characteristics versus other coatings
- Provide corrosion protection for the mold
- Improve wear resistance from galling and scratching
- Salvage worn, damaged or wrongly machined molds
- Extend the useful service life of the mold and reduce downtime
- Eliminate the need for release agents on mold surfaces

ELECTROLESS NICKEL PLATING PROCESS

Before beginning to process the mold component the plater must know the alloy of the mold to be plated. This is necessary to determine the optimum pretreatment cycle to insure excellent adhesion of the subsequent plate. Knowledge of the part's past history is also a very important consideration. The plater must make certain that the mold to be plated does not have any of the previous coating remaining (sometimes when molds are polished it is very difficult to detect by the naked eye, so it must be verified). Occasionally, the mold is magnetized which can create problems and cause roughness during the electroless nickel plating process. Also, the plater needs to understand if the part has undergone any previous heat treatment such as nitriding, which could affect the pretreatment cycle the plater will use before plating. In addition, the plater will need to know what temperature the subject piece is likely to see so that the correct type of electroless nickel can be recommended for each application. Finally, the plater needs to understand the overall thickness that needs to be applied and if the coating is to be applied over the entire mold or only in selected areas.

SURFACE PREPARATION

This is an extremely important part of the overall plating process that will insure excellent adhesion of the subsequent electroless nickel coating. Sometimes mechanical finishing is necessary with either a glass bead, corundum or other mechanical finishing techniques. Mechanical finishing can create small sites that can act as anchors for subsequent plating and promote adhesion. On molds that are highly polished or lapped already, mechanical finishing usually cannot be used and a chemical cleaning and activating cycle is used as below:

1. Alkaline degrease using ultrasonics, if possible.
2. Rinse
3. Electro-activation using periodic reverse.
4. Rinse
5. Woods Nickel strike entering the tank "live" if possible.
6. Rinse
7. Electroless nickel plate
8. Rinse

This plating cycle will work well on most steels and stainless steels. Please note that a hydrochloric acid pickle is not usually recommended(only in the case of severe rust or scale) because it will tend to cause hydrogen embrittlement in the base material.

COATING CHOICE

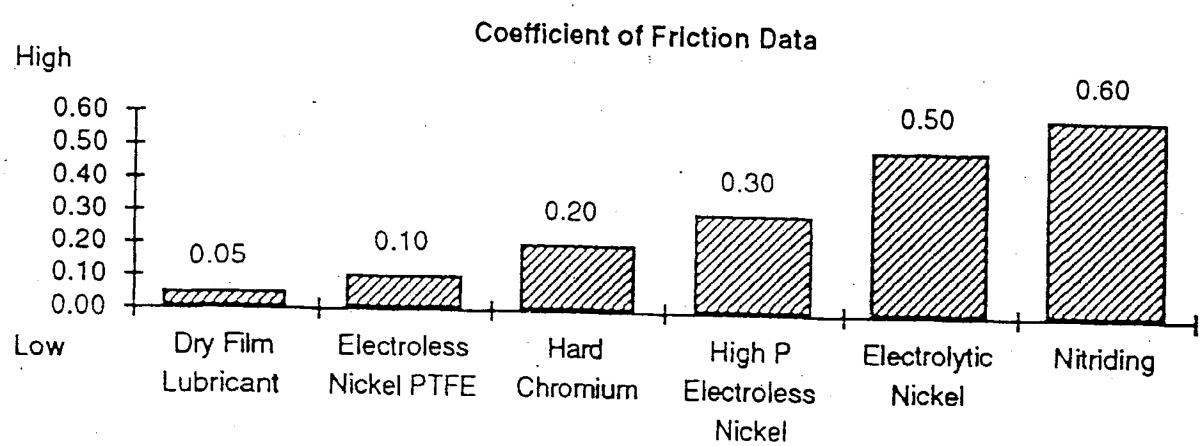
Electroless Nickel (Type)	Content	As-Plated Hardness (HV_{100})	(°F) Melting Point	Salt Spray ASTM B-117 (1 mil)
High P	10 - 12% P	450 - 500	1500 - 1600	1000 hours
Low P	2 - 4% P	625 - 675	2000-2200	96 hours
Nickel PTFE	9-11%P 20-25% PTFE	300-350	1500-1600	1000 hours

P refers to phosphorus

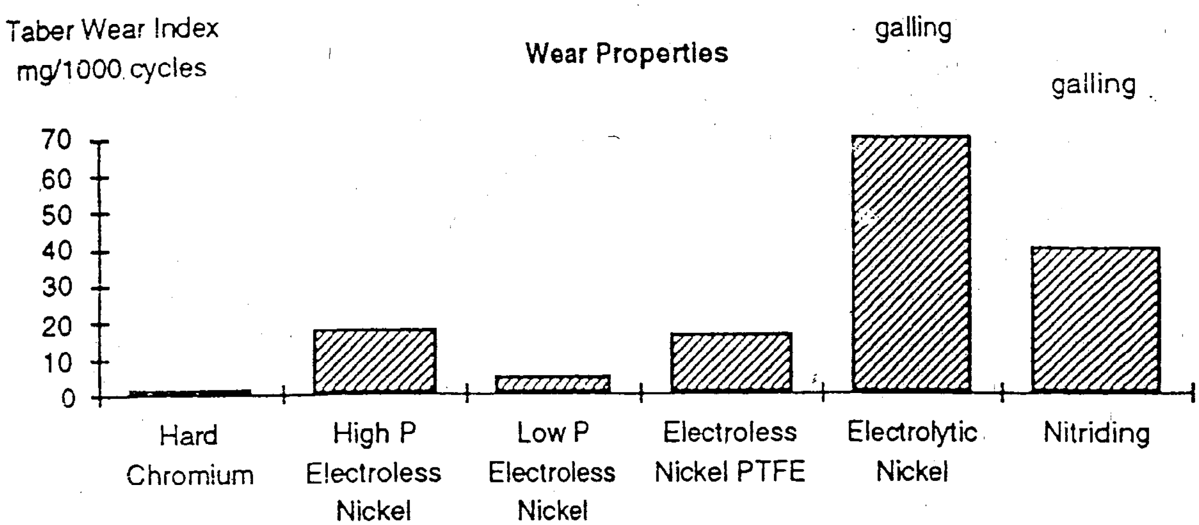
As is shown in the above matrix, there is a considerable difference between the physical properties of the three types of electroless nickel described. The high as plated hardness and high melting point range of the Low P electroless nickel coating make it an ideal candidate for use in the glass mold industry where silica is extremely abrasive towards mold surfaces and there is a need for a coating to withstand the extremely high temperatures. Where the ultimate in corrosion resistance is required, either a High P or Nickel PTFE composite coating is the right choice. It has been proven in the field that if it is necessary to deposit higher thicknesses (>2 mil) then the high phosphorus electroless nickel is preferred.

Coefficient of friction data is shown below that further differentiates the coatings. Hard chromium, electrolytic nickel, nitriding, and a dry film lubricant are also included in the matrix along with the three classes of electroless nickel.

Per ASTM D-2714 unlubricated



The dry abrasion resistance of coatings is commonly evaluated using the Taber Abraser wear tester.



All tests were performed using a CS-10 wheel and 1000g load.

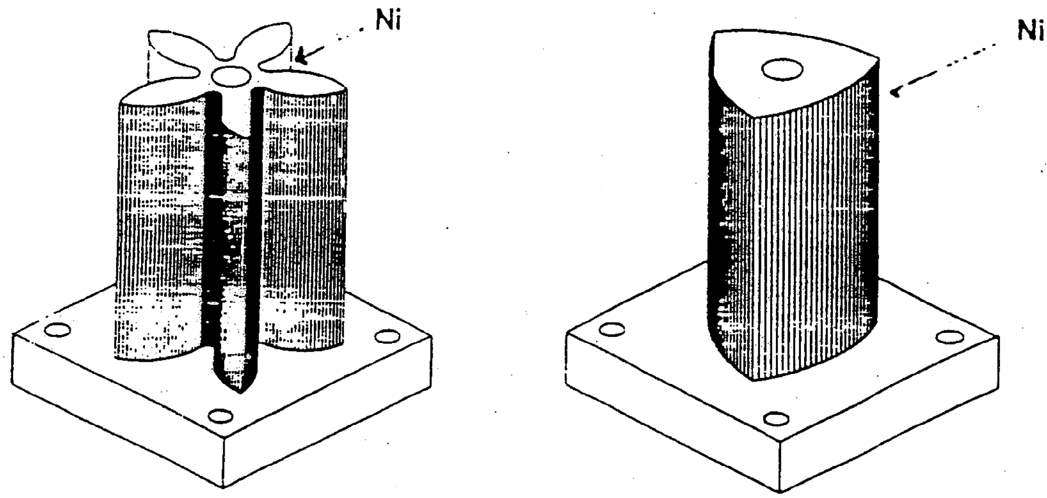
THERMAL TREATMENTS

Parts having a tensile strength of greater than 1050 MPa, that have been acid-stripped for recoating shall be rebaked in accordance with ASTM B-733 for embrittlement relief before plating. This usually requires a bake at 200 °C for 2-24 hours, depending on the stress. Peening prior to plating may be required on high-strength steel parts to induce residual compressive stresses in the surface, which can reduce loss of fatigue strength and stress corrosion resistance after plating.

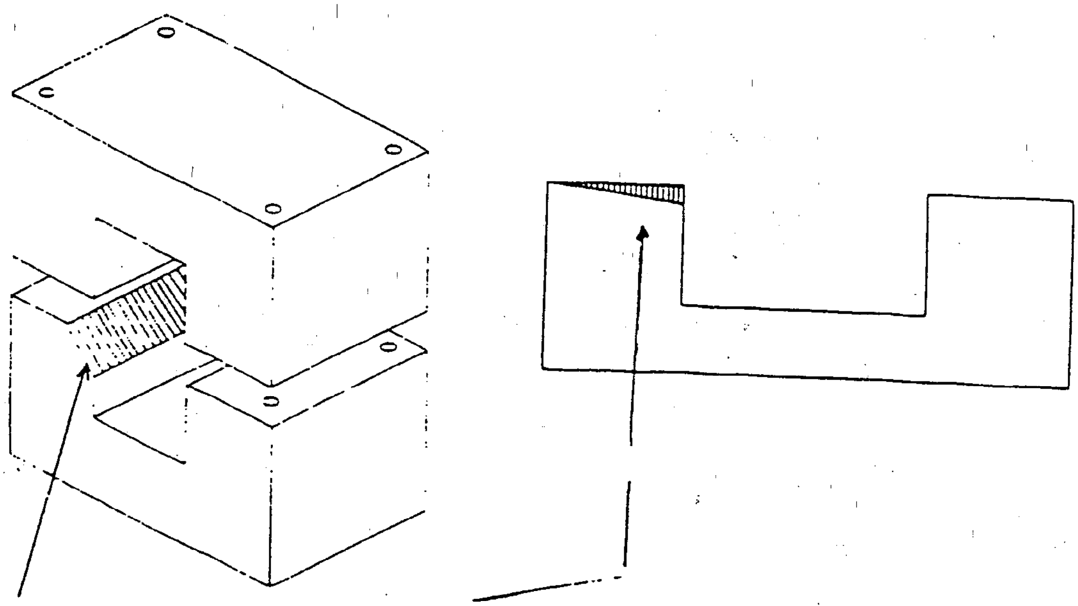
When metals are electrocleaned, pickled, and plated with autocatalytic nickel, they are exposed to hydrogen, which can be absorbed into the substrate crystal structure embrittling high-strength steel and inducing catastrophic cracking. Electroless nickel plating, by itself, does not cause hydrogen embrittlement. Hydrogen embrittlement is usually due to exposure to mono atomic hydrogen (H), particularly during the pretreatment cycle (eg: acid pickle). If required, the plated parts shall be stress relieved by heating to the appropriate temperature called out in ASTM B-733 within 4 hours after plating.

In order to achieve maximum coating hardness after plating it may be necessary to institute a thermal treatment of 400 °C for 1 hour or 280 °C for 12 hours. The exact heat treatment to achieve maximum coating hardness will vary depending on the alloy of the coating. Heat treatment after plating can also improve adhesion of the coating to various substrates.

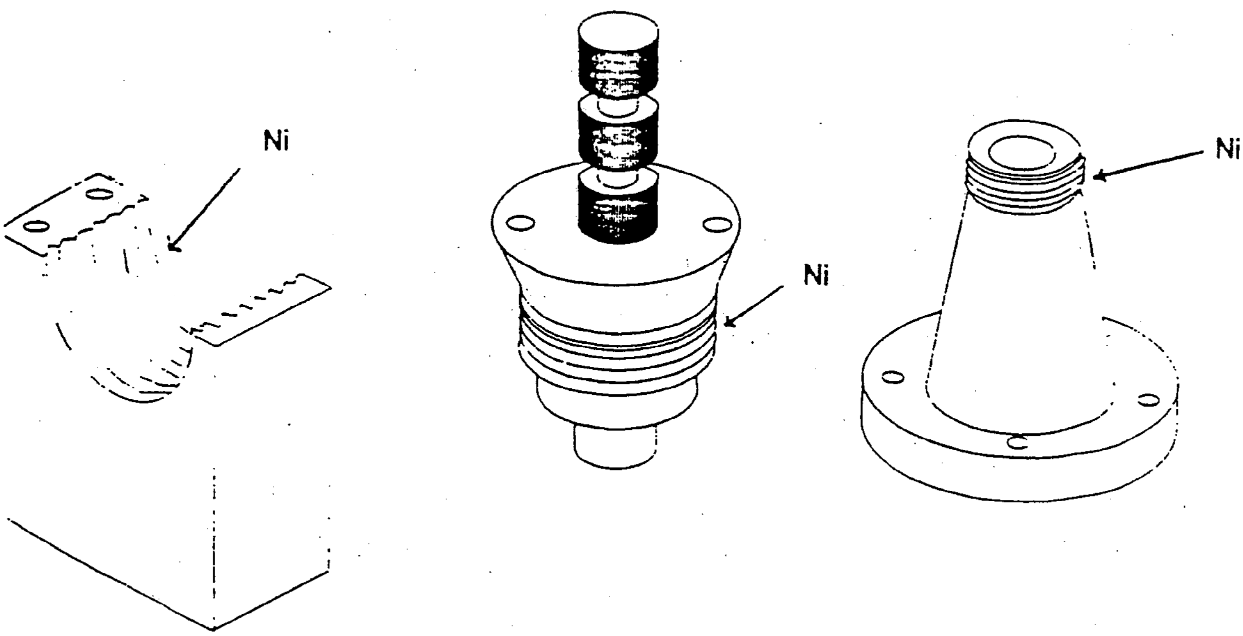
- Selective recoating of mold components where the geometry of the mold does not allow subsequent electroplating.



To insure "smooth parts" along parting lines

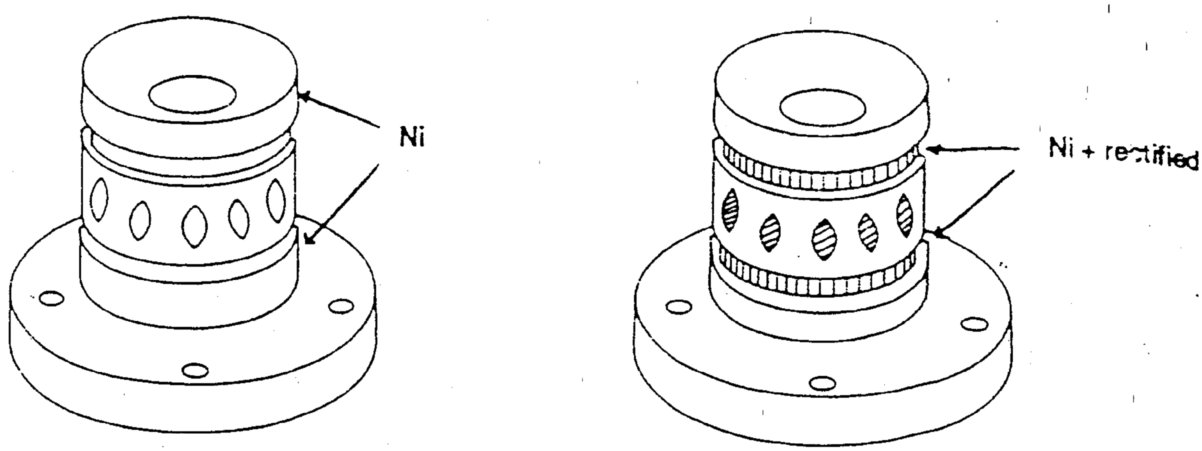


one to be repaired (wear)

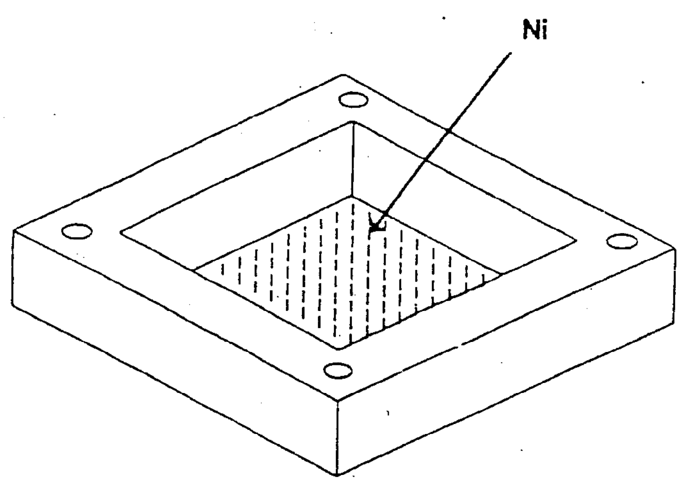


Slides with "thread" or "punch" with threaded head (bottle caps)

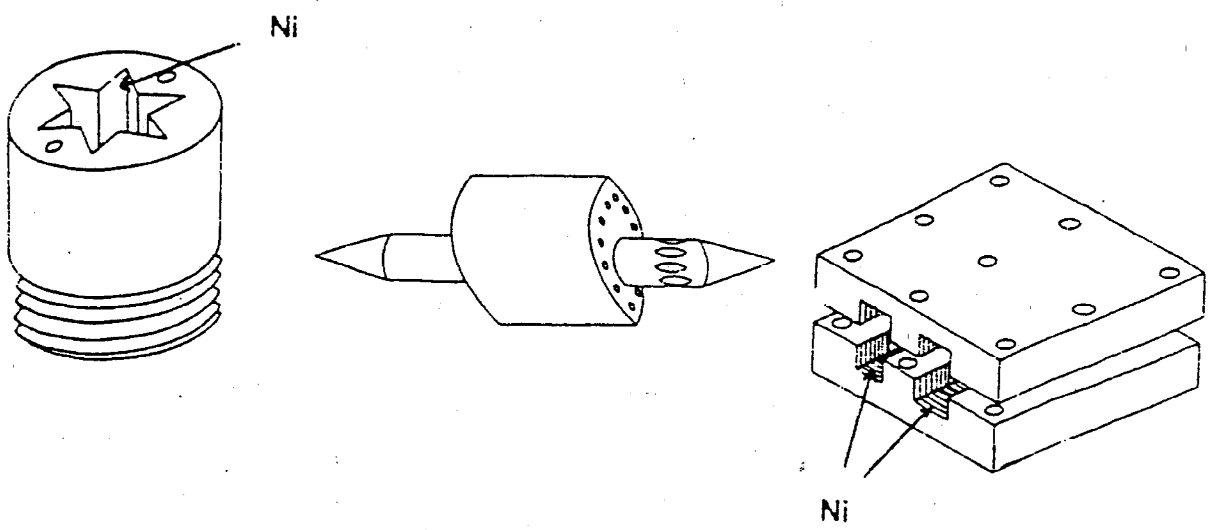
- Selective build up application



- Zones where the surface imprint (imitating leather) is to be protected to avoid wear



"nozzle" or rows of extrusion or injection of plastic materials



Molds for large production of pieces (when the thickness is to be reduced to allow use of less plastic material)