

Tire Mold Maintenance with engineered CO2 blasting systems.

I. Introduction

CO2 Particle Blast Cleaning in the Tire Industry

The use of CO2 solid particle blasting for non-abrasive cleaning of tire mold sidewalls without removing mold from the press or creating a secondary waste stream has intrigued tire manufacturers since the mid-1980's. The collective experiences of those tire manufacturers who were "early adopters" of this technology have led to a more pragmatic approach regarding the use and benefits of CO2 solid particle blasting. The result has been the continued success and growth of the CO2 blasting industry with significant support from the tire manufacturers. Mainstream technology acceptance has arrived in particular for the CO2 blasting technology suppliers who listened to these pioneer customers in the tire industry, and worked diligently with them to provide fully developed tire mold maintenance solutions.

Today, most tire manufacturers are aware of CO2 particle blasting technology and its potential to reduced production downtime, labor costs, and enhance product appearance. In fact, tire manufacturers make up a major segment of the CO2 particle blast cleaning equipment sales and contract cleaning services market. This will probably be true, at an increasing rate, for many years to come. While working to develop applications solutions for tire industry, CO2 blast cleaning technology suppliers began to find solutions for the general problems of noise, ergonomics, operator safety, work area accessibility, system reliability and operating costs. Within the tire industry, the economic impact of implementing CO2 particle blast mold cleaning is overwhelmingly significant. The cost to benefit analysis usually means a payback in terms of months, not years. In the course of developing supplier-customer relationships in the tire industry, it was discovered that a tire manufacturer could realize over a million dollars per year in savings from labor and mold rework cost reductions, increased mold and press up-time, increased tire production and reduced scrap tire rate. There has even been a significant cost reduction realized from not having to purchase thousands of drill bits per year to replace the ones broken off while attempting to clear clogged vents and microvents.

The following discussion will provide an in depth understanding of the state-of-the-art of solid CO2 particle blast tire mold cleaning technology. From a cost to benefit standpoint, solid CO2 particle blast mold cleaning is the best choice among many methods and technologies currently available. Within the CO2 particle blasting industry, however, there are a variety of technologies that offer different levels of tire mold cleaning cost and performance. The mold cleaning performance levels of the different types of CO2 particle blast systems are very significant. Failing to understand these fundamental differences may lead to the selection of an inappropriate system and a significant reduction in potential productivity increases and cost savings.

Similar to abrasive blasting equipment, there are two types of CO2 particle blast systems. One type is the direct feed or "single hose" system. The other is the inductive feed, or "two hose" system. In abrasive blast systems there may *not* be significant cleaning performance differences between the two types of systems. However, for CO2 particle blast systems there is a dramatic performance differential between the types which must be fully understood and considered before selecting a mold cleaning system. There are also two basic forms of the solid CO2 blasting media that must be understood. These are discrete "pelletized" dry ice particles, and shaved dry ice "flakes" produced from a block of dry ice. The purpose of this paper to provide the reader with a detailed understanding of these and other aspects of state-of-the-art CO2 particle blast tire mold cleaning technology.

Why Tire Curing Molds Need to be Cleaned

A major problem faced by all tire manufacturers is that of mold fouling, a residue build-up on the curing surfaces of tire molds caused primarily by chemical reactions of sulfur and zinc oxide under heat and pressure. Excessive fouling in the bead area of a tire mold can cause enough surface irregularity in the finished tire bead surface so that the tire will not seal properly on a wheel. Over time, the tire will slowly leak air, resulting in a highly dissatisfied or irate customer. The finely sculpted alpha-numeric characters of the D.O.T. information must, by government regulation, remain clear, crisp, and completely legible from cure to cure. The surface of the sidewalls must maintain a uniform texture and gloss level to satisfy the market demands for aesthetics. The tread area must be free of fouling to prevent light spots on the tread lugs. Also, the brand logo and lettering must remain very crisp and precise because that is usually the focus area from which customers develop an initial perception of a tire company's product quality.

These are all excellent and obvious reasons for keeping tire molds clean. However, they are not the only ones. A vast majority of the tire molds in use today have vents and/or microvents to expel air trapped between the green tire surface and the mold surface as the bladder expands the green tire into the mold cavity during cure. Typically, the microvents are between 0.020 to 0.040 inches (0.5mm to 1.0mm) in diameter, and vents are between 0.040 to 0.060 inches (1mm to 2mm) in diameter. Both types can extend an inch or more in depth into the mold. A typical passenger car tire mold contains thousands of these vents. The bladder expansion pressure, combined with the elevated curing temperature, causes some of the tire surface rubber to "extrude" into these vents. When the cure cycle is over and the tire is released from the mold, most of the extruded rubber in these vents remains attached to the cured tire and pulls back out to form the familiar rubber "whiskers" on new tires. However, not all of the microvents release their extruded "whiskers." Over time, more and more of the vents become plugged with rubber and cease to function. When this occurs, air trapped in the molds begins to cause surface irregularities and other faults on finished tires, which ultimately increases the production scrap rate.

Another area of concern is keeping mold surfaces that mate or come into intimate contact during cure, free of residue build-up. For two-piece tire molds, these are the surfaces between the two mold halves that come in contact when the mold is closed and produces a parting line in the mid-cross section of the tread pattern. If too much residue is allowed to build up in this area of the mold, the halves will not mate together completely, even under the extreme press squeeze pressure. The result is a noticeable flash around the circumference in the middle of the tread pattern on the finished tire. An excessive amount results in additional labor costs to remove the flash.

For larger and wider tires, curing is typically done with segmented molds. The fit between adjacent mold segments and the fit between the closed segment "ring" and the sidewall plates, have very tight tolerances. If too much residue builds up on these components, small gaps will develop resulting in flash on the tires. For tires cured in segmented molds, flash can be very noticeable and objectionable because it occurs partly on the sidewalls and across the tread pattern. Also, a build up of residue on the mating mold surfaces can cause high mechanical stresses in the fasteners which attach the segments and sidewall rings to the press. The high mechanical loads can cause fastener failures which typically result in very costly damage to both the mold and press.

II Cleaning Performance Aspects of CO2 Particle Blast Tire Mold Cleaning Systems

Mold Condition Factors That Effect Cleaning Performance...Temperature

Data gathered over the past decade, since the emergence of CO2 particle blast cleaning in the tire industry, supports the fact that tire molds between 300° F and 350° F, can be cleaned 3 to 4 times faster than the same molds at ambient temperature. Although the reasons and mechanisms which give rise to this phenomenon are not completely understood, mold cleaning experience in curing departments at many different tire manufacturers have proven this to be the case. In studies of tire mold fouling, it has been determined that the more reactive chemicals present in the base polymer, the chemicals in cure accelerators and inhibitors, and the chemicals in many mold release agents combine at the curing temperatures to form an almost glass-like material at the product-mold interface. This glass-like material is different from the polymer material of the cured product. The glass-like property of this fouling residue at elevated temperatures allows it to be easily removed from the mold surface and fractured into small particles by inducing high levels of thermal stress, or "thermal shock" with CO2 pellets. Since the temperature of solid CO2 is -109° F, the CO2 pellet blast stream is an ideal source for inducing thermal shock in the residue layer. At lower temperatures (below 150° F), the fouling residue becomes much more difficult to remove from the mold surface because it resembles a very hard visco-elastic material which absorbs the impact energy of the CO2 pellets. The thermal shock mechanism ceases to function because there is very little temperature differential between the material and the mold surface. The overall result is very difficult residue removal from room temperature, or "cold", tire molds, and sometimes the residue will not respond to the CO2 particle blasting at all.

Mold Surface Condition

Abrasive blast media, like plastic or glass beads, typically leaves a "bare metal" appearance after residue removal, even on steel tire molds. This "like new" appearance is deceiving because it is achieved at the expense of removing a small amount of metal from the mold surface, and by imparting a much "rougher" (more micro "peaks and valleys") surface finish into the mold from the chiseling effect of thousands of abrasive impacts. The rough surface creates an "anchor pattern" that was not present in the original mold surface. This causes fouling residue to adhere and accumulate at an even faster rate than it did on the original mold surface. This mold surface "erosion" will be discussed below in more

detail, but it is evident that what appears to be a "clean mold" surface is a step toward decreasing the useful life of a very expensive production tool.

CO₂ particle blasting does not abrade or erode the surface of most common mold materials. Since CO₂ particle blasting only removes the residue on the mold's surface and not any surface metal, any dark stains from cured tire compounds will remain on the mold's surface. Following CO₂ particle blasting, a functionally clean, residue free tire mold may not at first appear clean by the old standard of a bright, bare metal surface. The proof of the mold's cleanliness will be seen when the first tires are cured and inspected for the sharpness of the tread, lettering, and logo details, and sidewall surface gloss level.

III . Mold Maintenance Aspects of CO₂ Particle Blast Tire Mold Cleaning Systems

Tire Mold Cleaning Technologies and Mold Erosion / Damage

The most well known and widely used method of tire mold cleaning is abrasive particle blasting. This method is very cost effective, easy to install and maintain, and relatively easy to use. All forms of abrasive blasting MUST be done in an enclosed structure to prevent the distribution of fine airborne abrasive dust particles within the factory environment, and to capture and recycle the spent media. The most popular abrasives used to clean tire molds are glass, plastic, metallic and ceramic beads. These media have gained acceptance in the tire industry because they are regarded as only "mildly abrasive". Other particle blast media used in the tire industry includes silica sand, steel shot, walnut shells, bicarbonate of soda, and abrasive impregnated sponge. All of these abrasive blast media can typically be captured and recycled for use in more than one cleaning session. However, all of them eventually breakdown (pulverize) into a fine dust which must be disposed of in compliance with federal regulations. The fact that all of these media types are considered "abrasive" means that ultimately the tire molds will be eroded to a point where they must undergo extensive rework or be scrapped. Abrasive blast tire mold cleaning is at best, a compromise between a cost effective cleaning method and reduced tire mold life.

Abrasive, or "mildly abrasive", blasting causes other problems as well. The fine silica imbedded "dust" residual from sand or glass bead blasting, or the imbedded plastic "dust" from PMB blasting, can alter the surface of the tire mold enough to prevent the proper chemical bonding of certain release agents. These mold release agents, which depend on a completely metallic surface to bond to for providing many cure cycles worth of release, are actually pulled off of the mold surface and rendered ineffective in fewer cure cycles because of the "bond blocking" caused by grit residue imbedded in the mold surface. The same type of chemical "bond blocking" can occur when attempting to apply various mold coatings for long term product release capability. In general, all chemicals applied to a metal mold surface react much faster and more efficiently when all of the metal surface is available and not masked by grit residue.

Other non-abrasive tire mold cleaning technologies which exist, or are emerging, including laser ablation, chemical flushing, and mechanical adhesive bonding of residual rubber. These methods are very much in the developmental stages and do not offer a near-term solution to the immediate and near term needs of the tire industry. Of all the generally accepted "off the shelf" tire mold cleaning technologies currently available, only solid CO₂ particle blasting has been acknowledged to be non-abrasive, cost-effective, and not produce a secondary waste stream or bond blocking dust residue on the molds. **Tables 1 and 2**, on the next page, present data from two mold erosion studies that were conducted by a major tire manufacturer in 1991, and again in 1996. **Table 1** shows the results of the 1991 tests, where CO₂ pellet blasting was examined to see what erosion effects were apparent in four types of tire mold materials (steel, forged aluminum, and two types of cast aluminum) using three different CO₂ pellet blast nozzle configurations.

All samples were blasted with CO₂ pellets at 300 psig blast pressure. Pellet mass flow rate was 250 pounds per hour. Three different single hose system blast nozzles were used. Negligible effects of blasting were seen on the steel and forged aluminum samples, while both cast aluminum showed minimal to severe erosion. Nozzle design had the most significant effect on erosion rate and cleaning cycle time.

Material	Test Conditions	Average Change in Surface Roughness (m m)	Maximum Change in Surface Roughness (m m)	Rate of Change of Surf Rough per Clean Cycles	Average Change in Coupon Weight (grams)	Maximum Change in Coupon Weight (grams)
Steel	1	-0.82	0.2	-.036	0.01	-0.02
	2	-0.26	1.8	-.038	0.00	0.0
	3	-0.94	0.0	-.014	0.02*	-0.02
Forged Aluminum	1	0.24	1.0	-.005	0.00	0.0
	2	0.88	1.6	.022	0.02*	-0.02
	3	0.28	1.1	.001	0.02*	-0.02
Cast Aluminum A	1	2.88	5.2	.132	-1.57	-5.43
	2	-0.08	0.6	.014	-0.60	-4.02
	3	1.10	3.4	.027	-1.02	-4.55
Cast Aluminum B	1	2.30	4.0	.102	-0.93	-2.01
	2	1.90	1.9	.183	0.18*	0.18*
	3	6.85	6.85	.078	0.0	0.0

* weight gain attributed to oxide formation and/or foreign material

Table 1. - 1991 Tire Mold Material Erosion Rate Study Results

CO2 Mold Cleaning Abrasion Trials 9-19-96

Sample #	Pre-Cleaning Weight (grams)	Post-Cleaning Weight (grams)	Weight Loss (grams)	Cleaning Cycle Time (minutes)	Number of Cleaning Cycles	Equivalent Cleaning Duration
1	301.64	301.54	0.10	2	18	6 months
2	304.43	304.40	0.03	2	18	6 months
3	295.85	295.78	0.07	2	36	1 year
4	302.37	302.28	0.09	2	36	1 year
5	298.71	298.62	0.09	2	72	2 years
6	298.71	298.64	0.07	2	72	2 years

For purposes of this trial, the following parameters were used:

- 10-day pull schedule · CO2 pellets
- 250 psi blasting pressure (compressed air) · 360 production days
- 3" x 5" engraved 2618 - T6 aluminum coupons · 36 cleanings per year
- 2 minute cleaning cycle