CONDITIONED CUT WIRE SHOT: REQUIREMENTS, MANUFACTURE AND QUALITY ASSURANCE

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ABSTRACT

Shot Peening is in widespread use today as a means to increase the service life of safety parts. This presentation will focus exclusively on conditioned cut-wire shot for shot peening. To highlight this application, a short overview of patented drawn steel wire which forms the base product used for cut-wire shot will be given, and certain basic relationships between material analysis, heat treatment and drawing processes as well the resultant wire properties will be described in an initial part of this paper.

Afterwards we will deal with the cut-wire shot production proper. Cutting and rounding processes will be explained along with the quality requirements imposed on the final product and the individual manufacturing stages.

KEYWORDS

Shot Peening, conditioned cut-wire shot, patented drawn steel wire, cutting, conditioning, quality assurance.
INTRODUCTION

Let us now consider conditioned cut-wire shot for shot peening. We want to use some applications and potential uses of cut-wire shot as our point of departure.

The typical areas of applications and potential uses of shot peening are tabulated below for the sake of clarity.

As Figure 1 shows, shot peening is often used for treatment of parts that must show a high fatigue strength. It is understandable, therefore, that many automotive components exposed to continuous stress, parts used in mechanical engineering and for drive transmission and cast products are treated by shot peening.

Figure 2 shows some of the typical applications for peening with cut-wire shot; the applications are arranged according to grain sizes and processes. As you can see, the steel-wire shot used for wheel machines usually measures between 0.2 and 1 mm, while a grain size of between 0.25 and 0.6 mm is preferable for air blasting machines.

PRODUCTION OF CONDITIONED CUT-WIRE SHOT

The manufacture of optimized cut-wire shot for peening demands materials and production processes capable of meeting the very highest requirements to meet today's standards.

Taking the optimization of the peening media as our starting point, let us now consider the choice of material, the individual production processes, possible sources of defects and the means of detecting and avoiding sub-standard products.

Base material

The materials usually employed today in the production of cut-wire shot are the classical carbon steels such as D 75-2 (1.0614) and other steels of analytically comparable quality. The materials in question are high-carbon, hypoeutectoid spring steels. The mechanical properties and heat-treatment characteristics of these steels are determined primarily by their carbon content.

Wire production

The semi-finished product used to make steel-wire to manufacture cut-wire shot in the 0.2 to 2 mm range is usually wire rod with an average diameter of 5.5 mm. In the initial process, this rod is drawn in a number of passes to what is known as its patenting diameter.
Photo 1 [4] shows the pearlitic microstructure typical of wire rod with an average carbon content of 0.75%.
As this structure shows, the pearlite is mainly sorbitic infused with no more than a very minor proportion of coarse-lamellar and ferritic constituents. As is to be expected, the wire rod exhibits no traces of cold working.

The texture typical of cold working is the result of the reducing passes required to draw the wire to the patenting diameter (Photo 2). The characteristic feature is the elongation of the sorbitic grain.

The rod is patented in a continuous-feed hardening furnace (usually of the three-chamber type) under austenitizing conditions (approx. 900°C). As it exits from the furnace, the wire is usually quenched in a molten lead bath heated to approx. 530°C and remains until the requested structure is reached.

After patenting, the wire is drawn to its final diameter in multiple passes.

In accordance with the reduction in diameter in the finishing passes, the wire exhibits distinctive cold-working traces which, owing to the enormous elongation of the grains, means that the individual microconstituents are barely identifiable (Photo 3) [4].

This microstructural condition of the wire is the initial condition for the product which we know as cut-wire shot and, therefore, it has a crucial effect on the properties of this product.

Mechanical properties of wires

The results of tensile tests conducted with wire at the various stages of production (wire rod, drawn wire, patented wire and patented wire after drawing to final diameter) are shown in graphic and tabular form in Figure 3.

The graphs clearly show the changes in properties such as tensile strength, yield stress, yield point extension, etc. that result from the various cold-working processes and heat treatment.

Figure 4 [1] shows how tensile strength and the reduction in cross-section of patented, drawn wire are related to carbon content. Not surprisingly, tensile strength increase as the carbon content is increased and the cross-section is reduced. Note, moreover, that the curves show a parallel shift in an area of lower reduction in cross-section.

Allow us to show you a few examples that will illustrate the combinations of drawing and heat treatment employed to obtain certain properties in the finished product.
Individual characteristics for strength and toughness will serve to illustrate some of the basic relationships between material analysis, cold working and heat treatment of the wire, and the resulting properties.

Example a)

**Figure 5** [1] shows the relationship of strength and toughness to the reduction in cross-section for patented wires having carbon contents between 0.7 and 0.8 %.

As is to be expected, a reduction in cross-section is accompanied by an increase in tensile strength, yield stress and elastic limit, with a comparatively slightly reduction in elongation of fracture and reduction in area at fracture.

The relationship between yield stress and tensile strength, too, is important: this ratio typically characterizes the deformability of the wire. The ratios are tabulated in **Figure 6**.

Note, too, that the overall reduction in cross-section required to obtain a patented wire of a specified final strength (e.g. 2000 N/mm²) is less for wire with a higher carbon content.

Example b)

Let us suppose that steel wire having a specified diameter of 2 mm and a specified tensile strength of 1600 - 1800 N/mm² is required as the base material for cut-wire shot. **Figure 7** [1] shows a number of steps typical of this manufacturing process.

Fig. a shows an attempt to manufacture the required product from a wire rod having a carbon content of 0.60 %. Although strength increases as cross-section decreases, the rolled wire does only barely qualify at the required limit of strength.

Fig. b shows the results obtained with wire with a carbon content of 0.7 % patented, and drawn from its initial diameter 5 mm to its final diameter of 2 mm.

Although the total reduction in cross-section required to obtain the final diameter of 2 mm is less than that of the product shown in Fig. a, the finished product is of the required tensile strength because its carbon content is higher by approximately 10 % and because of the higher patenting strength.

Fig. c shows what happens when a patented wire rod measuring 5.5 mm in diameter and having a carbon content of 0.80 % is drawn to the patenting size of 3.45 mm, patented and drawn to a final diameter of 2 mm.
This process, too, yields a product that qualifies at a range of tensile strength between 1600 - 1800 N/mm² with an ample margin of safety.

When we consider reduction of area after fracture and elongation to fracture, however, we find that there is a great deal of variation in these properties even between specimens having the same dimension and comparable tensile strength.

Since the total reduction in cross-section after the last heat treatment and, in turn, the work-hardening of the wire diminishes from example b to example c, the latter shows the highest reduction of area after fracture and is therefore the most deformable of the two. This, in turn, means that the cut-wire shot made from this material has a longer working life.

These simple examples suffice to show how the choice of material, the thermal and mechanical processes (heat treatment and drawing passes) can influence the strength and toughness of the raw material used to produce the shot and thus the properties of the final product itself.

This is neither the time nor the place for an in-depth discussion of the factors that produce these differences and the principal variables such as heat treatment, drawing passes and aftertreatment. Instead, let us turn now to a brief summary and table illustrating the possible defects.

Sources of defects

The quality of the raw material depends on the smelting of the batch. Obviously, any defects due to smelting errors will have an effect on the wire and will lead to difficulties in the course of the manufacturing process. Other defects impairing the quality of the wire can occur during drawing and heat treatment.

Figure 8 is a chart summarizing typical wire defects and their symptoms. A distinction is drawn between internal and external defects and the defect mechanisms.

It is safe to consider as relatively minor the danger of external defects occurring in the production of cut-wire shot. Identifying defects of this nature is relatively straightforward - macroscopic analysis (visual inspection, dimensional checks, etc.) of the incoming goods and at each step in the manufacturing process up to and including the final drawing pass should suffice.

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Internal defects can be detected and identified by means of metallographic analysis as part of routine quality assurance. Each of these tests should make provision for quantitative defect analysis of the metallographic specimens.

The current manufacturing standard that applies to the production of wire rod is such that in the main, only the internal defects which result from patenting and the final drawing pass are relative to the quality of the final product. Inappropriate heat treatment during patenting can cause martensitic, ferritic or coarse-lamellar pearlitic structures to form, while drawing can lead to the formation of friction martensite. These defects can affect the microstructural condition of the patented wire to such an extent that the workability of the wire and the properties of the cut-wire shot (its working life, for example) are impaired.

If systematically matched tests are included in the routine checks to which the wire rod, the patented wire and the patented wire drawn to its final diameter are subjected, they should be more than sufficient to detect the majority of internal wire defects.

The following table (Figure 9) lists the tests that would normally be required for the finished product. The table also names the parties responsible for testing and defines the scope.

**Cutting process**

It is at this point, when the wire is cut to cylindrical shot, that the first production step involving direct control by the manufacturer of the cut-wire shot occurs. It is relatively easy to define the requirements for cutting and the cut shot.

The cutting process must be such as to yield a cylindrical product while ensuring minimal cold working and uniform length. Furthermore, the process should be of a nature that does not permit friction martensite to form on the cut face.

These requirements are defined in many national and international standards issued by individual manufacturers or their manufacturing associations; they are not discussed in detail here.

Photo 4 is the view through a stereoscopic microscope of a typical cut face. The specimen was selected at random from the production line and shows a cylindrical section with edges virtually free of overlap. Polished metallographic specimens confirm the microscopic analysis (Photo 5). These specimens also show the cold working of the sorbite produced when the patented wire is drawn, while the microstructure of the cut face (shearing effect, fracture edge, etc.) reveals a lot about the quality of the cutting procedure (machine settings, wear of cutting blades, etc.).
**Introduction of different cutting processes**

The two processes that have shown themselves capable of satisfying the requirements of the standards are milling cutting and parallel cutting.

Both these processes are based on the principle of a fixed blade plus more moving blades.

Milling cutting entails moving a rotating milling head (also known as the upper blade or cutting head) toward a stationary fixed blade so that the teeth (the blades, in other words) can slice through the wire as it is feed at a speed matching the rotary speed of the cutting head.

In a parallel cutting process, the upper blade moves parallel to the stationary blade and cuts through the wire at the cutting edge.

Parallel cutting was developed in 1984 by Josef Frohn and registered as a utility model by the company. This process produces cut shot of a considerably higher quality.

Whereas wear of the rotary blade used in a milling cutter means that the cutting edge changes during production until it can no longer be corrected and requires an adjustment of the cutting gap. In a parallel cutter the upper blade and the fixed blade remain parallel and so there is no significant increase in the gap. This means that the cut remains proper, although the cutting forces have to be increased as time goes on.

**Quality assurance**

Statistical in-process checks are an excellent means of monitoring the quality of the cut wire.

**Photo 6** will give you some impression of an existing quality-assurance system that has proved reliable under practical conditions.

The system is built up around a stereoscopic microscope with a cross-slide stage and high-quality graduated drums with digital outputs. The graduated drums are interfaced to a Computer Aided Quality Control System which measures at the cutting point. This system produces reproducible measurements at a magnification power of 25 and irrespective of the position of the individual specimens. The measured values are statistically processed, documented and archived.
Conditioning

Process

The conditioning-machine is a spinner drum in which the cut pieces of wire are flung out at calculated angles and known speeds against hard-end plates. The force of the impact deforms the shot (breaks the edges), thus rounding it off. Stored-program controllers (SPCs) control and monitor the rounding-off cycles (feed, dwell time and removal of the finished wire shot). This arrangement ensures that the finished product meets the high requirements placed on it. These requirements are discussed below.

Requirements

It is essential for the abrasive used in shot peening to be free of sharp edges and to satisfy the following technical requirements.

- Reproducibility of the conditioned product
- Comparable degree of conditioning across all the shot
- No inclusion of shot that has not been conditioned
- The cut pieces of wire must be conditioned slowly in order to avoid any reduction in useful life due to
  * extreme work hardening in the boundary area
  * the formation of friction martensite.

In order to ensure the quality of the conditioned cut-wire shot, the QA controllers often resort to catalogs of photographs illustrating the various assessment criteria (VDF 8001, D50TF11 S1 [2,3], Figure 11).

The various shot-peening applications for cut-wire shot allow us to draw a broad distinction between three degrees of rounding off (Figure 12).

Quality assurance

After conditioning, the finished product must be checked for sub-standard grains, because if a cylindrical piece of shot impacts the workpiece, the sharp edges could gouge a notch in the surface. Notching, as you are aware, can have a detrimental effect on the workpiece's fatigue strength.

For this test, the regulations specify the size of an area in which the number of sub-standard units are counted. The threshold is a function of shot size.
User specifications define a permissible content of substandard units in the region of 2 per mille of the total number of units on the test surface. Research and development efforts have bettered this user specification by one decimal place, placing the current state of the art at a content of 0.2 per mille of substandard grains in the finished product.

QUALITY-ASSURANCE SYSTEM

It was some years ago that exacting users of peening shot first required their suppliers to establish a quality-assurance system good enough to pass the critical scrutiny of external auditors. This system was to be based on ISO 9000 - 9004, a series of standards that enjoys worldwide validity. The characteristics required of a quality audit for cut-wire shot are outlined in the table shown in Figure 13.

This table includes only the technical features and ignores all other points that characterize a quality-assurance system to ISO 9000 - 9004.

CONCLUSION

In our opinion, the process for manufacturing wire shot specifically for shot peening is one that has been refined in step with the increasing requirements of the users. This manufacturing technologies of the wire (smelting, heat treatment and wire drawing) and the conditioned cut-wire shot (cutting and conditioning) offer reproducible performance. This means that the users have access to a medium that should meet today’s requirements in any case.

REFERENCES

(2) GE Aircraft Engines: Specifikation No. "D30TF11 Issue No. S1".
(4) "Anwendung von Drahtkorn beim Verfestigungsstrahlen", Dr.B.M. Heymann, Strahl-Tech 88 Zürich (CH).
USES OF SHOT PEENING

Automotive industry

- Crankshafts
- Camshafts
- Rockers
- Conrods
- Clutch springs
- Valve springs
- Suspension springs
- Springs for fuel injection pumps
- Leaf spring
- Torsion bars
- Stabilizer bars
- Valves

Drive transmission

- Gears
- Shafts
- Synchronizer rings
- Planet carriers

General mechanical engineering

- Coil springs
- Drilling bits
- Drilling heads for mining
- Chisels
- Stress bolts

Castings

- Steering knuckle housings
- Steering knuckles
- Conrods
Fig. 2 Major users of conditioned cut-wire shot, with grain sizes (in mm) and the methods used:

I. Automotive industry

1. Springs (wheel machines)

<table>
<thead>
<tr>
<th>Cold-worked springs for high-load applications</th>
<th>Hot-worked springs for chassis</th>
<th>Leaf springs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 - 0.6</td>
<td>0.6 - 0.8</td>
<td>0.9 - 1.0</td>
</tr>
</tbody>
</table>

2. Other chassis elements (wheel machines)

<table>
<thead>
<tr>
<th>Torsion bars</th>
<th>Stabilizer bars</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7 - 0.9</td>
<td>0.7 - 0.9</td>
</tr>
</tbody>
</table>

3. Drive transmission (wheel machines air, blast machine)

- Case-hardened components for high-load applications
  - 0.4 - 0.6

II. Aerospace industry (air blast machine)

- Propulsion-unit components for high-load applications
  - 0.25 - 0.4
Bild 11: Einfluß der Querschnittsabnahme auf die Zugfestigkeit; patentiert gezogener Stahldrähte (nach W. Püngel)
Fig. 5

Zugfestigkeit $\sigma_B$, Streckgrenze $\sigma_{0,2}$ und Elastizitätsgrenze $\sigma_{0,1}$, in kg/mm$^2$

Bruchdehnung $\delta_{55}$ und Bruchzähigkeit $\psi$, in %

Gesamtquerschnittsabnahme $\Delta Q$ in %

Drahtdurchmesser in mm

Anzahl der Züge

Anmerkung: Änderung der mechanischen Eigenschaften verschiedener Prüfleisten beim Ziehen (nach A. Pomp und W. Knackstedt)
Patented steel-wire with 0.7% carbon content

<table>
<thead>
<tr>
<th>Reduction in cross-section (in %)</th>
<th>Yield stress (kg/mm²)</th>
<th>Tensile strength (kg/mm²)</th>
<th>Ratio (in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>48</td>
<td>122</td>
<td>142</td>
<td>86</td>
</tr>
<tr>
<td>68</td>
<td>122</td>
<td>155</td>
<td>79</td>
</tr>
<tr>
<td>80</td>
<td>138</td>
<td>172</td>
<td>80</td>
</tr>
<tr>
<td>90</td>
<td>146</td>
<td>202</td>
<td>81</td>
</tr>
</tbody>
</table>

Patented steel-wire with 0.8% carbon content

<table>
<thead>
<tr>
<th>Reduction in cross-section (in %)</th>
<th>Yield stress (kg/mm²)</th>
<th>Tensile strength (kg/mm²)</th>
<th>Ratio (in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>118</td>
<td>156</td>
<td>75</td>
</tr>
<tr>
<td>60</td>
<td>122</td>
<td>161</td>
<td>75</td>
</tr>
<tr>
<td>72</td>
<td>141</td>
<td>181</td>
<td>78</td>
</tr>
<tr>
<td>82</td>
<td>161</td>
<td>213</td>
<td>75</td>
</tr>
</tbody>
</table>
Verschiedene Kombinationen von Zieh- und Wärmebehandlung, um bestimmte Drahteigenschaften zu erhalten (Ref. 01)
**Fig. 8** Potential sources of defects in the manufacture of steel wire

### Defects due to smelting

<table>
<thead>
<tr>
<th>Internal defects</th>
<th>External defects</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Cavities</td>
<td>- Shell</td>
</tr>
<tr>
<td>- Seigregations</td>
<td></td>
</tr>
<tr>
<td>- Cracks</td>
<td></td>
</tr>
</tbody>
</table>

### Defects due to heat treatment

<table>
<thead>
<tr>
<th>Internal defects</th>
<th>External defects</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Carburization</td>
<td>- Scale</td>
</tr>
<tr>
<td>- Hardening structure</td>
<td></td>
</tr>
</tbody>
</table>

### Defects due to drawing process

<table>
<thead>
<tr>
<th>Internal defects</th>
<th>External defects</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Friction martensite</td>
<td>- Out-of-round</td>
</tr>
<tr>
<td>- Excessive/inadequate strength</td>
<td>- Scores</td>
</tr>
</tbody>
</table>
### Examination of Steel-Wire

<table>
<thead>
<tr>
<th>Feature</th>
<th>Volume of Examination</th>
<th>Responsibility for examination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength</td>
<td>Test tensile strength of the wire from each spool.</td>
<td>Wire works Supplier of cut-wire shot</td>
</tr>
<tr>
<td>Torsional strength</td>
<td>Test torsional strength of the wire from each spool.</td>
<td>Wire works Supplier of cut-wire shot</td>
</tr>
<tr>
<td>Hardness</td>
<td>Test Vickers hardness (HV 1) of 20% of the wire received in spools.</td>
<td>Supplier of cut-wire shot Wire works</td>
</tr>
<tr>
<td>Metallographic analysis</td>
<td>Analyze microstructure of 20% of the wire received in spools.</td>
<td>Supplier of cut-wire shot</td>
</tr>
<tr>
<td></td>
<td>Continuous monitoring of patenting plant and random testing of outgoing goods.</td>
<td>Wire works</td>
</tr>
</tbody>
</table>
- Reproducibility of the conditioned product

- Comparable degree of conditioning across all the shot

- No inclusion of shot that has not been conditioned

- The cut pieces of wire must be conditioned slowly in order to avoid any reduction in useful life due to
  * extreme work hardening in the boundary area
  * the formation of friction martensite.
1. Acceptable Shapes of Conditioned Cut Wire Shot

2. Unacceptable Shapes; Partially and Unconditioned Cut Wire Shot

3. Unacceptable Shapes; Broken

Figure 1 - Acceptable And Unacceptable Shapes of Media
<table>
<thead>
<tr>
<th>Manufacturer's designation</th>
<th>Appearance of shot</th>
<th>Specimen applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal conditioning</td>
<td>Circumferential edges of cylinder slightly broken</td>
<td>Chassis springs, leaf springs, stabilizers, etc.</td>
</tr>
<tr>
<td>Double conditioning</td>
<td>Edges broken to a minimum radius. The original cylinder is still recognizable.</td>
<td>Cold-worked springs, general components having smaller material cross-sections than those above.</td>
</tr>
<tr>
<td>Spherical conditioning</td>
<td>At macroscopic magnifications, the shot appears spherical. The original cylindrical shape is no longer recognizable.</td>
<td>Aerospace industry</td>
</tr>
<tr>
<td>Sampling location</td>
<td>Feature</td>
<td>Recording</td>
</tr>
<tr>
<td>-------------------------</td>
<td>--------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>Incoming goods inspection</td>
<td>Wire diameter</td>
<td>quant.</td>
</tr>
<tr>
<td></td>
<td>General condition</td>
<td>qual.</td>
</tr>
<tr>
<td></td>
<td>(winding, corrosion, etc.)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strength or hardness</td>
<td>qual.</td>
</tr>
<tr>
<td>In-process inspection</td>
<td>Length of cut shot</td>
<td>quant.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final inspection</td>
<td>Shot geometry</td>
<td>qual.</td>
</tr>
<tr>
<td></td>
<td>Hardness</td>
<td>quant.</td>
</tr>
<tr>
<td></td>
<td>Screening</td>
<td>quant.</td>
</tr>
</tbody>
</table>
Photo 2
V 500:1
Drawn wire rod

Photo 3
V 400:1
Patented drawn steel-wire
Photo 7.1
V 15:1 CCW32
Normal conditioning

Photo 8.1
V 15:1 CCW32
Double conditioning

Photo 9.1
V 15:1 CCW32
Spherical conditioning