LAWD – LASER ASSISTED WIRE DRAWING

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Abstract

In conventional wire drawing the diameter of a wire or rod-like workpiece is reduced by drawing it through a conical die. Dieless drawing of a wire or a rod is realized by a localized heating of the work piece. As heat source for example an induction coil can be used. Immediately after having passed the heating zone the work piece is cooled to restrict the heat input on very small region. By applying a drawing force to the workpiece, deformation and thus the required diameter reduction appears in the heated zone. The diameter of the wire can be chosen in a flexible way by adjusting the velocities of the rod or wire in front of and behind the forming zone. Since temperature represents a sensible process parameter, even very small changes can lead to fracture.
In the present work, a laser was chosen as a heat source of the dieless wire drawing process, together with closed-loop control of forces and temperatures. Laser heating allows an excellent control of temporal as well as spatial heat input. A wire drawing apparatus has been constructed which used a speed controlled electric motor together with a controllable brake for applying the drawing forces. Heat input was realized by a 1 kW diode laser system. Wires have been cooled by compressed air immediately after the laser heated zone.
FEM analysis of the process showed that for relatively low drawing speeds one single laser is sufficient since heat spreads fast enough through the wire. Different wire types and diameters have been used during the experiments.
Results of the theoretical and experimental work showed that it is possible to draw wires with this new process. For example, with copper- or steel wires it was possible to reduce the cross section of the wires by more than 20 % in one step.

Keywords: advanced laser technologies, laser assisted wire drawing

1 Introduction

An important production process is forming, that allows to change the shape and dimension of metallic raw materials, either sheet metal, tubes, bars or wires under the action of strong mechanical forces. An example for these forming processes is wire drawing, where an initially rather thick wire is forced through a narrow nozzle-like tool, the drawing die. The wire thus obtains a reduced and calibrated cross section as it is needed for various applications. A main disadvantage of this process is, that the hole in the die suffers from great wear and thus causes substantial costs. In the case that drawing is performed at ambient temperature ("cold working") an increase of the strength of the material by work hardening has to be expected which reduces the possible degree of deformation from step to step. For materials with poor cold-forming properties therefore heat treatment between drawing steps or even heated drawing dies ("hot working") may be required [1]. Especially if the wire is drawn at elevated temperatures, the necessary lubrication is also difficult. Therefore, already in 1970 other possibilities of producing a wire were investigated, as for instance dieless drawing [8]. Since then it has mainly been used for drawing titanium and high temperature steels [6]. An industrial application of this process has already been reported, mainly for the production of strings with variable diameters in Japan [12- 14].

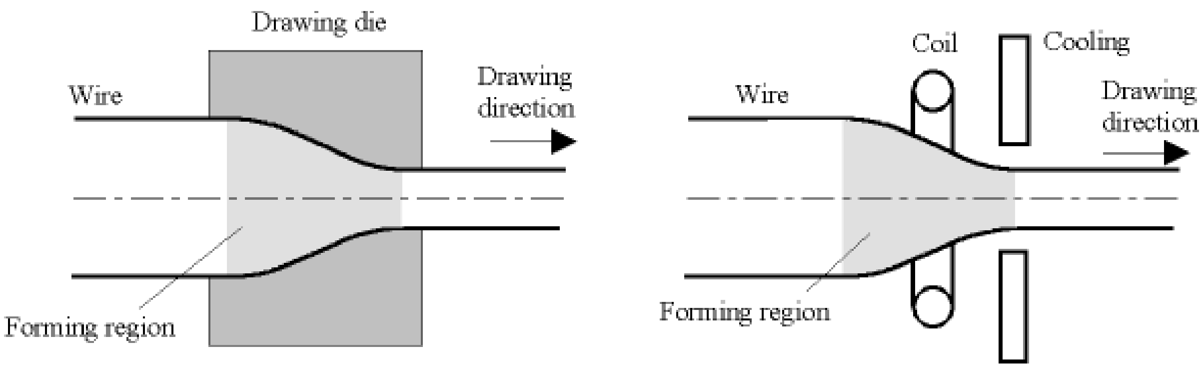

***Fig. 1**: Conventional and dieless wire drawing*

A schematic layout of the dieless drawing process is shown in fig. 1 and fig. 2. The wire is heated only locally which reduces the strength of the wire in that region. A force acting in axial direction causes yielding of the wire in the heated zone, leading to a constriction. After the deformation, the wire is cooled with pressurized air or in special cases with inert gases. The cross section after deformation can be determined from the equality between the volume flow in and out of the heated zone. ($v_{1,2}$, $A_{1,2}$ speed and cross section of the wire before and after deformation).

$$v_1 * A_1 = v_2 * A_2 \quad (1)$$

$$A_2 = A_1 * \frac{v_1}{v_2} \quad (2)$$

This means that the cross-section of the constricted wire can be determined by the ratio of speeds prior to the forming process and afterwards. Important advantages of dieless drawing are the total absence of a die and therefore wear and necessity of lubrication.

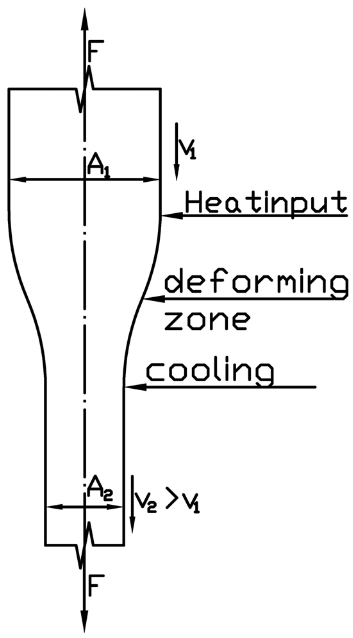

***Fig. 2:** Principle of the dieless wire*

Furthermore, the absence of frictional forces in the die and the reduction of the yield stress due to heating allow deformations which are considerable higher than in the conventional cold forming with drawing tools. In addition, the absence of a geometrically defined drawing tool favours the production of variable cross sections over the length of the wire by changing heat input and forces acting during the process. It is also possible to produce non-circular, asymmetric cross-sections or hollow profiles [4], [5].

A further side effect of dieless drawing is the thermo-mechanical treatment which is inherent in the dieless drawing process. By a proper selection of the time constants involved in heating and cooling in the region where forming takes place, the micro-structure of the material can be influenced in various ways [9].

It is well known, that the temperature represents a critical process parameter in the dieless drawing process. Small deviations of the temperature, for example caused by convection, can sufficiently interfere with the drawing process and lead to fracture [9]. Also the drawing force reacts in a sensitive way to disturbances. All the known heating sources for wire drawing (induction, electric resistance, baths, etc.) lack the necessary spatial and temporal control of the heat input in order to compensate for such effects.

2 Experimental setup

Fig. 3 shows the setup used for the experiments schematically. The wire to be calibrated is fed by a storage coil to the processing region, where a focused high power laser beam hits the material practically point-like, and heats it to a temperature below the melting point. The material is thus strongly softened and finally collected by a second coil, that applies a certain tension on the wire and therefore the wire yields in the heated region, that means it is extended and due to the necessary constancy of volume it is also constricted as the final goal of the process. Due to this effect, new regions of the wire enter the processing zone permanently and are heated subsequently, meaning that the whole wire leaving the processing zone shows a reduced diameter.

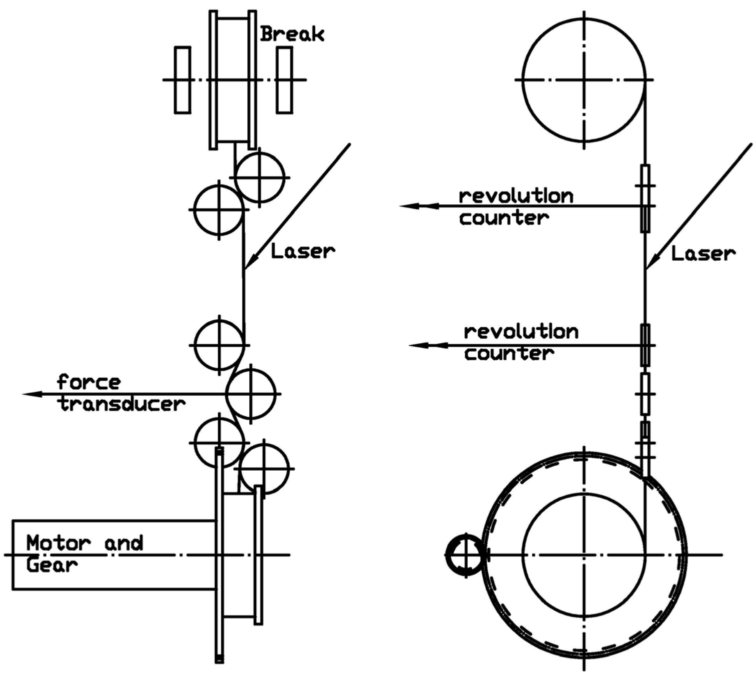

Fig. 3: *Principle of the experimental set-up*

Since its length is increased, the second coil must rotate a little bit faster than the feeder coil mentioned before. Therefore, important process parameters are the laser power, responsible for heating, the speed of the wire entering the processing zone, since the latter quantity determines the interaction time between heating source and material and finally the rotation speed of the collecting coil, since it determines the tension exercised to the wire.

Fig. 4 shows the experimental setup. It consist of the upper and lower coils, five guide rollers for the guidance of the wire, a brushless DC-motor with a gearbox connected to the lower coil and two multiple disk brakes on the upper coil. To keep the tensile force constant the torque of the brakes have to be controlled. The force is measured with a load cell at one of the guide rollers. The wire is heated up by a 1 kW diode laser at the centre of the experimental setup. The temperature is measured by a pyrometer. As mentioned above, the constriction of the wire is defined by the wire speed before and after deformation. Therefore it is very important to keep these velocities constant to achieve the desired constant cross section of the wire. The rotational speed of the guide rollers before and after the deformation zone is therefore measured with a revolution counter. As there is no slip it is assumed that the speed of the wire is equal to the speed of the guide roller at its circumference.

The control of the torque and rotation speed of the motor, the torque of the brakes and the laser power is performed by a computer using two multi I/O cards, that receive the actual values of the temperature and force as well as the speed of the wire before and after deformation. A PI-Controller has been built-up with the software program "LabView". The controller has been used to calculate the target values for laser power and other parameters finally being fed to the experimental setup, thus enabling a continuous constriction of the wire without break and rupture.

Fig. 4: *Experimental setup*

3 FE- simulation

Prior to the experiments a simulation of the process has been done by the finite elements method. The FEM-program ANSYS has been used for modelling the wire under the action of axial forces together with a heat source. Results of the simulation proved the feasibility of the laser assisted wire drawing process and have been used for the layout of the basic design of the experimental setup.

Calculations have been divided into several steps. First, the temperature distribution within the wire after heat input by a heat source has been calculated. The calculated temperature distribution has been used as a boundary condition for the next step where the deformation under the action of an axial force has been calculated. The deformed wire has been used as input for the next calculation of the heat distribution within the wire. The upper end of the wire has been fixed while the lower end was moved. These steps have been repeated continuously.

In contrary to the experiments, it was assumed that the laser beam hits the surface of the wire rotation-symmetrical. A comparision between a simulation with a rotational-symmetrical heat input and a point-like heat input into the deformation zone of the wire showed that the differences of the resulting temperature distributions are negligible. Therefore it is safe to assume that the resulting wire shapes are nearly identical for both models.

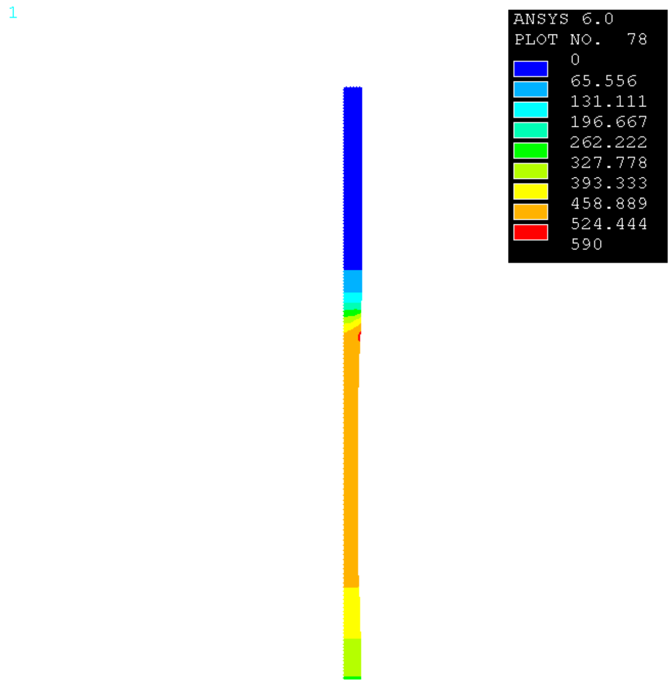

***Fig. 5**: Temperature distribution after heating by a laser beam and elongation in axial direction*

The results of a FE-simulation are shown in **Fig. 5**. The modell has been calculated rotation-symmetrical. The symmetry axis is on the left side of the figure.

4 Experimental results

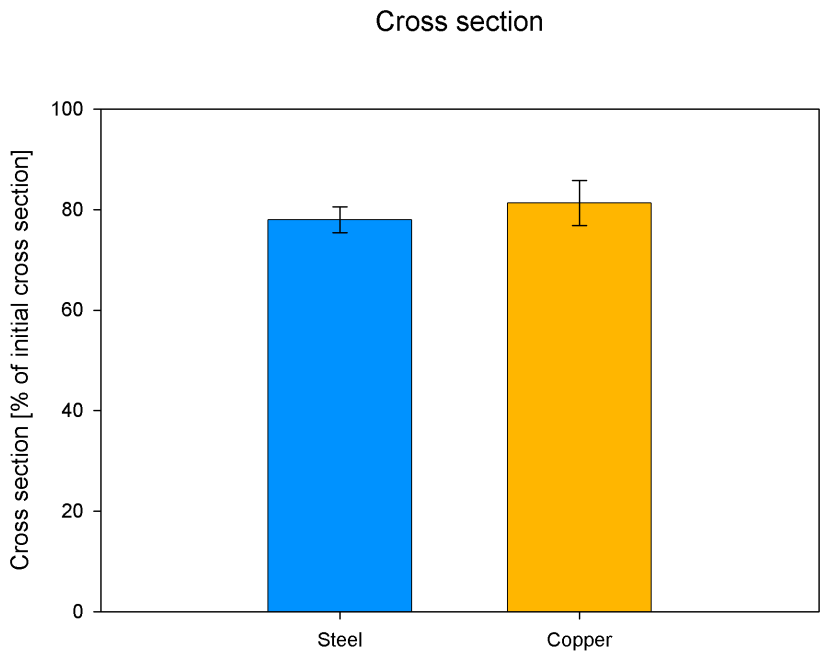

Fig. 6: *Cross section of the drawn wires*

The experimental setup shown in **Fig. 4** that has been used for the experiments. During the experiments wire speed, laser power and forces have been varied to achieve stable results. Wire diameters have been measured before and after drawing. Due to the complexity of the experimental setup with several controlled variables it was difficult to achieve constant wire diameters for longer wires. It turned out that the main reason for failures was the software solution for the controller which controls forces, temperatures and wire speed.

Nevertheless, it was possible to draw wires from different materials successfully. In the case of steel wires it was possible to reduce the cross section of the wire by more than 20% in one single drawing step. Copper wires show a slightly lower reduction of the cross section, see **Fig 6**.

5 Conclusion

With the laser assisted dieless wire drawing process it was possible to draw wires with good results in one single step. Results from theoretical simulations and experiments show good agreement. Although it was possible to reduce the cross section by about 20% in one single drawing step, the process lacks of stability. It is assumed that a replacement of the slow control algorithm used for the current experiments by a faster system the stability as well as the reliability can be increased which is important for an industrial application.

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References

[1] K. Lange, Umformtechnik, Handbuch für Industrie und Wissenschaft, Band 2: Massivumformung, 2. Auflage, Springer, 1988

[2] H. Sekiguchi, K. Kobatke, K. Osakada, A fundamental Study on dieless Drawing, Article from Machine tool design and Research 1974/75 Volume 5

[3] M. Kaltenbrunner, Laserunterstütztes Drahtziehen, Dissertation at the Vienna University of Technology, School of Mechanical Engineering, 2004

[4] O. Pawelski, W. Raps, A. Kolling, K. Schmeißer, Dieless Drawing; eine Alternative zum konventionellen Drahtziehen, DGM, Obererursel, pp 143 – 151 (1994)

[5] O. Pawelski, W. Raps, U. Weidig, Dieless Drawing, Proc. of MEFORM´98, Freiburg, 1998

[6] J. M. Alexander, W. Turner, A Preliminary Investigation of the Die-less drawing of Titanium and some Steels, Department of Mechanical Engineering, Imperial College of Science and Technology

[7] K. Schröder, D. Schuöcker, Verfahren zum Drahtziehen ohne Ziehring, Österreichische Patentanmeldung (GZ 453-99)

[8] V. Weiss, R.A. Kot, Dieless wire drawing with transformation plasticity, Wire Journal 9, pp. 182 – 189 (1969)

[9] H. Böhm, Einführung in die Metallkunde, B.I. Hochschultaschenbuch Band 196, Wissenschaftsverlag, Mannheim, 1992

[10] O. Pawelski, W. Raps, U. Weiding, W. Wegenroth, Fortschritte beim Dieless Drawing MPI für Eisenforschung GmbH, Düsseldorf

[11] O. Pawelski, W. Raps, U. Weiding, W. Wegenroth, Fortschritte beim Dieless Drawing MPI für Eisenforschung GmbH, Düsseldorf

[12] K. Kobatake, H. Sekiguchi, K. Oskada, K. Yoshikava, An Analysis of temperature distribution in continuous dieless drawing, Proc. 18^{th} MTDR Conf., London 1977, pp. 259- 265

[13] Y. Kawaguchi, K. Katsube, M. Murahashi, Y. Yamada, Applications of dieless drawing of TiNi wire drawing and tapered steel manufacturing, Wire Journal International, pp. 53- 58

[14] K. Kobatke, T. Miura, S. Kimura, H. Sekiguchi, G.A. Luan, New forming method of non-circular tapered pipes, Proc. 4^{th} ICTP, Peking 1993, pp. 67- 72