SHOT-PEENING

Studies conducted by qualified organisations like NASA, Ford Motor Company, Fiat Research Centre, and a number of Italian and foreign universities show that shot-peening is an extremely effective treatment for increasing fatigue strength and for lengthening the lifespan of many mechanical components.
Controlled shot-peening can be used on all mechanical components for the majority of endurance phenomena, in particular on gears, springs, connecting rods, shafts, axles, and even mechanical components with welds. Theoretical principles and field experience show that there are many factors affecting the good outcome of controlled shot-peening. Each case must be treated and resolved specifically. Controlled shot-peening is a sophisticated process that must be performed in very rigorous and controlled conditions.

HOW SHOT-PEENING WORKS

The Process

Controlled shot-peening is a cold mechanical process that consists of "bombarding" metal surfaces with a controlled jet of microballs shot at high velocity. For more conventional treatments, the speed of the balls is generally between 20 m/s and 100 m/s. The impact of the balls causes the component's surface fibres permanent set. In general, the effects extend to a few tenths of a millimetre deep. The external fibres, plasticized, tend to stretch while the internal ones tend to push them back to the original position. From the resulting balance, a residual compression remains on the surface thereby increasing the resistance to fatigue of the treated area.

Fatigue

Fatigue is the phenomenon responsible for the majority of failures of machine mechanisms. It's been calculated that more than 90% of mechanical component breakage is due to fatigue phenomena and it is often the cause of large accidents that involve vehicles, trains, planes, etc. Fatigue is a mechanism of damage accumulation and propagation in a mechanical component subjected to variable stress over time, whether they be cyclical and regular or completely random. Even if the loads applied can be substantially lower than the ultimate tensile stress or static yield point of the material itself, on the surface of the component, corresponding to the most stressed points, micro cracks are generated. As the fatigue stress continues, the cracks continue to grow until the component fails completely. It is an extremely complex phenomenon that, even today, is not possible to describe in a single formulation and is not easy to assess during design. Fatigue manifests itself with an unexpected sudden failure and is therefore particularly insidious.

The Benefits

As a general rule, it can be said that shot-peening increases strength from a minimum of 15-20% up to 70-80% and more, with suitable treatments optimised through specific experimental plans. Through opportune residual compression stress, controlled shot-peening can be used to increase resistance in all cases of fatigue caused by bending, twisting, or pulling-compression of parts even with strong coefficients of stress concentration. It can be used with success even in cases of contact fatigue like pitting, fretting, and TIFF - tooth internal fatigue fracture. The residual compression stress and opportune reticular distortion levels are also effective in increasing resistance to stress corrosion cracking. The micro-roughness of the surface generated by suitable treatments can also resolve problems of lubrication and noise in the gears.

The Systems

Shot-peening systems are totally automatic and are a fundamental part of the process. Shot-peening falls in the category of “special processes” that are not verifiable *ex post*. Therefore, the only way to control the process is to be sure that the operational settings constantly remain within strict tolerances throughout the treatment. The compressed-air systems are universally held to provide the best possible quality. While structured in different ways, they must have fundamental technological elements (cabin, handling unit, elevator - tube, separation cyclone, sorter unit, shooting system, controller). The cabin is essentially made of metal structural work of various sizes in relation to the use of the machine. Inside are housed the handling units for workpiece or shot-peening gun nozzles. The handling unit, in relation to the various types of parts to be processed, can include one or more elements and must guarantee reciprocal movement between the part being processed and the nozzles. In the most evolved systems, there can be robots to move the nozzles and tables for workpiece positioning.

The elevator and tube convey the balls and processing dust to the cyclone separator, which uses centrifugal force to separate dust from the balls according to differing specific weights. The sorter unit is made of a set of vibrating sifters that makes sure that the circulating balls remain within the required size ranges and shape. The shooting system for the grit consists in pressurised tanks able to feed up to four nozzles. It must be equipped with valves to adjust air pressure and ball flow rate. The controller can be either a PLC or an actual computer. In any case it must guarantee the correct management of all operational parameters and must keep them within the expected range throughout the full duration of the process.

The Principle and the Effects

When the ball impacts the surface of the workpiece, it produces a micro-imprint, a dimple with a small surrounding edge. The imprint is a result of two events that occur at the same time. When the ball (grit) hits the workpiece, it exerts Hertzian pressure on the workpiece sub-surface layers. As is well known, according to Hertz’s theory, the maximum stress exerted during contact occurs at a depth that depends on the shapes in play, principally the diameter of the ball, and by the load applied, i.e., by the speed of impact of the ball itself. The residual stress deriving from the Hertzian effect similarly produce a contribution that reaches its maximum at a depth that depends on the diameter of the ball and its speed of impact. In addition, during impact there is also a cold flow, which is responsible for the generation of the imprint edge, producing a virtual stretching of the surface fibres. The residual stress deriving from the stretching of the surface layers produces a contribution that reaches its maximum on the surface of the component. The overlapping of the two contributions produces a profile of residual stress with a high surface compression and an eventual sub-surface spike that depend on the process conditions. The residual compression stress generated by the shot-peening process is the main cause of the increase in resistance to fatigue of the parts peened.

The Technology

The technological history of controlled shot-peening is relatively new and still evolving. The process is characterised by a large quantity of operational parameters that, through consistent focus on standardisation, have been concentrated and summarised in fundamental parameters independent of operational systems. The process is represented by three basic parameters: Ball, Intensity, Coverage
The ball is “the tool” that introduces residual compression stress. Its shape must absolutely be round. Balls with sharp shapes are extremely dangerous. They can generate micro cuts in the surface with negative effects on the component’s fatigue strength. Intensity is a parameter that is measured through a “saturation curve” and represents the average kinetic energy of the ball stream. Coverage is expressed as a percentage relationship between the sum of the ball imprint areas and the area of the surface to be treated. The three basic parameters are both control parameters and design parameters. Controlling the basic parameters guarantees perfect reproducibility and repeatability of the process. The correct choice of the parameter values guarantees achieving optimal performance of the components. To achieve the best performance it is therefore necessary to work on two issues: the “design” of the controlled shot-peening, and a strict control of the process.

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Know-how and Masking

To get the most out of the treatment, maximum attention must be paid to all phases of the process, and it is necessary to carefully define the areas of the component that need to be treated. Very often the surfaces of mechanical parts have special surface finishes. It is therefore important to consider the variations of roughness that the treatment can generate. So, carefully assess the process parameters, if necessary adjusting them according to the specific requirements, and then identify the areas needing treatment and those that, for functional necessity, must remain protected. Notwithstanding the apparent simplicity, the workpiece masking and clamping equipment is fundamentally important in achieving the proper results. It must permit access to the areas being treated, ensure correct protection during treatment and, above all, the protected surfaces must not be damaged when removing it. To make the masking equipment, special materials are used and specific skills and expertise are necessary, truly a “profession within a profession.”

Design

Knowledge of the process and experience with actual cases are basic requirements for optimal design of the shot-peening treatment. Design is a multidisciplinary process involving metallurgical skills regarding the material to be treated, design ability for the definition of the fatigue conditions and relative critical volumes, and finally, obviously, the specific skills regarding treatment technology. Today there are no analytical methods able to foresee with precision the performance of a component, given the treatment parameters. From the dimensions, shape, material, external loads to which the component is subjected, and through an opportune analysis of design and technological constraints, the key characteristics of a shot-peening treatment optimised for the specific case are calculated. Even though digital simulations are increasingly refined, experimental research, the measurement of residual stress, and a capacity for analysis today remain fundamental elements for a high-level design.

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