VOLATILE MEDIA AS LUBRICANT SUBSTITUTES IN DEEP DRAWING AND TRACKING OF INDIVIDUAL WORKPIECES IN HOT FORGING PLANTS

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The paper consists of reports on two individual research projects performed by the Institute for Metal Forming Technology (IFU) at the University of Stuttgart. First part of paper deals with a new approach on sustainability in sheet metal forming technology and second part deals with an introduction of a adaptive closed loop control system for drop forging.

Abstract

Reduction in use of conventional oil-lubricates in drawing processes has been important working aims of many investigations in sheet metal forming from past until today. A completely new approach is developed at the University of Stuttgart, using volatile media like N_2 or CO_2 as lubrication for sheet metal deep drawing processes. Doing so, remarkable results were obtained regarding friction behaviour of this new tribological system. Sustainability, environmental protection and economic efficiency are the most outstanding advantages of this new process compared to conventional oil based lubrication. The paper includes perspective results from fundamental investigations friction investigations to testing and validating the applicability of the new process in a deep drawing tool.

Tracking of workpieces provides two advantages in forging technology. First, the matching of workpiece with the monitored process information makes the root-cause analysis for product quality possible. Second, the process steps can be adapted based on the incoming workpiece properties to improve the robustness of hot forging process chain. For that purpose, a general tracking methodology was developed and labelling experiments on steel and aluminium parts appropriate for harsh drop-forging environments has been conducted. Furthermore, a multidimensional approach to model and to analyse the workpiece information for individual and batch-tracking as well as a framework for streaming and processing of large amounts of real-time data are presented in this contribution.

Keywords: Dry Deep Drawing, Aerostatic Lubrication, Sustainability, Digitization, Traceability, Hot Forging, Adaptive Control

1 VOLATILE MEDIA AS LUBRICANT SUBSTITUTE

1.1 Introduction – Sustainability

In deep drawing processes, the design of the tribological system poses a major challenge due to the complex interactions of components of system such as tool surface, sheet and lubricant. Here, for conventional deep drawing, liquid lubricants in the form of drawing oils and, for some years now, oil-water suspensions are used in industry. The purpose of lubricants acting in the tribological system is to reduce friction in the forming zones (contact area between sheet material and blank holder, between sheet material and die entry radius as well as between sheet material and tool) and thus to reduce tool wear through abrasion and adhesion by separating tool surface and sheet material. In addition, lubricants protect sheet materials from corrosion for example by a prelube layer, which is applied directly after the rolling process. [1]

However, the use of lubricants and corrosion protection oils also has disadvantages. Thus, corrosion protection oils have to be frequently removed from the sheet materials and drawing oils have to be applied again before the actual forming processes. Furthermore, drawing oils have to be removed again after the forming processes, as these lubricants adversely influence the downstream production processes such as bonding, thermal joining and painting of automobile bodies in a negative manner. Not only for these reasons, dry forming processes, in which conventional lubricants are abandoned, are of enormous importance and subject of current research work reported about in this contribution.

In this context, a dry forming process was developed at the Institute for Metal Forming Technology, University of Stuttgart, which is based on the use of volatile media as a lubricant substitute (see Fig. 1). Thereby, carbon dioxide or nitrogen is introduced into the contact surface between sheet metal and tool via laser-drilled microholes serving as feeding channels in order to separate them during the deep drawing process.

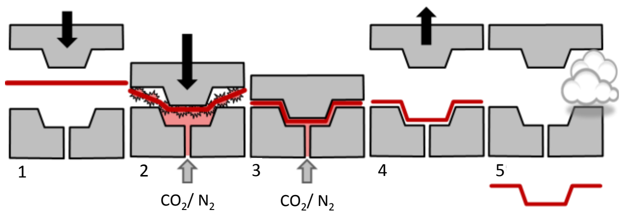

Figure 1: Process sequence of sheet metal forming using volatile media as lubricant substitute [2].

Since the volatile media are released into the environment without any residue after the process, the process chain shortened by two process steps, which are the application of the drawing oil and the cleaning of the component before further processing. Furthermore, any avoidance of conventional lubricants and the additives contained therein, such as chlorine paraffin, results in an ecological advantage, since N_2 and CO_2 are not harmful to the environment and health in the context of this use. From an economic point of view, the elimination of conventional lubricants and the associated reduction of the process chain lead to cost savings in production.

In the following, an expert of gained results using aerostatic lubrication in deep drawing processes of a rectangular cup is presented.

1.2 Dry deep drawing – tool design

In order to reduce the drilling depth for the laser process without reducing the tool strength a segmented tool design was chosen (see Figure 2). The base plate contains the holes for the media supply and a sealing to avoid an uncontrolled flow out between the plates while the upper plate contains different supply channels and laser-drilled microholes. The position of the supply channels determines the location of microholes. In order to avoid a free flow out of the media through the microholes due to blank edge draw-in right at the end of the forming process the position of the supply channels was optimized using a sheet metal forming simulation of the blank draw-in. As a result, one ring channel was integrated next to the die radius and four additional channels were arranged with regard to the blank draw-in. Each supply channel can be controlled separately by a valve to stop free flow out of volatile lubricant during deep drawing.

One row of microholes was drilled perpendicular into the supply channel having a depth of 5 mm and one row was incorporated by an angle of 35° and a length of around 7 mm. Additional microholes were placed in the die radius area. In total, 154 microholes were distributed over the tool surface of the die. For the blankholder, the same design was chosen though without radius. Here about 100 microholes were drilled into the tool.

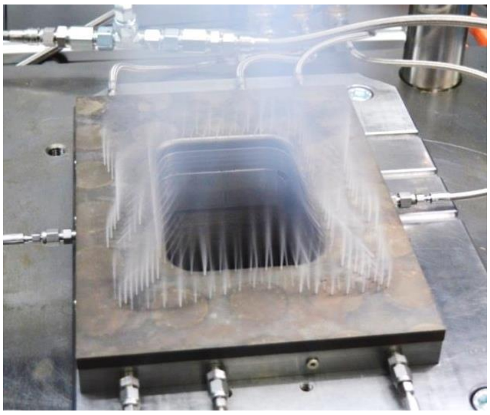

Figure 2: Free flow out of the CO_2 through laser-drilled microholes in the die of the deep drawing tool.

Due to some problems in the tool manufacturing, it was necessary to re-mill the die radius after die laser drilling. For this purpose, the tool was connected to a compressed air system applying a pressure level of 2 bar (0.2 MPa) during the milling process. By doing so, surprisingly none microhole was blocked due to the machining process. Also after the final hardening process of the tool, no blockage of the microholes could be observed. The final assembly of the tool is shown in Figure 2 while a free flow out of CO_2 media through the laser-drilled microholes is activated.

1.3 Dry deep drawing – Experimental setup

The aim of this project is the development of a new method for dry metal forming by using volatile media injected through laser-drilled microholes. Focus of research project was put on the investigation of any practical e.g. manufacturing oriented feasibility of this new approach. Therefore, emerging process limits were investigated and compared to the conventional deep drawing process using mineral oil- or wax-based lubricants. A crucial task to be solved at the beginning is determination of the valid process window. Usually in research the blank holder force and the drawing ratio is varied in the deep drawing process in order to find maximum drawing depth without wrinkles or cracks. By doing so, the valid process window can be determined to find the feasible ranges of blank holder force versus achievable drawing depth without occurring tears or wrinkles. For non-rotational parts the drawing depth is used instead of the drawing ratio.

All drawing experiments were carried out using electrolytic galvanized sheet material DC05. The sheets were cleaned manually and then degreased in an acetone bath in order to remove remaining oil layers on the sheet. Liquid CO_2 having an initial pressure level $p_{initial}$ of 60 bar (6 MPa) and gaseous N_2 exhausting at the same pressure level were used as temporarily acting lubricant for dry metal forming. The supply of the media was controlled by special valves being controlled with respect to press ram movement. The supply was switched on at moment of the first contact between the tool and the sheet and shut down at the bottom dead center of the press. Additionally, drawing tests were performed with the lubricant Wisura ZO3368 (1.5 g/m²) were investigated using the same tool material. All tests were carried out on an AIDA servo press at a ram speed of 6 strokes per minute which corresponds approximately to a ram speed of 100 mm/s at the beginning of the forming process.

1.4 Dry deep drawing –Results und discussion

Presented approach for dry metal forming was tested successfully and so, a rectangular cup was deep drawn using N_2 and CO_2 as temporarily acting lubrication for the very first time. In accordance with former tests results investigating the coefficient of friction [3] and the deep drawing of a U-shaped profile geometry [4], the new lubrication system performed better than the conventional one using a mineral oil-based lubricant (see Figure 3).

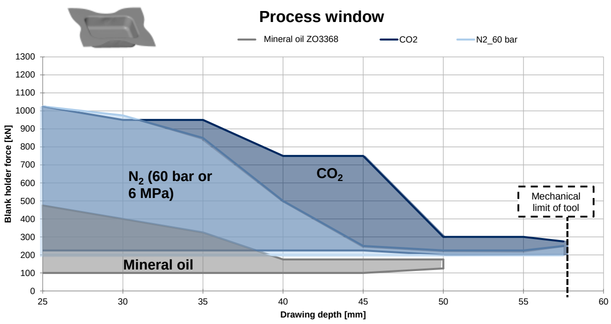

Figure 3: Process windows for deep drawing of a rectangular cup using different lubrication systems.

The maximum drawing depth in these test could be increased from 45-50 mm to 57.5 mm by using CO_2 and N_2. This depth corresponds to the mechanical limit of the tool. By using lubricant ZO3368 only 50 mm as a maximum drawing depth was achieved. Also the fracture limit was raised up to 50% depending on the drawing depth by using CO_2 as well as N_2. Thereby, CO_2 performs better for deeper cups than N_2. It is assumed that this is caused by different pressure levels acting in the gap between the sheet and the tool resulting by the different media [5]. In general this pressure in the gap p_{gap} is influenced by microholes (position, numbers, nozzle type), the initial pressure level of the injected media $p_{initial}$ and the sealing effect between tool surface and the sheet. Also this sealing effect is influenced by many factors such as the blankholder force $F_{Blankholder}$, the tool and sheet surface roughness and the thinning and thickening of part flange during deep drawing. Finally, there are interactions between the sealing effect, the pressure level p_{gap} and the height of the mean gap h_{gap} between the sheet asperities and the forming tool. A schematic illustration of the conditions in the gap and the applied designations are shown in Figure 4.

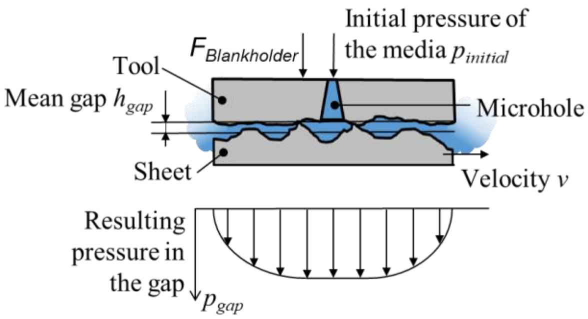

Figure 4: Schematic illustration of the resulting pressure between sheet and tool.

By deep drawing with volatile media acting as lubrication not only the fracture limit, but also the wrinkle limit was increased noticeably (see Figure 3). This effect also can be explained by the assumption that the mean gap h_{gap} and the pressure p_{gap} mainly do influence the sheet metal forming behaviour. For lower blank holder forces a higher gap h_{gap} occur without or with minimum contact areas between the tool and the sheet asperities. While forming, wrinkles of 1st order develop due to increasing tension stress in the blank without prevention by the blank holder. Thereby, the pressure in the gap, which is a scalar quantity acting in all directions, cannot avoid the local development of wrinkles. The outflowing gas through the wrinkles support such development additionally. Other tests indicate that the wrinkle limit is raised further by using a pressure $p_{initial}$ of N_2 higher than 60 bar (6 MPa). However, also the fracture limit can be increased extremely. This confirms the assumption that the resulting pressure level p_{gap} of the volatile media between the sheet and tool mainly influences the friction behaviour and therefore the forming limits of the deep drawing process of this new approach.

In addition to those investigations on process limits in deep drawing, the cooling effect on the sheet surface caused by the Joule-Thomson effect during the expansion of CO_2 and N_2 was investigated. The temperature was measured visually after the deep drawing process using a thermal camera.

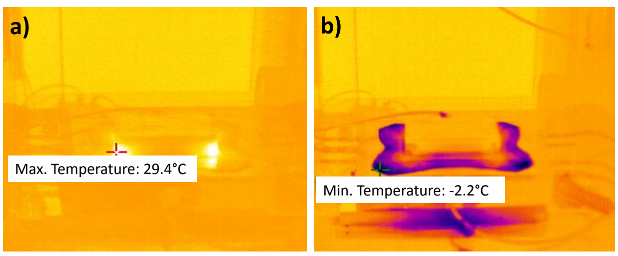

Figure 5: Measured temperature on the part surface after deep drawing using (a) nitrogen and (b) liquid carbon dioxide as volatile lubricant

In Figure 5, the visualized temperature is shown using nitrogen (a) and liquid carbon dioxide (b) as lubricant for the same process achieving a drawing depth of 35 mm by use of a blank holder force of 275 kN. The maximum measured temperature (29.4°C) after deep drawing when applying nitrogen appears almost similar to the sheet temperature when using mineral oil-based lubricants (30.1°C). The heating in the corner of the cup is caused by dissipating forming energy and friction heat. By contrast, using liquid CO_2 as temporally acting lubricant reduces the sheet temperature in the flange area down to -2.2°C (see Figure 5(b)). Compared to the first deep drawing experiments using a U-profile geometry [4], a cooling effect of only a few degrees Celsius was measured. The cooling effect merges much more significantly when deep drawing the rectangular cup. Additional to that the control of valves also plays an important role. Finding the right timing to switch on and off the flow of media appear more complex for the drawing process of a rectangular cup having curved arrangements of microhole positions onto the tool surface and more complex draw-in compared to previous drawn part as described. Another reason might be given by effect of changing flange thickness during drawing counteracting to local blank holder force. Small gaps between the tool and the sheet induced by small wrinkles of 1st order can occur supporting the flow out of the CO_2 and therefore the cooling of the sheet due to high velocity of media. According to these results, the flow control and also the position of microholes have to be optimized in further research work in order to reduce observed extreme cooling of the sheet. A different approach is given to use the cooling effect actively to reduce the heating in drawing process, while heating of parts due to friction heat and dissipating forming energy is undesirable.

However, overall presented results show that sheet metal forming by dry means based on temporally acting volatile media looks possible. Performed investigations show, that an equivalent substitution of mineral oil-based lubricants as well as an enhancement of process limits in sheet metal forming simultaneously were achieved. Especially when using nitrogen evaporating at a pressure level adjusted to respective process conditions looks extremely promising.

1.5 Dry deep drawing – Outlook

The progress in the use of volatile media as lubricant substitutes in the deep drawing process in this paper was demonstrated based on achieved results. Thus, deepened knowledge could be gained experimentally and simulatively by examining emerging friction conditions in the tool contact zone. Furthermore, after deep drawing of approximately 300 cups under dry as well as lubricated conditions none of the microholes were blocked by zinc abrasion or other effects. So it can be assumed that blockage of the microholes is not a limitating factor for this new approach. In a next step, these results have to be confirmed by prospective deep drawing endurance tests. Further performed measures also will be implemented into the test stand in further investigations. The tool radii of a new testing rig, which are subjected to high friction and wear loads, will be provided with feedholes for volatile media flow too. Complex friction conditions at tool radii and interactions with the deep-drawing process will be investigated in this new special testing rig. A further goal of future research is to expand the range of applications for zinc-coated steel sheets to include selected aluminium sheet materials, which poses enormous challenges with regard to a more complex tribological system and its susceptibility to failure. Furthermore, the theoretical knowledge of the friction behaviour of volatile media in the tribological system is to be further deepened in order to understand and specifically influence the occurring effects and thus to ensure robust and stable deep drawing processes.

1.6 Acknowledgement

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2 TRACKING OF WORKPIECES IN DROP FORGING

2.1 Introduction

Hot forging is one of the technologies bearing a great potential of improvements in the spirit of Industry 4.0 [6]. The product quality and process stability are evaluated usually after forming or even after heat treatment, based on properties of randomly selected workpieces. The state-of-the-art in industry show, that drop forging manufacturing lines and quality assurance department are working in different and disconnected digitalisation. As a result, the cause of scatter in the product properties today cannot be linked with the individual process variables and parameter fluctuations. Efficient data communication and exchange of manufacturing data within a forging system can only be achieved by hard backtracking and linking online labelled measurements with physical workpiece, otherwise, correlations and patterns cannot be extracted. Furthermore, the reduction of the scrap rate by adaptive process parameters based on incoming material or part properties cannot be achieved in an efficient manner.

Cannolly [7] in 2005 has reviewed the use of bar and matrix codes in assembly operations and for part tracking in an manufacturing environment. Types of codes, marking methods and machine vision equipment were compared and the superiority of matrix code labelling is emphasized. Denkena et al. [8] introduced a vibration assisted face milling technology enabling the machining of a matrix code or similar shapes into the component surface eliminating an additional marking step. Vedel-Smith et al. [9] developed a matrix code marking strategy for green sand castings where a flexible insert tool is used to emboss the mould itself before the melt is poured in. Montanini et al. [10] explored the possibilities of active infrared thermography in restoring covered and abraded marks obtained by laser, dot peen, impact, press and scribe marking on a steel surface.

The common application of part marking in forging companies today depends usually on the size of workpiece and the production rate. Large workpieces with small production numbers are tracked by using labels, needling or mechanical marking. Small workpieces being manufactured in high production volumes do allow batch tracking. The ability to sample accurate process data and to correctly assign them to corresponding workpieces is a major challenge regarding the heterogeneity of data sources concerning data formats, protocols and sampling rates. Hence, software modules are needed that uniformly transfers the collected data from the machine level to a factory-cloud level storage. Fundamentals of this concept are paved by Faul et al. [11].

The aim of this paper is on the one hand to formalise the know-how necessary for the workpiece tracking in forging plants using the state-of-the-art hardware and software techniques. On the other hand, a deep focus is put on further investigation of physical tags and data driven modelling of traceability. A successful workpiece tracking system needs robust tags *and* components wired with tracking software running at both machine and factory-cloud level. In this context, at first a general workpiece tracking methodology is developed and supported with multi-dimensional modelling of data-driven-traceability built on PLC-based data acquisition and processing. This methodology can be used to build a tailor-made tracking system. Second, practical tags appropriate for forging environment are investigated thoroughly and laser-engraving of Quick Response (QR)-codes are performed onto the hot surface of forged aluminium and steel workpieces. Finally, an assistance system for a single/batch tracking for that purpose is introduced in this paper.

2.2 Workpiece tracking metholodogy

This section introduces elements of a generalized methodology that can be tailored to a variety of production systems found in forging plants. Workpieces can be tracked on a batch level or individually. Harshness of the process, tag durability, process and tagging speed at the end determines the tracking intensity. A complete production line may contain processes such as casting, extrusion, sawing, turning, transfer, storage, heating, forging, blasting and heat treatment. Process information can be stored in the factory-cloud and can be associated to a specific workpiece by means of a master-identity. It is not necessary to store the complete master-identity on a tag fixed to the workpiece. Local or temporary identities can be assigned and reused at the machine level provided that the corresponding master-identities are distinct. In case economic and physical conditions desire for the next process relabelling can be performed. Tracking of a workpiece over a master-identity using various local-identities throughout the production line requires networking of the technical tracking systems in real time. Manual identification, transfer and registration of identities can be a part of this network. Provided the practical realisation of such a networking, the overall tracking problem reduces to localized tracking of workpieces throughout individual processes.

Process Formalisation:

Process in a forging production line may be clustered into the following process categories (PC):

- (PC1) Tag endures throughout the process.
- (PC2) Tag does not endure throughout drop forging prochess and
- (PC3) batch processing is performed.

Processes belonging to PC1 category do not damage the tag applied onto the workpiece, so the tag can be identified flawlessly after processing. Examples are storage, transfer or heat treatment. Workpieces qualified as scrap can be identified and registered easily. *Processes belonging to PC2* category do damage the tag, but the sequential processing allows the tracking of the identity within and after processing according to the identity scanned before the process. Parts can be qualified as scrap during or right after the process. Especially scrap determined and separated during process has to be registered in real time, which can be automated or performed by manual triggering. Applications belonging to the State-of-the-art such as force measurements and part proximity sensors located at grippers can be used for recognition of missing parts. *Processes belonging to PC3* category do damage the tag as well, the individual identity of produced part unfortunately is lost since a dedicated portion of workpieces are processed within a short time frame. In this case individual relabelling of each workpiece is not practical due to high production rate or other constraints given by logistics. Such processes (e.g.heat-treatment, blast cleaning) consequently permit only batches to be tracked. Individual information of workpieces processed together can be merged in a “statistical representation” stored in the factory-cloud and only can be associated to batches.

The operative tracking actions are tagging with the (part or batch) identity and tag scanning to recall the (part or batch) identity and the corresponding information in the factory-cloud. The computational tracking actions are locating the identity in the factory network, providing the required information from the factory-cloud to the process machine and storing the generated production information to the factory-cloud.

The category of a process can be altered by a process redesign to improve the traceability. Workpiece conveyors or workpiece carriers with a strict preservation of processing order instead of a disorderly transfer are trivial examples for such an improvement. At least, small workpiece containers providing reduced batch sizes can be used to increase the specificity of the statistical representation of the associated information.

Programmable Logic Controller (PLC) based data acquisition and processing:

The individual interfaces of the connector software do run on control devices and the standardized interface is operating in the factory-cloud. The individual interface is basically implemented as state machine that can be integrated into the PLC code. Two major cycles can be distinguished. Firstly, a “read”-cycle that scans the protocol and extracts data depending on the bus system. Secondly, a “write”-cycle that uses a Representational State Transfer model to describe the extracted data. The measured process parameters are converted and mapped onto the model and posted to the standardized interface that runs on the cloud server. The standardized interface forwards the data for further processing. It is either stored in a relational database where data analytics techniques are applied or forwarded to a real-time database in order to conduct ad-hoc calculations and online analytical processing. The real-time database is used for the association of workpiece identity and process parameters along the entire process chain. It allows an online tracking of single parts or batches. The general concept is depicted in Figure 6.

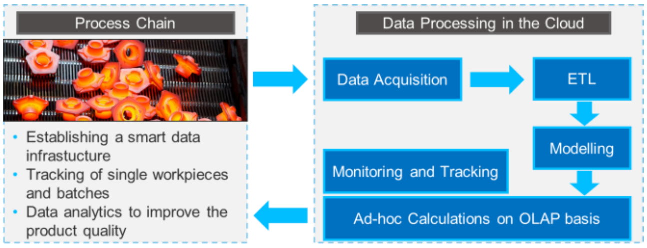

Figure 6: Concept and system architecture.

2.3 Practical tags and tagging experiments

The design of a complete tracking system considers applied processes, part geometry and material. The discussion in this field is limited to the comparison of the known characteristics of the tag. In this context, laser-engraving tests on hot steel and aluminium surfaces have been conducted and the results are compared to needling technology. Part or batch tracking solutions for operations such as machining, sawing, transfer or storage are already in use in industry. The harsh forging environment, possibly covering heating of billet, forging, blasting and heat treatment allow use of cips for Radio Frequency Identification (RFID), labelling, needling, marking, laser-engraving and virtual tagging to be useful throughout these processes. Tags should not cause any harm, they must endure and could be tagged around 500°C for aluminium and 1200°C for steel. Oxide-layer has to be removed before tagging, but the tag endure the development of the oxide-layer as shown in Figure 7. A heatproof RFID is durable up to 350 °C at the transponder, [12], with a size of 10×7×3 cm being practical on containers for batch tracking. There are also labels durable up to 1250°C, providing flexible size and content for individual or batch tracking [13]. Difficulties may arise when attaching, keeping and removing the labels. Although they are just superficial, needling, marking and laser-engraving become a part of the workpiece. They affect the geometry and even the material locally. Table 1 compares functionality of needling, marking, laser-engraving based on market research conducted during experiments.

QR-Code can provide successful recognition even a part of the label would be damaged. Figure 7 demonstrates on the left a QR-Code generated by a fibre-laser on aluminium at 550°C and worn afterwards by collisions with other parts during shaky batch transfer in a container, yet the recognition is functional. Figure 7 demonstrates on the right cold marked steel which is covered by oxide-layer for three hours at 900°C. Visible markings on the oxide-layer and on the clean surface after removal of the oxide-layer are both identified by QR-Code readers. If the QR-Code reader should fail, the attached clear text is thoroughly legible.

Figure 7: QR-Codes generated by fibre-laser: Aluminium at 550°C damaged by collisions (left); Steel at RT covered by an oxide-layer development at 900°C for three hours (right). All codes have been recognised successfully.

Table 1: Comparison of functionality of commercial tags

	Marking	Needling	Fiber Laser-Engraving (50W)
Content	Clear text	QR-Code, Clear text	
Marking depth	Limited	Strike energy	Beam energy and repetitive shots
Tagging Time	~ 1 sec.	~ 4 sec.	~ 8 sec. for 50 W Fibre Laser (increases with size and surface preparation, reduces with power)
Clarity	Missing contrast	Missing contrast	Superior due to surface preparation
Size	Marker size	Needle size	Flexible
Resolution	-	Fixed	Flexible within a label
Surface Curvature	Slight curvatures		Flexible with adaptive focusing
Clear Text	High quality	Dotted	Dotted with flexible resolution
Temperat.	Tested at 550 °C for Aluminium, 1200 °C for Steel		
Investment	~ 10.000 €		~ 30.000 €
Scanning automation	Optical recognition	QR-Code reader,OCR	QR-Code Reader, OCR (Superior with surface preparation)
Blasting resistance	Poor. Increase with the dot size and depth.		

Needling and laser-engraving can both be used to mark QR-Codes and clear texts on the surface. Since the resolution of the needling is limited with the needle diameter the marking size is not flexible. The depth of dots can be influenced by the impact energy. Overlapping dots by needling appear as not useful in production, but this is totally harmless for a laser-engraver and can be performed to increase the depth of each dot and even the resolution of the engraving. A QR-Code together with the content in clear text is difficult to generate by needling compared to laser-engraving. Figure 8 compares such high resolution laser-engraving marking (where a single dot is generated with many tiny dots) with the result of the needling to demonstrate clearly the limits of the needling and the capabilities of laser-engraving. A laser-engraving with single-dot-resolution also is provided to demonstrate the difference between the characteristics of dot indentation. The size and depth of the dots in QR-Code has to be increased for a better durability against blast-cleaning.

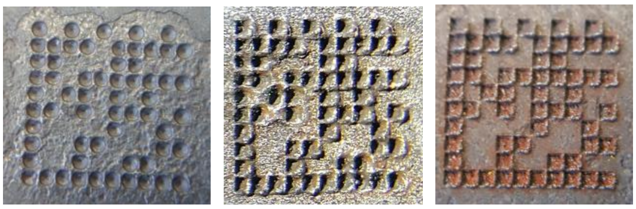

Figure 8: QR-Codes generated by needling (left), low resolution laser-engraving (middle) and high resolution laser engraving (right), all with successful optical recognition.

2.4 Conclusion of tracking of workpieces in drop forging environments

Authors propose a general workpiece tracking methodology for hot forging plants covering process formalisation, multidimensional modelling of data-driven-traceability and PLC-based data acquisition and processing. Practical solution of tag design were reviewed and compared in this paper and tagging experiments were performed to extend the possibilities of individual workpiece tracking also. The realisation of individual workpiece tracking for high production rates requires re-design of processes like transfer, storage heating and heat treatment based on the introduced process formalisation. Real-time registration of scraps is a requirement in the tracking problem. QR-Code with clear text extension is suggested for manually aided automation. Standard QR-Codes use square dots fully covering the grid-cell in the code. Needling and laser-engraving with single-dot-resolution for each grid-cell however generate round dots without filling that grid-cell. Furthermore, the colour and contrast in a dotted grid-cell is not optimal. Readability of a QR-Code depends on the recognition of a dot, having a distinguished contrast from a free grid-cell. Since digital image correlation based identification of QR-Code does consider this standardised praxis, which is biased towards the printed codes with sharp and recognizable gradients in contrast, identification of the engraved codes may fail in case of bad lighting. In this study, commercial readers were used and mostly successful results are obtained with proper lighting.

2.5 Acknowledgement

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3 REFERENCES

1. Vollertsen, F., Schmidt, F., “Dry metal forming: Definition, Chances and Challenges,” Int. J. Precis. Eng. Manuf. - Green Technol., vol. 1, no. 1, pp. 59–62, (2014).
2. Liewald, M., Graf, T., Hirth, T., et al., “Tribosysteme für die Kaltumformung auf der Basis von flüchtigen Schmiermedien und laserstrukturierten Oberflächen,” Dry Met. Form. OAJ FMT 1, vol. 1, pp. 22–33, (2015).
3. Woerz, C., Liewald, M., Singer, M., “Investigation of Tribological Conditions in the Strip Drawing Test Using Liquid CO_2 and N_2 as a Volatile Lubricant,” 7th International Conference on Tribology in Manufacturing Processes (ICTMP), pp. 140–148, (2016).
4. Woerz, C., Zahedi, E., Umlauf, G., et al., “Tiefziehen eines U-Profils mit flüchtigen Medien als Schmierstoffersatz“, Dry Met. Forming OAJ FMT, 3, 50-61, (2017).
5. Woerz, C., Reichardt, G., Liewald, M., Zahedi, E., Weber, R., “Dry deep drawing of a rectangular cup assisted by volatile media injected from laser-drilled microholes,” Dry Met. Form. OAJ FMT 4, vol. 4, pp. 1–8, (2018).
6. Liewald, M., Karadogan, C., Felde, A., Lodwig, R., 2017, Development and Integration of Digital Technologies in the Forging Process Sequence, New Developments in Forging Technology, 245-256.
7. Connolly, C., 2005, Part- tracking labelling and machine vision, Assembly Automation, 25/3:182-187.
8. Denkena, B., Grove, T., Seibel, A., 2016, Direct Part Marking by Vibration Assisted Face Milling, Procedia Technology, 26:185-191.
9. Vedel-Smith, N.K., Lenau T.A., 2012, Casting traceability with direct part marking using reconfigurable pin-type tooling based on paraffin–graphite actuators, Journal of Manufacturing Systems, 31:113-120.
10. Montanini, R., Quattrocchi, A., Piccolo, S.A., 2016, Active thermography and post-processing image enhancement for recovering of abraded and paint-covered alphanumeric identification marks, Infrared Phys Technol., 78:24-30.
11. Faul, A., Jazdi, N., Weyrich M., 2016, Approach to interconnect existing industrial automation systems with the industrial internet. 21st IEEE International Conference on Emerging Technologies and Factory Automation (ETFA) 2016.
12. http://sawcomponents.de/produkte/saw-sensorik-und-rfid/
13. http://heatproof.eu/produc