

Saw Wire and Method for Producing It

The invention relates to a saw wire and a method for producing it.

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In the following, saw wires are described that are used to cut metallic and mineral materials and in particular wafers for the manufacture of electronic components.

10 It is known, for example, to cut wafers from silicon rods for this purpose; the cutting is carried out by guiding a metal wire with guide rollers around it, in which the rod to be cut is positioned in a cutting area and is cut abrasively by the cutting wire.

15 To be more precise, the material of the rod to be cut is not cut by the metal wire itself here, but by abrasive components in a slurry that is transported into the kerf by the wire. This is also referred to as wire cutting and lapping; in this case, the wire is moved in its longitudinal direction from an unwinding spool to a winding spool; there are designs with wire movement in only one direction and wire movement with constant reversal of the movement direction. The wire must therefore be able to bring abrasive components into the kerf and ensure that the abrasive components are able to have an abrasive effect on the material to be cut. For example, the slurry
20 here is a mixture of relatively high-viscosity glycerin and silicon carbide particles. The small, hard silicon carbide grains here break fine particles out of the base matrix of the material to be machined. It is naturally also possible to use other oils or liquid carrier media and other hard materials.

25 But in order to carry such a slurry at all, the saw wire needs a surface design that enables it to carry the highly viscous slurry along. Wires that are exclusively cylindrical carry the slurry only through adhesive interaction, but the cutting process leads to a rapid stripping of the slurry and a loss of the cutting action.

30 In order to improve the wire's capacity to transport the slurry, the saw wires are provided with a structure; the structure is applied by what is commonly called crimping. This crimping is a controlled bending process in which a structure is stamped into the wire, for example by means of two gears offset by 90°, which mechanically deflect or bend the wire plastically away from a central middle position. In this case, the structure is created by bending the wire around a
35 rounded tip, for example a suitably shaped tooth of a gear.

Such a wire is of course also subject to wear during the cutting process since the abrasive particles that are carried along act not only on the material to be cut, but also on the wire or more precisely, the material to be cut can also have an abrasive effect on the wire. In particular, the wire is subject to wear on the outside of the crimp; excessive wear can lead to the loss of the crimping and a stretching of the wire, which take away its ability to carry a sufficient amount of slurry.

WO2018/149631 A1 discloses a wire saw, wire guide rollers, and a method for simultaneously cutting a plurality of slices from a rod. This document states that structured wires made of smooth, round steel wires, which have cross-sections that are periodically displaced equal amounts perpendicular to the longitudinal direction of the wire and along their entire length without changing the shape and size of their cross-sectional area, are of particular importance for the above-mentioned methods. It also states that these displacements are often referred to as crimps, where the amount of displacement is referred to as the amplitude of the crimps and the length in the longitudinal direction between displacements is referred to as the wavelength. The document also states that the spaces between the crimps act as pockets or reservoirs in which more slurry can be carried by the wire as the wire moves in the longitudinal direction of the wire without being stripped away than would be possible for a smooth wire of comparable diameter. For a structured wire, the envelope is defined as the smallest-diameter right circular cylinder that completely contains the entire structured wire. The base area of this right circular cylinder is defined as the effective cross-section, the diameter of the base area of the cylinder is defined as the effective diameter of the structured wire, and the longitudinal axis of the envelope of the cylinder is defined as the longitudinal axis of the structured wire.

The diameter of the core wire should be between 130 μm and 175 μm , wherein the diameter of the envelope of the structured wire should be 1.02 – 1.25 times the diameter of the core wire. Due to the wear, an anisotropic wear becomes apparent in the region of the exposed tips of the crimps, which causes the wire to become oval in this region.

WO2015/119344 A1 discloses a structured saw wire that is supposed to retain its crimped properties even under tension. This document also mentions the need to preserve the structure of the wire under sawing conditions in order to be able to carry the cutting material. This saw wire should have a continuous, zigzag-shaped crimping and the bending radius of the actual crimp is supposed to be 5-20 times the diameter of the wire itself. During sawing, this wire is subjected to a tension in the longitudinal direction, which acts in the direction toward an opening of the

bend of the crimp. This reduces the crimp amplitude and stretches the wire. It should be noted that a bending radius that is only 5 times the diameter of the wire or less can lead to excessive bending, which can cause the wire to already break during the production process. On the other hand, a bending radius of more than 20 times the diameter of the wire causes the cutting wire to stretch very easily when cutting tension is applied, which greatly increases the degree of wear on the wire and reduces the cutting efficiency. According to this document, the crimp is embodied not only two-dimensionally, but three-dimensionally in that the crimping is rotated around the longitudinal axis so that the crimp lies in the XZ plane and in the YZ plane in alternating fashion, thus producing a helix. This increases the cutting capacity by improving the slurry-carrying capacity.

The problem of the invention is to create a method for producing a saw wire, which produces a saw wire that has a geometric dimensional stability that is improved compared to the prior art and is thus more independent from wear.

The problem is solved with a method having the features of claim 1.

Advantageous modifications are disclosed in the dependent claims thereof.

Another problem is to produce a saw wire, which has a geometric dimensional stability that exhibits improved resistance to wear in such a way that it exhibits an independence from changes in shape and thus retains the ability to carry abrasive substances.

The problem is solved with a saw wire having the features of claim 12.

Advantageous modifications are disclosed in the dependent claims thereof.

The approach of increasing the residual tensile stresses of a wire in order to ensure dimensional stability is known from the prior art. The inventors have discovered, however, that higher residual tensile stresses have negligible effects because they are located in the outer phase of a wire and their influence is immediately reduced with the occurrence of a plastic deformation with a depth of 1 – 3 μm .

According to the invention, a saw wire is structured. The structuring represents a solution to Apollonius's problem, i.e. the wire attempts to find a position between three gear tips that are

used for deformation (two tips opposite each other, one tip crimping). In this case, the wire will form a plastic hinge at the crimping site; the gear tip should have a suitable radius for this. A suitable radius, for example, is on the order of 1-3 times the diameter of the wire. As a result, the practical elongation of the outer fibers can be between 10% and 30%, in particular about 17% to 23%. Accordingly, a maximum of 20%, in particular a maximum of 10%, of the whole wire cross-section is within the range of an elastic deformation while the remaining cross-sectional area of the wire is plastically deformed. The high plastic deformation reduces the overall tensile strength of the wire by only 2 – 6%, which corresponds to the load rating of plastic hinges.

Accordingly, a compressive stress occurs at the position of the crimp on the crimped wire on the outside, which, depending on the diameter, extends 20 – 40 μm below the surface before the stresses become residual tensile stresses due to the necessary equilibrium of moments in the wire. The high plastic deformation makes the wire largely insensitive to fluctuations in external conditions since a wear of 0.3 – 0.8 μm and thus represents only a change of 1 – 2% in the mechanical conditions.

According to the invention, the range of possible wire shapes can be increased if a tensile force is applied to the wire during the crimping. In particular, it has turned out to be advantageous if this tensile force is dimensioned such that it amounts to at least 8%, in particular at least 12%, and at most 35%, in particular at most 24%, of the product of the tensile strength R_m and the wire cross-section A . This tensile stress leads to a further increase in the plastic deformation range so that an influence of external wear conditions on wire geometries can be further reduced and the possible shapes of the wire geometry are subject to far fewer restrictions.

Since the tensile stresses resulting from the tensile force during the crimping can no longer be present after crimping due to the nature of the system, only compressive stresses occur in the outer fibers of the finished wire.

The influencing variables according to the invention are the geometry of the gear head, in particular the radius of the teeth of the gears, the stretching force during the structuring, and the yield point ratio R_e/R_m .

The invention relates in particular to a method for producing a structured saw wire, wherein a metal wire with an at least two-dimensional structure is formed in such a way that the wire is

crimped along a longitudinal axis of the wire such that the wire is deformed plastically with bulges, wherein a tensile stress amounting to 10 – 20% of the tensile strength of the wire is exerted during the crimping.

- 5 According to one modification, in order to produce a three-dimensional structure, the wire is crimped in several planes that are angled relative to one another.

According to one modification, the wire forms a plastic hinge during the crimping, wherein the bending radius is on the order of 1-2 times the diameter of the wire so that the practical elonga-
10 tion is about 17% to 23%, in particular about 20%.

According to one modification, the yield point starts at 1.5 – 1.7%, wherein a maximum of 5 – 20% of the total wire cross-section is within the range of an elastic deformation while the re-
15 maining 80 – 95% of the wire is deformed plastically so that the plastic deformation reduces the tensile strength of the wire by only 2 – 6% in total, which corresponds to the load rating of plas-
tic hinges.

According to one modification, a compressive stress is set at the position of the crimp on the outside of the crimped wire, which reaches 20 – 40 μm below the surface before the stress be-
20 comes residual tensile stress there.

According to one modification, the wire is bent around a rounded tip, in particular by means of a suitably shaped tooth of a gear or by means of regularly impinging forming pins.

- 25 According to one modification, the spacing of the deformation (hitting the wire from two sides) is about 10-15 times the diameter of the wire, thus making the wavelength about 20-30 times the diameter.

According to one modification, the structure is independently applied from directions that are
30 offset by 80° to 90°, wherein care is taken to ensure that the resulting wavelengths have the highest possible least common multiple.

According to one modification, the amplitude is set so that the apparent diameter of the wire (diameter of the envelope circle in the longitudinal direction) is approximately 8 to 12 μm and in
35 particular 10 μm when working tension is applied in the wire field of a wire saw and/or is

8-24%, in particular 10 to 20%, larger than the actual wire diameter when no tensile force is applied.

According to one modification, the yield point ratio R_e to R_m of the wire material is set to 85 to 95% and in particular 90%.

Another aspect of the invention relates to a saw wire, in particular produced with a method described above, wherein the wire is crimped in one or more planes that are angled relative to one another.

According to one modification, the bending radius at the point of crimping is 1-2 times the diameter of the wire, the spacing of the deformation hitting the wire from two sides is 5 to 15 times and in particular 10 times the diameter of the wire, and the wavelength is 10 to 30 and in particular 20 times the diameter of the wire.

According to one modification, a compressive stress is present at the position of the crimp on the outside of the crimped wire, which extends to 20 – 40 μm below the surface of the wire before the stress becomes residual tensile stress there.

According to one modification, the tensile strength of the drawn wire R_m is between 3000 and 4200, in particular 3200 and 4000, more preferably between 3400 and 3800 MPa and the yield strength of the drawn wire is between 2500 and 4000, in particular 2900 and 3800, and preferably 3000 and 3450 MPa.

According to one modification, the wire has a diameter of 0.12 to 0.17 mm and a three-dimensional crimp structure, wherein the bending radius is 0.24 to 0.34 mm, the amplitude is 0.14 to 0.2 mm, and the wavelength is between 2 and 4 mm.

The invention will be explained below based on an example; the table in Figure 1 shows the corresponding data.

A wire with a diameter of 0.15 mm is provided with a three-dimensional crimp structure, wherein the bending radius is twice the diameter, namely 0.3 mm. The resulting amplitude is 0.17 mm, while the wavelength is 3.1 mm. The necessary elongation in the outer fibers is 20%, wherein the material-dictated yield point is 1.7%. Accordingly, the plastic elongation percentage

is 18.3%. The resulting distance from the center line to the yield point is 5.61 μm , while the distance from the edge to the zero stress line is 35.36 μm . The residual elongation finally remaining in the outer fibers after the load is removed upon completion of the bending process is minus 1.6% (compression).

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The yield point ratio R_e to R_m of the wire material is 90%, wherein the tensile strength of the drawn wire R_m was 3600 MPa. The yield strength of the drawn wire is 3240 MPa.

Under the conditions mentioned above, a residual stress of 453 MPa occurred in the outer fibers, which was also caused by the fact that a tensile stress of 8 Newton was exerted during structuring. It is clear that at the tensile strength R_m of the drawn wire of 3600 MPa, a stress was therefore exerted in the longitudinal direction during structuring, which is approximately 12.6% and produces a pre-elongation of 0.2%.

Existing residual stresses in the outer fibers of a drawn wire can reach close to the yield strength of the wire, but are deliberately reduced somewhat in the last drawing step by a final, smaller forming. As an example, a residual tensile stress of 1500 MPa is assumed, but this drops to zero at a depth of about 3 μm . The residual stress with its maximum pre-elongation of 0.8% results in the yield point being reached more quickly, thus causing its influence on the final wire properties to be immediately lost at the start of the plastic deformation.

Claims

1. A method for producing a structured saw wire, wherein a metal wire with an at least
5 two-dimensional structure is formed in such a way that the wire is crimped along a longitudinal axis of the wire such that the wire is predominantly deformed plastically with bulges, characterized in that during the crimping, a maximum of 20%, in particular a maximum of 10%, of the whole wire cross-section is within the range of an elastic deformation while the remaining
10 cross-sectional area of the wire is plastically deformed.
2. The method according to claim 1, characterized in that in order to produce a three-dimensional structure, the wire is crimped in several planes that are angled relative to one another.
3. The method according to claim 1 or 2, characterized in that the wire forms a plastic
15 hinge during the crimping, wherein the bending radius is on the order of 1-3 times the diameter of the wire so that the practical elongation of the outer fibers is between 10% and 30%, in particular about 17% to 23%.
4. The method according to one of the preceding claims, characterized in that the area in
20 which a plastic deformation occurs is increased by the fact that a tensile force is applied to the wire during the crimping.
5. The method according to claim 4, wherein this tensile force is at least 8%, in particular at least 12%, and at most 35%, in particular at most 24%, of the product of the tensile strength R_m and the wire cross-section A .
6. The method according to one of the preceding claims, characterized in that a compressive
25 stress is present at the position of the crimp on the outside of the crimped wire, which extends to 20 – 40 μm below the surface of the wire before the stress becomes residual tensile stress there.

7. The method according to one of the preceding claims, characterized in that the wire is bent around a rounded tip, in particular by means of a suitably shaped tooth of a gear or by means of regularly impinging forming pins.
- 5 8. The method according to one of the preceding claims, characterized in that the spacing of the deformation (hitting the wire from two sides) is about 10 times the diameter of the wire, thus making the wavelength about 20 times the diameter.
9. The method according to one of the preceding claims, characterized in that the structure is independently applied from directions that are offset by 80° to 90° , wherein care is taken to ensure that the resulting wavelengths have the highest possible least common multiple.
- 10 10. The method according to one of the preceding claims, characterized in that the amplitude is set so that the apparent diameter of the wire (envelope circle in the longitudinal direction) is approximately 8 to 12 μm and in particular 10 μm when working tension is applied in the wire field of a wire saw and/or is 8-24%, in particular 10 to 20%, larger than the actual wire diameter when no tensile force is applied.
- 15 11. The method according to one of the preceding claims, characterized in that the yield point ratio R_e to R_m of the wire material is set to 85 to 95% and in particular 90%.
12. A saw wire, in particular produced with a method according to one of the preceding claims, characterized in that the wire is crimped in one or more planes that are angled relative to one another, wherein the yield point ratio R_e to R_m of the wire material is set to 85 to 95% and in particular 90%.
- 20 13. The saw wire according to claim 12, characterized in that the bending radius is 1-2 times the diameter of the wire, the spacing of the deformation hitting the wire from two sides is 5 to 15 times and in particular 10 times the diameter of the wire, and the wavelength is 10 to 30 and in particular 20 times the diameter of the wire.
- 25 14. The saw wire according to claim 12, characterized in that a compressive stress is present at the position of the crimp on the outside of the crimped wire, which extends to 20 –

40 μm below the surface of the wire before the stress becomes residual tensile stress there.

5 15. The saw wire according to one of claims 12 to 14, characterized in that the tensile strength of the drawn wire R_m is between 3000 and 4200, in particular 3200 and 4000, more preferably between 3400 and 3800 MPa and the yield strength of the drawn wire is between 2500 and 4000, in particular 2900 and 3800, and preferably 3000 and 3450 MPa.

10 16. The saw wire according to one of claims 12 to 15, characterized in that the wire has a diameter of 0.12 to 0.17 mm and a three-dimensional crimp structure, wherein the bending radius is 0.24 to 0.34 mm, the amplitude is 0.14 to 0.2 mm, and the wavelength is between 2 and 4 mm.