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"Increasing the Value of Die Cast Tooling with Ferritic Nitrocarburizing & the Duplex Diffusion Process"

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Abstract
Maximizing tool life is crucial because of the substantial investment that the Die Cast tooling represents. Tool life depends upon the design as well as a variety of mechanical properties inherent in the steel. These mechanical properties are developed by utilizing the proper heat treatment and can be maximized by choosing a surface treatment that will enhance those properties. The value of a Die Cast Tool equals the total cost of the tool, including manufacturing cost, heat treat cost and surface treating or coating cost divided by Tool performance. The performance of two Fluidized Bed surface treatments will be compared to Titanium Nitride, Chromium Nitride, and salt bath nitriding (Kolene). The two Fluidized Bed Surface Treatments studied are: a combination Ferritic Nitrocarburizing and steam blueing process known as DYNA-BLUE® and a duplex diffusion process called DST-Cr which combines the Ferritic Nitrocarburizing process with a diffused layer of Chromium.

Tests performed include Dry Sliding against Aluminum, Dunk Testing, Solder Buildup Test, Vickers Hardness Test, Microscopic Examination, and Glow Discharge Optical Emission Spectroscopy. Also a real life Case Study was performed by a Die Caster comparing Tool life of an FNC process to a Chrome Nitride process as well as the DST-Cr process. A "Value Calculator" is also included to determine the true value (cost effectiveness) of any surface treatment or coating.
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INTRODUCTION
The value of a Die Cast Die is dependant on "tool life, or longevity of the tool, along with amount of pieces produced by the tool. "Tool life is dependant upon controlling the wear, corrosion resistance, heat checking, and release or welding of the aluminum, magnesium or zinc on the mold surface. Two Fluidized Bed surface treatments that were developed to achieve these properties will be explored in this presentation. Fluidized Bed processing is known for it's temperature uniformity (± 5°F) and rapid heat transfer as well as producing a uniform surface layer at a much faster rate than conventional Nitriding. The economics of Fluidized Bed processing have been well know and documented. Utilizing a Fluidized Bed Furnace for Ferritic Nitrocarburizing has proven to be efficient and has given the process unique capabilities. Incorporating Fluidized Bed Nitrocarburizing and a steam oxide like process (DYNA-BLUE) to increase tool life.

KEY TERMS AND DEFINITIONS

- (DYNA-BLUE) A combination process incorporating Fluidized Bed Ferritic Nitrocarburizing and a Blue Oxide process. This is a low temperature, thermochemical, diffusion process of nitrogen and carbon [(1)] that yields 1) a compound layer @75+HRC, 2) a nitrogen diffusion zone [(2)] that supports that white layer and 3) a steam blue layer for corrosion resistance.
- (Dst-Cr) A Duplex Diffusion Process incorporating Fluidized Bed Ferritic Nitrocarburizing with the addition of a Thermo Reactive Deposition (Cr) layer causing diffusion of nitrogen from the compound & diffusion zone towards the surface, which reacts with the alloy powder (N-2 +Cr) to form distinct surface layer of Cr that is diffused into the surface and is no longer just a coating laying on the surface.
- Fluidization is the term applied when making aluminum oxide or sand particles react like a liquid [(3)] in a heat treating furnace. Process gases are introduced to the furnace through a diffusion plate, located in the bottom of the furnace. The gases are pressurized thus lifting and moving the sand in a random motion over immersed metal objects of varying part geometry and/or blind holes, thereby ensuring a consistent metallurgical properties pattern, all the while scrubbing the part with fresh reactive gases. The furnace is heated with heating elements, located outside the working zone of the furnace. Through the fluidization process, the heat is uniformly transferred to the product rapidly. The process is not inhibited by part geometry or blind holes, thereby ensuring consistent metallurgical properties.
- Value is defined as an amount expressed in money or another medium of exchange that is thought to be a fair exchange for something, the adequate or satisfactory return on something the worth, importance, or usefulness of something to somebody, or to rate something according to its perceived worth, importance, or usefulness.

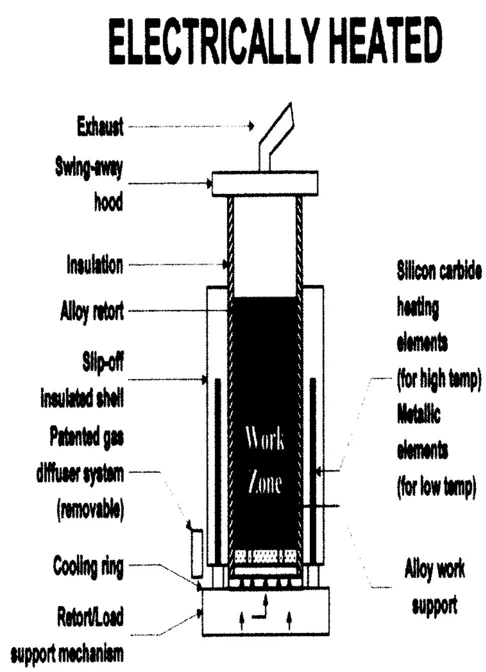


Figure 1- Fluidized Bed Schematic

Coating/ Surface Treating Properties needed to increase die cast tool performance

- 1- High Surface Hardness to reduce wear & erosion
- 2-Impervious surface layer to reduce soldering (attachment of Al)
- 3- Increased lubricity for good metal flow
- 4- High Compressive Residual Stresses to reduce heat checking
- 5- Good adhesion to resist flaking, peeling, delamination
- 6- Good thermal fatigue properties
- 7 -Low Dimensional variation
- 8-Resistance to softening at elevated temperatures
- 9-Able to be repaired and good weldability

COMPARITIVE INDEPENDENT STUDY

Testing was performed on a DYNA-BLUE treated sample at Case Western University by Professor Jack Wallace and Professor David Schwam in November 2000 [4]. The results show the total crack area H-13 with no treatment was160, Kolene treated sample had 140 and the DYNA-BLUE sample had virtually no cracks after 15,000 cycles in the “Dip Tank”.

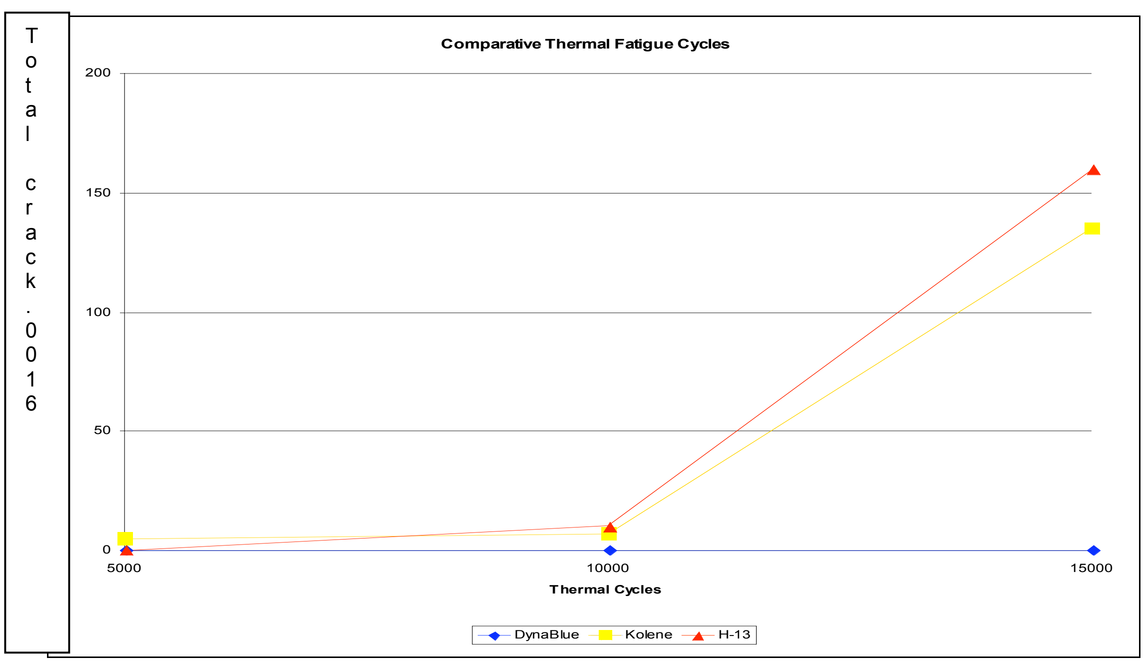


Figure 2- Results of “Dip Tank” study performed at Case Western showing total cracks.

FERRITIC NITROCARBURIZING MICROSTRUCTURE
The microstructure of a Ferritic Nitrocarburized treated sample consists of a hard (75+ HRC) compound zone of carbon and nitrogen with a nitrogen rich diffusion zone beneath for support. The hard compound layer increases wear and corrosion resistance, has high compressive residual stress to resist heat checking and when combined with a layer of Iron Oxide on the surface prevents atomic bonding of the steel surface with aluminum reduces the coefficient of friction.

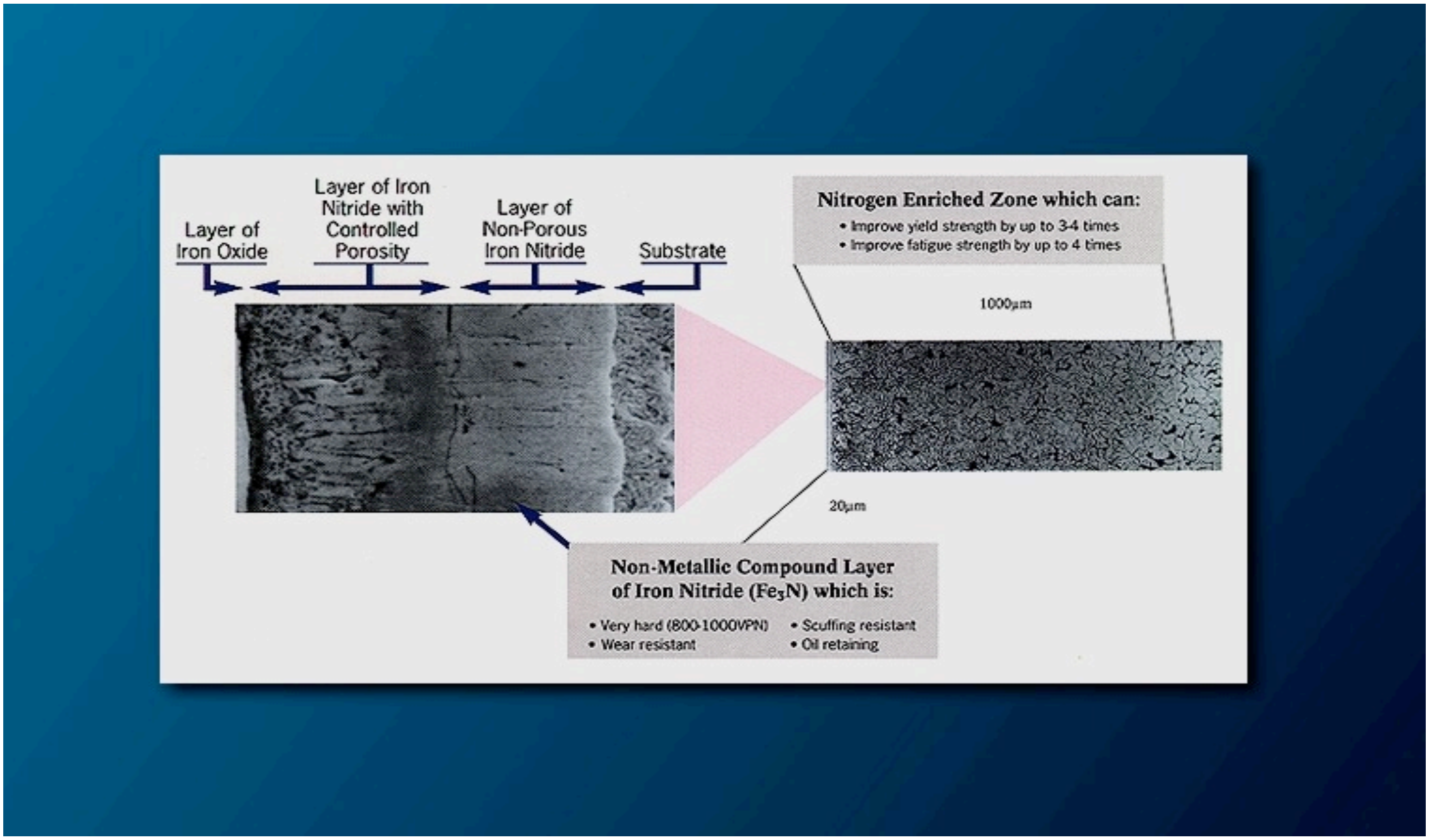
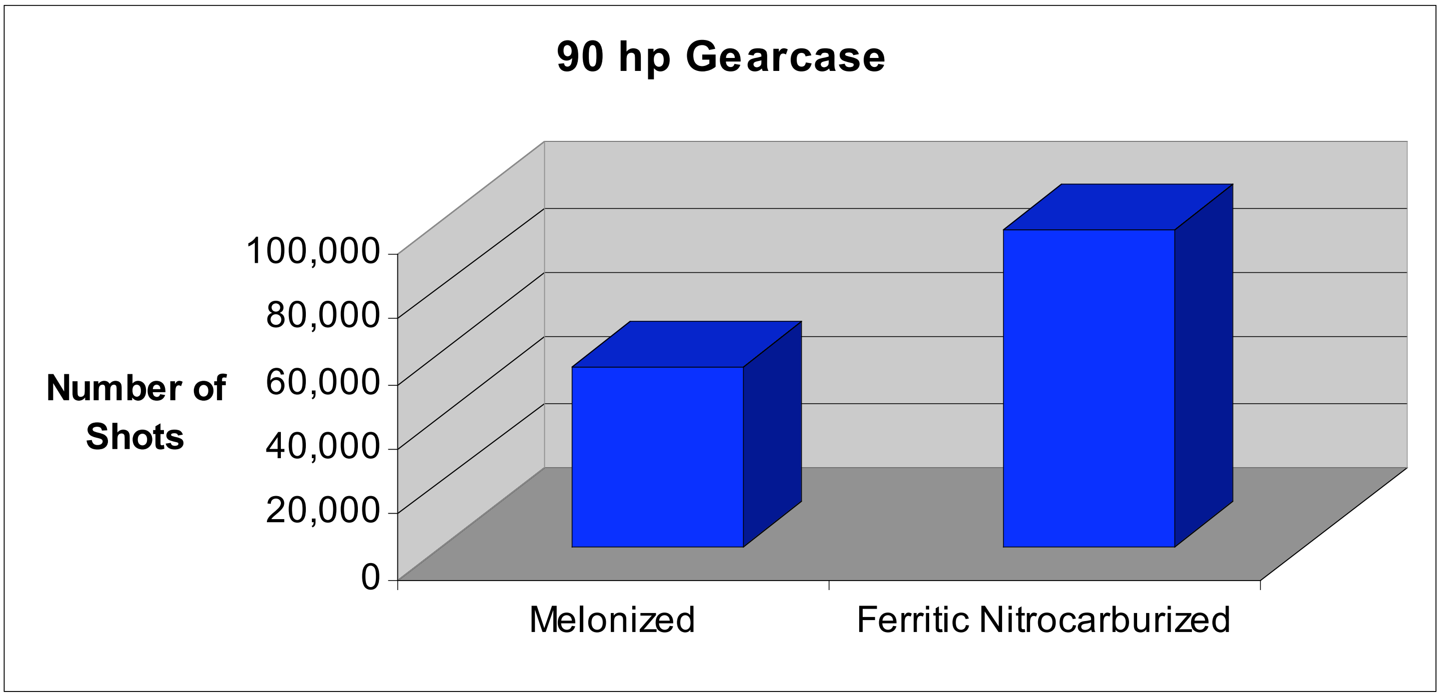


Figure 3- Microstructure of Ferritic Nitrocarburizing [(5)]

Performance Tracking

A multi cavity tool was tested with a melonizing process on one cavity and a Fluidized Bed Ferritic Nitrocarburizing process on another. The results were compared with an uncoated tool. The tool material was H-13 hardened and double tempered to 44-46 HRC. The part that was die cast was a 90 hp gear case made out of A360 Aluminum Alloy. After 62,000 shots the melonized cavity was heat checked and washed out and needed repair while the Ferritic Nitrocaburized cavity lasted 120,000 shots and only had minor heat checking and wear.

Table 1- results of testing a Fluidized Bed Ferritic Nitrocarburized treated cavity vs a Melonized treated cavity



DST-Cr DUPLEX DIFFUSION PROCESS

The combination of two surface techniques is commonly referred to as "duplex surface engineering". This new development has combined a ferritic nitrocarburiizing process with a low temperature (575ºC) chromium thermoreactive deposition layer. This duplex process forms a hard chromium carbonitride surface layer that is diffused into the steel. This process is accomplished via a diffusion alloying reaction between the nitrogen from the nitrocarburized layer and the deposited chromium metal (6). The low temperature used does not soften the hardened steel matrix. Because the DST-Cr process forms a Chromium, Titanium, etc layer that is diffused into the surface that alleviates flaking, peeling, and delamination associated with PVD coatings. Titanium Nitride, Chromium Nitride, Chromium Carbide, are coatings that are deposited on the surface with no support or metallurgical bond. When the substrate goes into "plastic deformation or deflection" the hard coating flakes off. With the DST-Cr Process, support is provided with the ferritic nitrocarburizing process beneath the extremely hard surface.

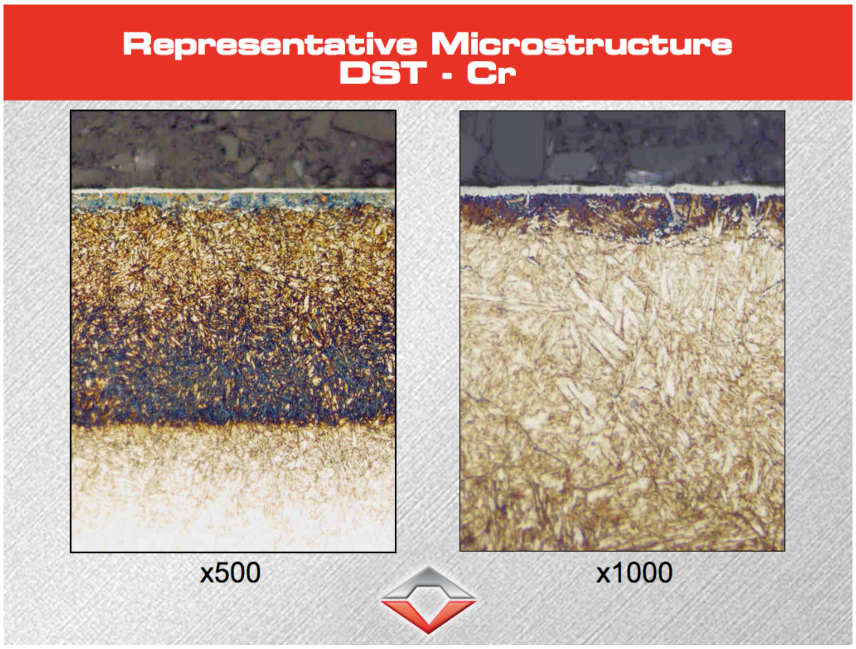


Figure 5 Microstructure of DST-Cr process at 500x, 1000x (7)

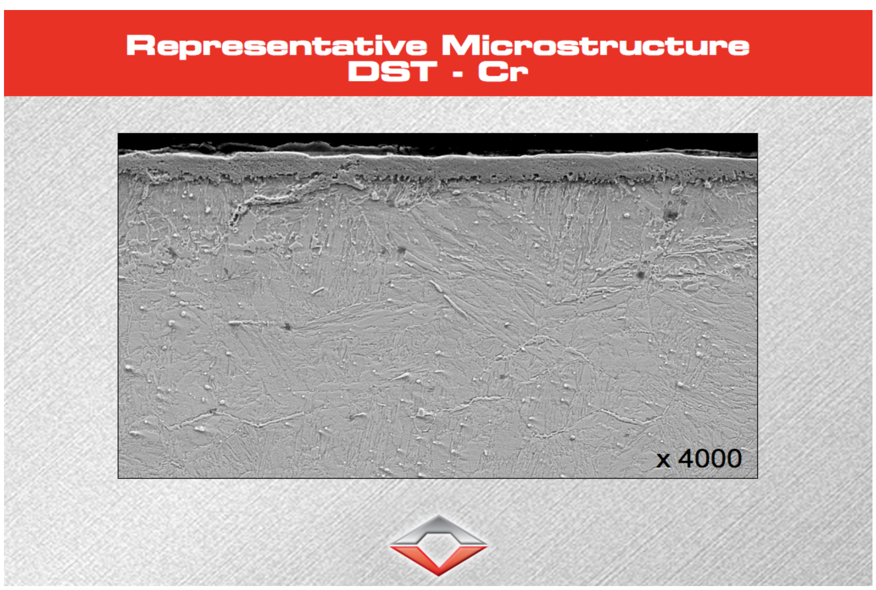


Figure 6- Microstructure of DST-Cr Duplex Diffusion Process at 4000x (8).

HARDNESS TESTING OF DST-Cr

Vickers hardness testing was conducted using a load of 10µN on the surface layer and a 25 g load beneath the surface layer to the core. The surface layer was determined to be 1520 Hv and a diffusion zone from 1050 to 650 Hv. This also revealed that the nitrocarburized diffusion layer was retained after the DST-Cr process with a gradual hardness transition down to the core. This deep diffusion layer provides good support for the hard Chromium layer. It is also evident that the original core hardness of the H-13 steel was maintained.

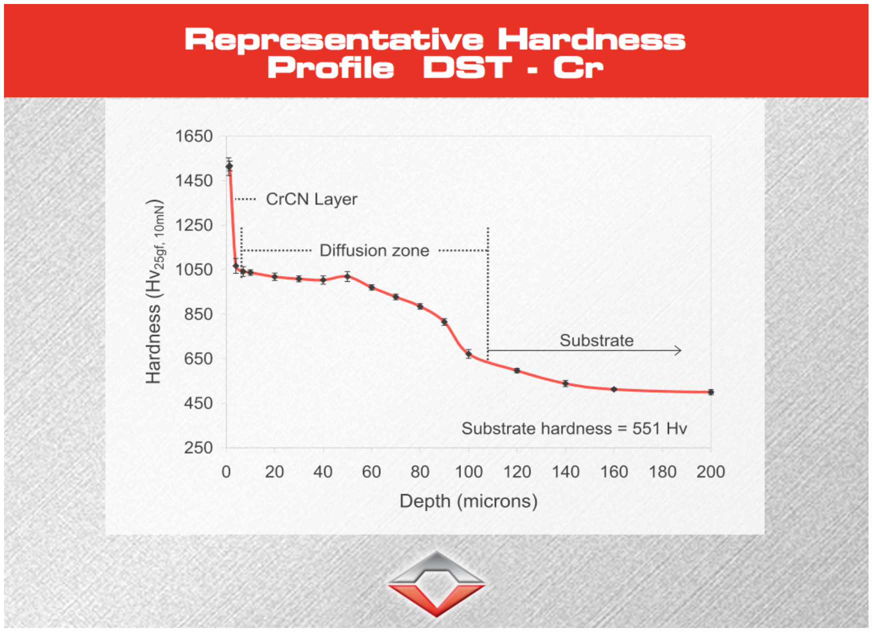


Figure 7 Hardness profile of the DST-Cr process [9]

GLOW DISCHARGE OPTICAL EMISSION SPECTROMETRY OF DST-Cr

Quantitative depth profiling was performed using Glow Discharge Optical Emission Spectrometry. The GDOES revealed that the surface layer was rich in chromium and nitrogen with smaller amounts of carbon, iron, and oxygen present. Due to the presence of carbon, the surface layer is refereed to as chromium carbonitride.

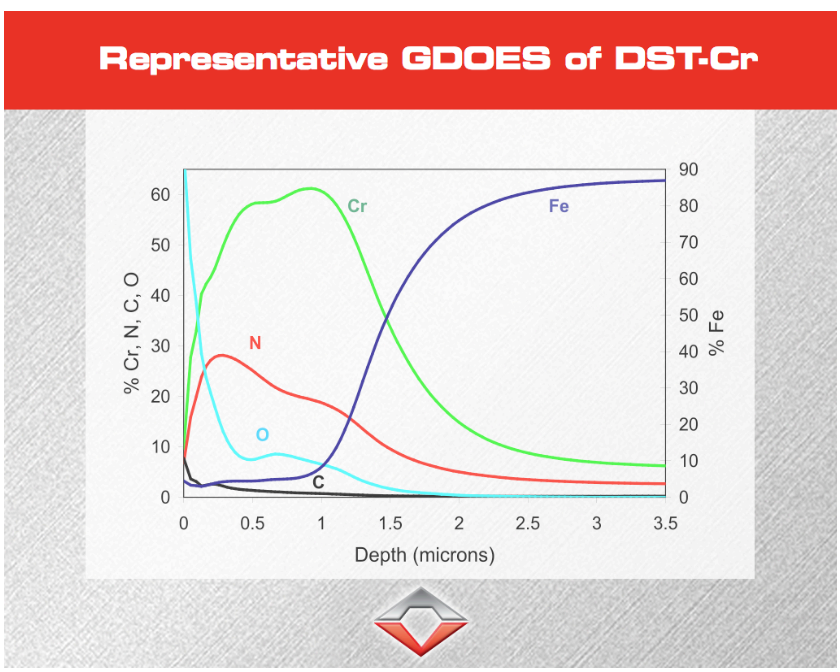


Figure 8 GDOES of DST-Cr process [10]

PIN ON DISK "COEFFICIENT OF FRICTION" TEST
A Pin on Disk test was used to determine the coefficient of friction of untreated, ferritic nitrocarburized and DST-Cr treated samples against 99.98% aluminum. A 1N load was used with .2 m/s on unlubricated sample with Ra 0.2 ±0.04. The test revealed a coefficient of friction for untreated at an average of 1.1 nitrocarburized at .7, and DST-Cr at .4

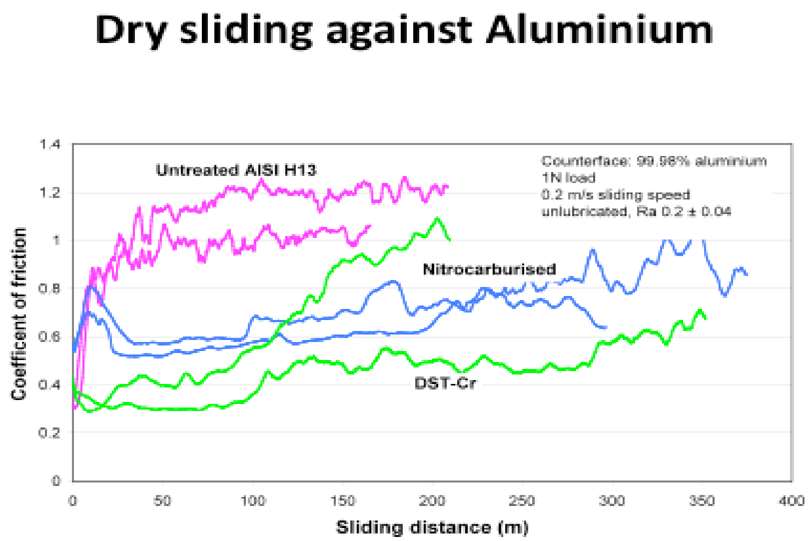


Figure 9 Pin on Disk Test comparing untreated H-13 to Nitrocarburized and DST-Cr [11]

SOLDER/ BUILDUP TEST
A test was performed using a CSIRO Diecast Machine to determine solder/ buildup resistance of untreated H-13, TiN, CrN, TiCN and nitrided. This shows that surface finish is very important to prevent solder/buildup.

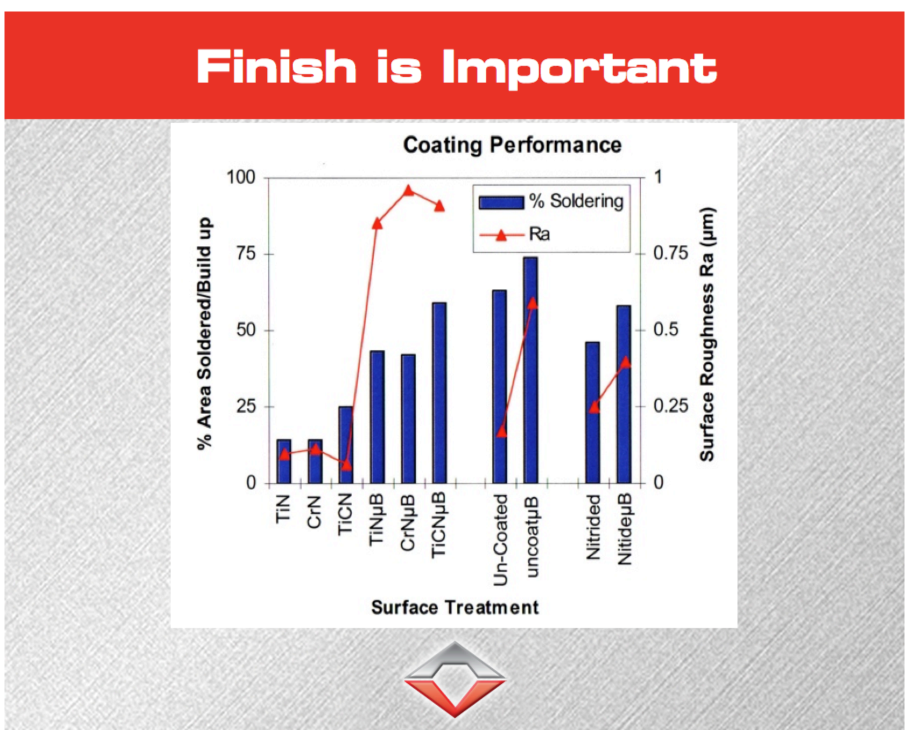


Figure 10 CSIRO Diecast Machine Test on untreated, TiN, CrN, TiCn and nitrided. [12]

PERFORMANCE TESTING
A tool performance study was done by a die cast facility (Mercury Marine) to provide real life test data of Ferritic Nitrodcarburizing, DST-Cr and a PVD Chromium Nitride processes. This test revealed that the DST-Cr process had the greatest increase in tool life. The test tool was a die cast core located near an end gate with an extreme amount of wear. The FNC process yielded 10,000 shots, while the DYNA-MAX Cr yielded 59,425. The typical life for PVD Chromium Nitride was 18,000 shots. (13)

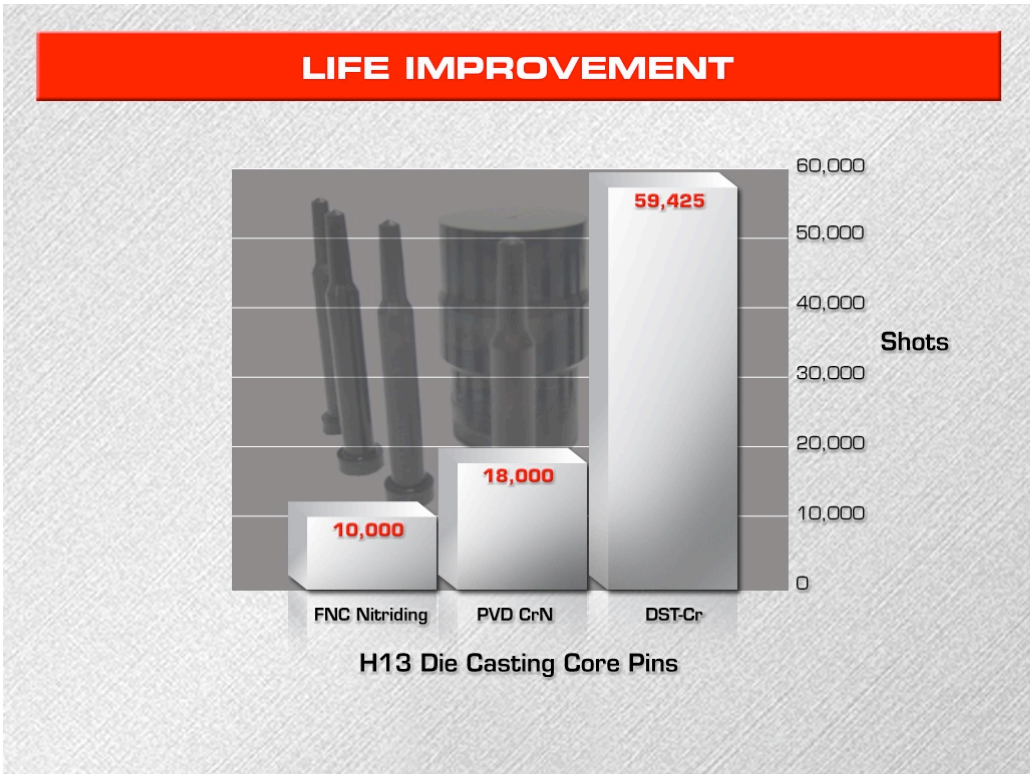


Table 2- results of tracking the DYNA-BLUE process vs the DYNA-MAX Cr Duplex Diffusion process

CALCULATING VALUE OF SURFACE TREATMENTS AND COATINGS
To determine the value of a surface treatment or coating the tool cost, including surface treatment or coating is divided by the total number of shots produced by the tool (tool life). This will show you cost per shot. This should be compared to untreated steel to reveal the cost effectiveness of the surface treatment or coating. This is magnified by looking at total number of parts that need to be produced and how many tools it will take to accomplish this.

	Untreated	**Surface Treated or Coated**
Cost of Tool	$	$
Cost of Surface Treament/coating		$
Cost to repair heat checking, etc	$	$
Total Cost per Tool	$	$
Tool Life(shots or parts produced)	Number	number
Cost per piece	Divide total cost by parts produced	Divide total cost by parts produced
Required parts per year (qty)	Number	Number
Required tools per year (qty)	Divide required parts per year by tool life	Divide required parts per year by tool iife
Total Cost per year	Total cost of tools needed	Total cost of tools needed

CONCLUSION

Analyzing the data from the case studies presented show that the Fluidized Bed Ferritic Nitrocarburizing performed 2-6 times longer than competitive process such as Kolene, Melonizing. The DST-Cr process performed 5 times longer than the Nitrocarburizing process and 3 times longer than PVD Chromium Nitride. Analysis of coating/surface treating cost to tool performance should also be studied to look at cost effectiveness or value. Depending on how high the production is will determine which surface treatment/coating is the best value.

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