

EasyForm – Final summary report

(Public)

EasyForm – Laser-assisted metal spinning for an efficient and flexible processing of nickel- and titanium-alloys (Grant Agreement 315111)

Research for the benefit of SMEs

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Executive Summary

The demand for parts made from high-performance materials such as titanium and nickel based alloys is increasing – particularly in the automotive and aerospace industries. However, conventional forming operations conducted on these materials are generally very laborious and time-consuming. This is where the limitations of metal spinning also become apparent. However, the formability of materials can be enhanced when a laser is used to apply localized heat, permitting even materials which are difficult to form to be processed considerably more efficiently since there is no longer any need for additional time-consuming and cost-intensive external heat treatment.

»EasyForm«, the EU-funded project (Funding Code: 315111) was initiated with the aim of proving the industrial applicability of laser-assisted metal spinning for the processing of titanium and nickel alloys. Within this project, Fraunhofer IPT developed the forming process and the associated system technology in collaboration with the Austrian Materials Center Leoben Forschung GmbH research facility and four companies from various European countries.

The project has been divided into four sub-tasks in order to achieve the superordinate project goal:

- (1) Development, set-up and commissioning of a prototypical machining system
- (2) Development of machining strategies for laser-assisted metal spinning operations conducted on materials which are difficult to form
- (3) Development of a test methodology for quality assurance
- (4) Economic and technological evaluation of laser-assisted metal spinning in comparison with conventional forming processes.

Applying the new technology facilitated to improve the maximum deformation degree by up to 65 per cent compared to cold forming. Because intermediate heat treatment operations can be avoided, throughput time could be reduced from several days to some hours in the defined case study. In contrast with conventional ways of heat treatment laser-assisted processing reduces costs at the same time. Furthermore, the consortium could prove that the component quality regarding dimension and shape can be enhanced by the use of the new technology.

The main advantage compared to conventional ways of heat treatment is that the heat is applied only briefly to the area in which it is needed. In contrast to hot forming with gas burner assistance or annealing operations, the thermal load of the work piece can be reduced to a minimum and controlled accurately. This facilitates to suppress any detrimental impact on the microstructure of the material while ensuring a uniform part quality at the same time. The future application of laser-assisted spinning technology represents a substantial benefit for the partners of this cooperative venture. Thus they intend to foster the industrial application of laser-assisted metal spinning. The EasyForm project has been a fine step forward to do so.

Summary description of project context and objectives

The demand for parts made from high-performance materials such as titanium and nickel based alloys is increasing – particularly in the automotive and aerospace industries. However, conventional forming operations conducted on these materials are generally very laborious and time-consuming. This is where the limitations of metal spinning also become apparent. Furthermore, if high deformation degrees are required, the process is also pushed to its limits for steel and aluminum alloys due to strain hardening during deformation that leads to embrittlement and early failure during forming. Today, metal spinning companies follow two different main approaches for heat treatment to expand these forming limits: cold metal spinning with intermediate recrystallization steps in external furnaces or simultaneous heating of the work piece using gas burners. Both methods show substantial drawbacks in terms of production technology. Applying cold spinning usually requires several forming steps alternating with intermediate recrystallization heat treatment. Due to the limited formability of materials, the geometrical flexibility per forming step is limited as well. Like that, long process chains incur, comprising high efforts regarding set-up, transport and storage. Using gas burners instead to reduce the material's strength during the process, the energy applied to the work piece can hardly be controlled. This can cause adverse effects on the microstructure of the manufactured component and a low reproducibility of the product quality.

Until now, companies of metal-working sector have to deal with following challenges:

- Increasing market demand for high performance components made of challenging materials
- Increasing quality demand vs. limited production quality which is obtainable by state-of-the-art processes
- Complex and time-consuming state-of-the-art forming processes with need of expensive rework to reach customers' expectations and pricing pressure which reduces the competitiveness of metal spinning companies.

Furthermore, existing processes implicate several limitations for the processing of challenging materials. These can be summarized as follows

- Limited cold formability of challenging materials requires numerous forming steps with intermediate heat treatments. Like that the possible component complexity is restricted
- Intermediate heat treatments between several forming steps are expensive and time-consuming because of increased efforts for transportation and set-up
- Processing in more than one clamping results in limited positioning and repeat accuracy
- Hot forming with manual gas burner heating is imprecise and difficult to control, thus component quality is limited
- Long heating times due to gas burner causes impairment of surface and subsurface zone
- Heating with gas burners impairs key components of the machine (e.g. roller bearings) which leads to loss of precision
- Gas burner heating downgrades working conditions because of radiated heat, noise and emissions.

To face the specified challenges and overcome the aforementioned limitations of state-of-the-art processes a continuous development of new technological approaches is obligatory. One innovative approach for this purpose is laser-assisted metal spinning because the formability of materials can be enhanced when a laser is used to apply heat locally. Thus a laser beam is used to heat the area of the work piece just ahead of the forming roller contact zone. This permits to process even materials which are difficult to form with high efficiency since on the one hand there is no longer any need for additional time-consuming and cost-intensive external heat treatment and on the other hand the energy input can be well controlled.

The project EasyForm (Funding Code: 315111) was initiated with the aim of proving the applicability of laser-assisted metal spinning for the processing of titanium and nickel alloys. Therefore the main objectives have been

- (1) The development of laser-assisted metal spinning. Therefore the objective can be divided in the development of an adequate laser integration to an existing machine tool and process development.
- (2) The increase of process capability by increase in deformation degree and/or increase of deformation rate by at least 25 per cent.
- (3) A 30 per cent reduction of the throughput time and costs by applying the new technology in comparison with other state of the art processes as well as
- (4) An increase in production quality by heating the work piece only locally in the forming zone, thus controlling the heat input and keeping the thermal load of the component to a minimum.

In order to prove the approach the project has been divided into four sub-tasks in order to achieve the objectives thus the superordinate project goal:

- (1) Development, set-up and commissioning of a prototypical machining system
- (2) Development of machining strategies for laser-assisted metal spinning operations conducted on materials which are difficult to form
- (3) Development of a test methodology for quality assurance
- (4) Economic and technological evaluation of laser-assisted metal spinning in comparison with conventional forming processes.

Description of main S & T results/foregrounds

For laser-assisted metal spinning, laser radiation is used to induce a temporal local heating of the forming zone simultaneous to the forming (spinning) process. First, the rotating sheet metal blank is pre-heated by an oscillating movement of the laser beam. Then the sheet metal blank is heated by the laser and simultaneously formed with a forming roller. Therefore, the focal spot of the laser is positioned directly ahead of the forming roller and the focal spot geometry is adjusted to ensure that only the forming zone is heated. With a high power density, modern high power lasers guarantee very short heating times. The rotating sheet metal blank can thus be formed reliably onto the mandrel without any intermediate annealing steps.

Laser-assisted metal spinning can basically be characterized by a decrease in flow stress and eliminated strain hardening at the same time. Thus, higher deformation degrees become obtainable. Intermediate heat treatments can be eliminated and components can be manufactured in one single clamping. Because of the characteristic of laser radiation to concentrate a high amount of energy into a precise defined area, it is very suitable for the selective local heating. Temporal and local heating enable optimized surface and subsurface quality. Furthermore, a perfect controllability of the laser source guarantees an excellent reproducibility. Even complex shapes can be realized due to increased plasticity and characteristics of metal spinning without negative consequences of conventional heating by gas burners.

Development of machining system

To be able to develop the laser-assisted forming process the availability of a suitable test bench is the essential precondition. Therefore the specifications for a retro-fit laser integration into an existing spinning lathe have been defined. Based on the specifications different concepts for laser-integration have been developed and assessed. A specific laser optic has been implemented into a spinning lathe with two additional linear and two additional rotational axes in order to ensure the required flexibility to ensure a reliable heating of the forming zone during laser-assisted spinning process. The concept has been designed and assembled. Furthermore, an additional control system for the motion system of the laser head has been developed and set up. Therefore the requirements for interfaces between machine, laser, control system of laser head and metrology have been defined and the different systems have been linked accordingly. In order to assure laser safety during experimental investigations, the spinning lathe with laser integration has been set up in a laser safety box at the facilities of Fraunhofer IPT and the safety circuits of machine, laser and laser safety box have been connected. Finally the system has been tested and qualified for use. Figure 1 shows the machine tool before and after retro-fitting.

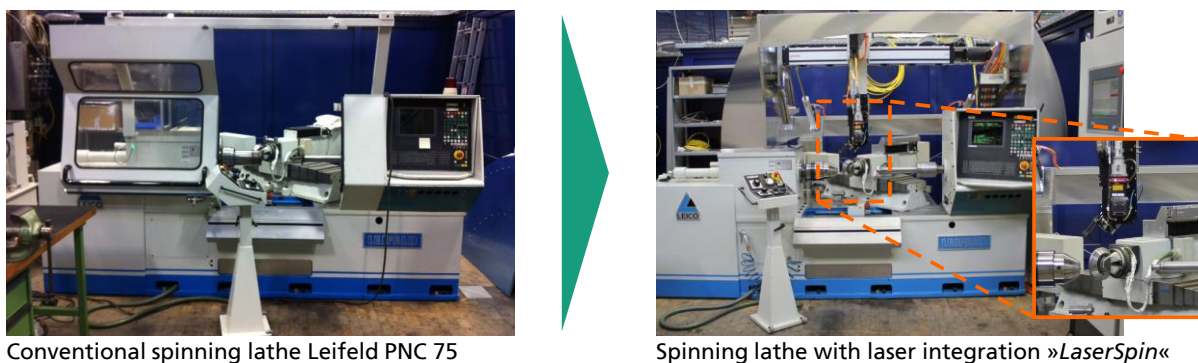


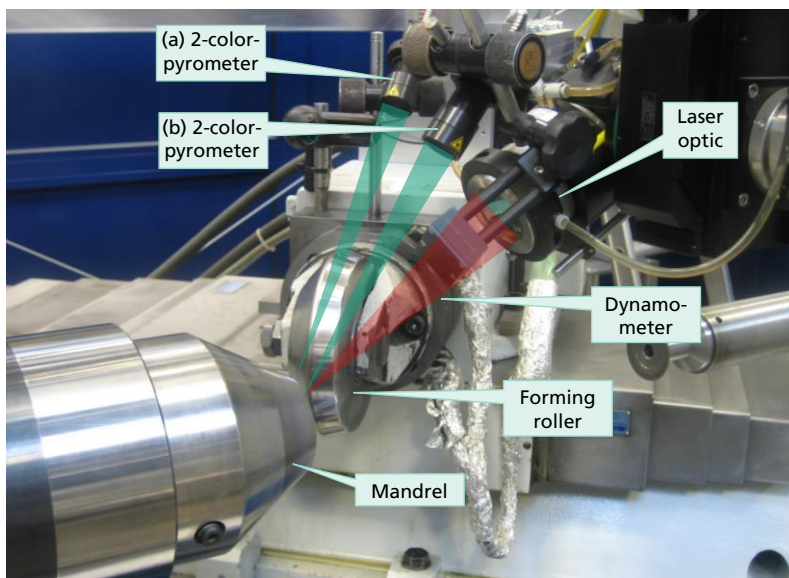
Figure 1: Retro-fit laser integration into an existing spinning lathe

Process development

To validate the approach of laser-assisted spinning three technically important materials (titanium grade 2, nickel-based alloy Inconel 718 and stainless steel 1.4301) have been defined. By a basic characterization

the relevant material properties of the defined project materials have been identified. For each of the three investigated materials a suitable temperature range has been identified for processing by laser-assisted metal spinning. With respect to the required temperature field heating strategies for the different materials by means of a focused laser beam have been developed in experimental investigations. Supplementary materials' characteristics have been analyzed after laser heating operations. Therefore the microstructure and hardness of the as-delivered stainless steel 1.4301, titanium grade 2 and Inconel 718 as well as the material after laser heating have been investigated. The comparison of microstructure and hardness before and after laser heating showed that neither for stainless steel 1.4301 nor for Inconel 718 or titanium grade 2 the short time laser heating had a considerable effect on the local microstructure and hardness after heating. It can therefore be concluded that differences in the local microstructure and hardness measured on the demonstration parts after forming result only from the forming process and not from the laser heating alone.

In order to investigate the process capability of laser-assisted metal spinning processes in contrast with conventional cold forming the correlation between input parameters and resulting output parameters has been investigated by laser-assisted shear forming with the experimental set-up shown in Figure 2. In contrast with the individual forming steps in spinning operations the forming step is distinctively determined by the shape of the mandrel thus the results can be evaluated reliably. In order to prevent high temperature gradients in the component a pre-heating before forming has been applied. Furthermore, the laser spot position has been evaluated as sensitive parameter for the forming operation and adjusted accordingly.



- For temperature measurement, two 2-color-pyrometers have been installed to
 - a) Control the temperature in the forming zone
 - b) Measure the temperature in the focal spot
- For the measurement of forming forces a dynamometer is installed behind the forming roller

Figure 2: Experimental set-up for laser-assisted forming operations

Figure 3 shows as an example the effect of laser-assistance during shear forming of titanium grade 2. Cold shear forming of the used titanium material has not been possible without failure of the component during processing. By applying laser-assistance during forming the formability of the material has been significantly enhanced thus a successful component manufacture has been possible.



Figure 3: Laser-assisted shear forming of titanium grade 2 facilitates successful component manufacture in contrast with cold shear forming

The manufactured components have been analyzed comprehensively and the results have been summarized in a guideline for quality control. The guideline for quality control shows a number of characterization techniques considering the specifics of parts produced via laser-assisted spinning technologies. Basically the quality assurance techniques can be separated in (a) simple and fast techniques and (b) techniques that require either expensive equipment or destruction of the component. The first category is suitable for the quality control during every day production. The second category of characterization techniques can be applied if the customer requires specific quality features such as a quantified minimum roughness of the part surfaces, a predefined value of the minimum wall thickness in the final part or a uniform material strength throughout the part.

Manufacture of demonstrators and assessment of laser-assisted spinning

For the manufacture of demonstration components by laser-assisted metal spinning, machining strategies have been developed for the different investigated materials stainless steel 1.4301, titanium grade 2 and Inconel 718. In addition components made of aluminum alloy AlMg3 have been manufactured due to the high economic relevance of this material for the participating SMEs.

In contrast with cold forming Inconel 718, titanium grade 2 and aluminum alloy AlMg3 have been successfully processed by laser-assisted metal spinning without failure of the component. Figure 4 gives an impression on the laser-assisted spinning process showing the steps pre-heating, processing, and finishing/planning.

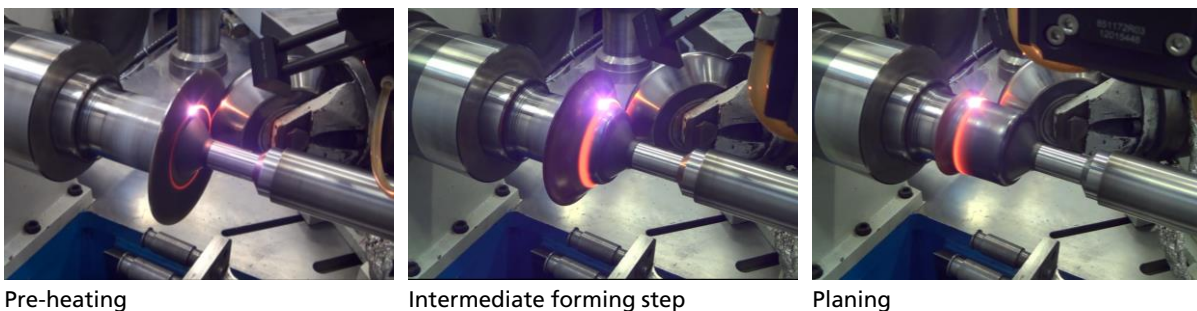


Figure 4: Laser-assisted spinning process

Figure 5 shows on the left the effect of non-sufficient heating during metal spinning of nickel based alloy Inconel 718. Due to severe strain hardening leading to embrittlement and failure of the component no successful manufacture of the demonstrator could be achieved without sufficient heating during processing. As consequence of strain hardening leading to embrittlement the work piece broke during processing. By applying laser-assistance the required forming temperature of 900 °C can be ensured in the forming zone thus the demonstrator could be manufactured successfully.



Figure 5: Laser-assisted metal spinning facilitates successful manufacture of Inconel demonstrator in contrast with cold forming

Titanium grade 2 could basically be formed in cold condition but the forming operation resulted in cracks at the component rim due to strain hardening in the component (see Figure 6, left side). Furthermore, by cold forming only a poor dimensional accuracy could be achieved due to spring-back effect. Laser-assisted hot forming of titanium grade 2 in the range of 400 to 600 °C facilitated to improve the manufacture of the demonstrator (see Figure 6, right side). Thus a successful crack-free manufacture of demonstrators has been achieved while enhancing dimensional accuracy at the same time. In particular inside and outside diameters could be improved with regard to the nominal dimension. The deviation in roundness has been reduced from approximately 400 µm after cold forming to approximately 100 µm after laser-assisted forming. The deviation in concentricity has been improved from approximately 1500 µm after cold forming to approximately 400 µm after laser-assisted hot forming. Furthermore, surface roughness can be decreased by 50 per cent compared with cold forming.



Figure 6: Laser-assisted metal spinning facilitates crack-free manufacture of titanium demonstrator

The processing of aluminum alloy AlMg3 posed a particular challenge. Cold spinning of the material resulted in orange peel formation on the inside of the work piece and finally failure by crack formation on the rim of the work piece during processing. In contrast with the other investigated materials the required forming temperature is comparatively low with approximately 250 °C. As consequence no reliable measurement with a 2-color-pyrometer could be realized thus the process could not be operated temperature controlled. Furthermore, the material is highly reflective for the used laser radiation. In order to operate the process laser power had to be defined manually during processing. Like that formability could be enhanced and demonstrators have successfully been manufactured. With regard to deviations in concentricity and roundness the accuracy has been improved with increasing laser power. Compared to conventional manufacture with gas burner assistance the parts manufactured with laser-assisted metal spinning showed a considerably lower surface roughness. Nonetheless the facts that no reliable temperature control by means of a 2-color-pyrometer has been possible and a big amount of the applied laser power is reflected by the material hamper the applicability of laser-assisted forming for aluminum.

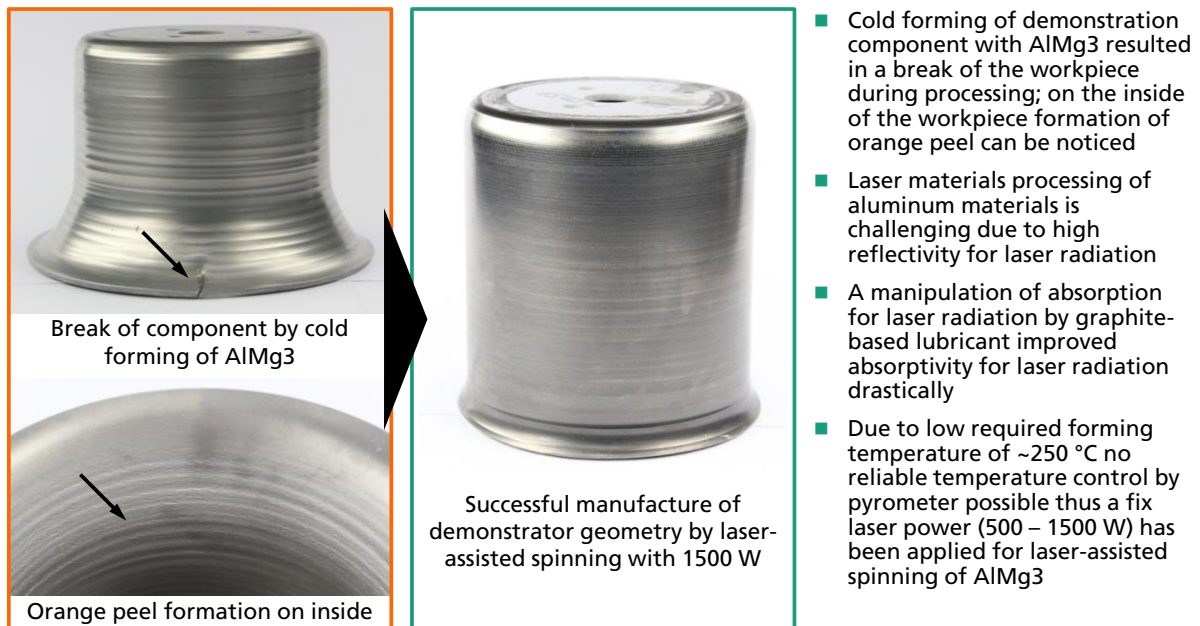


Figure 7: Laser-assisted spinning facilitates manufacture of aluminum AlMg3 demonstrator

For all materials the laser heating in combination with the applied lubricants yielded in a darkening of the surface that increased with the forming temperature. Detailed investigations showed that this darkening can be attributed to a chemical reaction (oxidation) between the lubricant and the metal surface. This surface oxidation was measured to be approx. 30 µm deep, thus it could be removed by finishing of the parts.

In order to assess the new technology »laser-assisted metal spinning« in comparison with state of the art forming technologies a case study has been defined. Therefore demonstration components made of stainless steel 1.4301 have been manufactured by deep drawing, metal spinning with intermediate recrystallization heat treatment and gas burner assisted metal spinning as reference. Like that the industrial applicability of the new technology could be evaluated on a well-grounded basis by comparison of component quality as well as production time and costs.

In workshops at facilities of the participating companies reference components have been manufactured for the technology assessment at a later date. At the facilities of Radkersburger Metallwarenfabrik GmbH components have been manufactured by metal spinning with gas burner assistance. The components were formed in 13 steps whereas steps 1 to 12 were performed with gas burner heating up to 700 °C to 800 °C and step 13 was performed without gas burner (see Figure 8).

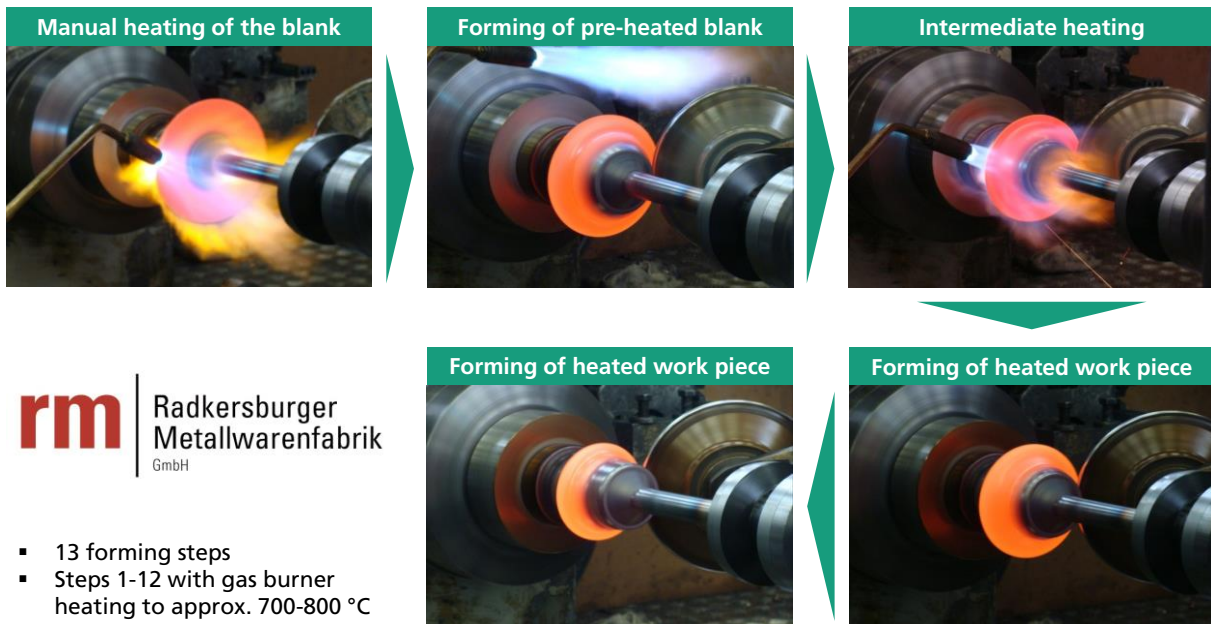


Figure 8: Manufacture of reference components by gas burner assisted spinning

At Multiform S.A.S. components have been manufactured by deep drawing in two strokes. Cutting of the seam was performed on a spinning lathe (see Figure 9).



Figure 9: Manufacture of reference components by deep drawing

At the facilities of Olsen Metal reference components have been manufactured by metal spinning with intermediate annealing in an external furnace. 12 forming steps have been performed before annealing and 2 steps after annealing (see Figure 10).



OLSEN METAL
SHEET METAL FORMING TECHNOLOGY

Route 1

- 7 forming steps
- Annealing
- 7 further forming steps

Route 2

- 12 forming steps
- Annealing
- 2 further forming steps



Figure 10: Manufacture of reference component by conventional spinning with intermediate annealing

At the facilities of Fraunhofer IPT demonstrator components made of stainless steel 1.4301 have been manufactured by laser-assisted metal spinning (see Figure 11) applying temperatures between 600 °C and 800 °C in the forming zone.



Figure 11: EasyForm demonstrators manufactured by laser-assisted spinning

The demonstrators manufactured with different forming technologies have been analyzed regarding accuracy in dimension and shape. Laser-assisted metal spinning offered the best results regarding deviations in roundness and concentricity. Regarding surface roughness the laser-assisted process offered the best values on the outside of the component. The surface roughness on the inside was comparable for all processes except spinning with intermediate annealing showed some advantage.

Compared to cold metal spinning the deformation degree could be increased by up to 65 per cent by laser-assisted metal spinning based on the knowledge that a heat treatment is required for spinning ratios (initial blank diameter divided by final blank diameter) ≥ 1.27 . The achievable deformation rate was equal to conventional spinning processes and could not be speeded up due to the limited thermal conductivity in the workpiece. Because intermediate heat treatment operations can be avoided, throughput time could be reduced from several days to some hours in the defined case study. Furthermore, the consortium could prove that the component quality regarding dimension and shape can be enhanced by the use of the new technology. In the defined case study roundness has been improved by up to factor of 15, concentricity even by up to a factor of 100 and surface roughness has been improved by up to 20 per cent.

1.4301 steel parts produced without laser but with intermediate annealing steps in external furnaces showed a considerable amount of recrystallization, i.e. a coarsening of the crystal structure. The microstructure investigations on the laser heated demonstration parts showed that the low heating times during the laser assisted spin forming did not yield a detectable recrystallization in any of the three investigated materials. Tensile tests revealed that 1.4301 steel demonstration parts formed with laser assistance showed both a higher tensile strength (attributed to strain hardening) and a higher fracture resistance (attributed to lower surface roughness) than the parts formed with gas burner assistance. It is remarkable that the (longer) gas burner assisted forming of stainless steel 1.4301 produced even darker surfaces than the (shorter) laser assisted forming of the same materials at the highest investigated temperature.

Beneath product and process specific aspects a comparison of heat treatment costs has been carried out. A calculation of heat treatment costs for the different processing routes showed that the use of a laser for heat treatment offers a significant advantage regarding variable costs. Compared to gas burner assisted spinning heat treatment costs could be reduced by 75 per cent. When comparing laser-assisted metal spinning with metal spinning with intermediate annealing at an external company the heat treatment costs per part can even be reduced more. Another advantage compared to external annealing is a significant reduction of throughput time. A general overview on the assessment of laser-assisted metal spinning in comparison to the conventional processes metal spinning with intermediate annealing, gas burner assisted metal spinning and deep drawing is shown in Figure 12.

		Annealing	Gas burner	Deep drawing
Laser-assisted metal spinning	Costs	+ Omission of external costs for heat treatment operation - Higher costs for invest	+ Reduction of energy costs by $\frac{3}{4}$ for heating operation - Higher invest for laser (250 k€) vs. invest for gas burner (1 k€)	+ Reduction of tooling costs + Improvement of flexibility + Processing of high strength materials
	Time	+ Drastic reduction of time for heat treatment + Drastic reduction of throughput time	= Comparable	+ Shorter through-put times for small batch sizes ↕ - Longer processing times for large batch sizes
	Quality	+ Improvement of accuracy in dimension & shape + Improvement of surface roughness	+ Improvement of reproducibility of heat input & reduced oxidation + Improvement of accuracy and Ra	+ Feasibility of complex component shapes + Improvement of accuracy in dimension & shape and surface roughness

Figure 12: Assessment of laser-assisted metal spinning compared to conventional processes

Figure 13 shows a more detailed comparison of the different processes. Therefore the most important aspects regarding processing time (processing time per part and time for machine set-up), costs (tooling costs, heat treatment costs per part) and component quality (surface roughness, deviations in roundness and concentricity) have been compared. Therefore standardized values have been plotted in a radar chart for each process whereat the lowest values (in the center of the plot) represent the best results. Comparing the different charts it becomes obvious that laser-assisted spinning offers clear advantages in the present study.

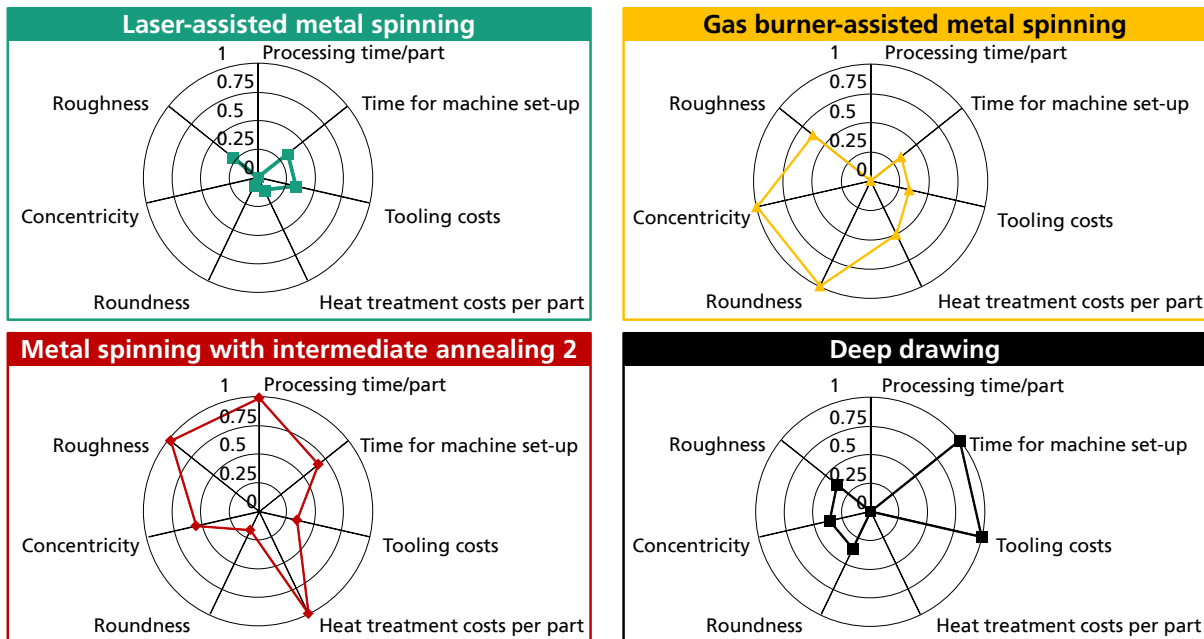


Figure 13: Evaluation of laser-assisted metal spinning compared to conventional processes

Finally, in order to qualify industrial partners' staff for the new process »laser-assisted metal spinning« a training course has been organized covering lectures about the basics of laser technology, requirements on laser safety, specifics of component analysis as well as an on-site training on the machine.

Summarizing the main advantage of laser-assistance compared to conventional ways of heat treatment during metal spinning is that the heat is applied only briefly to the area in which it is needed. In contrast to hot forming with gas burner assistance or annealing operations, the thermal load of the work piece can be reduced to a minimum and controlled accurately. This facilitates to suppress detrimental impact on the microstructure of the material while ensuring a uniform part quality at the same time. The future application of laser-assisted spinning technology represents a substantial benefit for the partners of this cooperative venture. Thus they intend to foster the industrial application of laser-assisted metal spinning. The EasyForm project has been a fine step forward to do so. Based on the achieved positive results further requirements for research have been identified. Especially the study of laser-assisted spinning of parts with big diameters and big wall thicknesses should be objective of a follow up project.

Potential impact and main dissemination activities and exploitation results

Metal spinning industry is a domain of SMEs. Considering that SMEs generate about 80 per cent of value added in the EU-27's metal products manufacturing sector¹ their importance for economy and society becomes apparent. Admittedly, new competitors from China, Russia, Brazil and India are gaining ground by being able to produce at lower costs. In order to stay globally competitive SMEs are obliged to overcome the limitations of state of the art processes by a continuous development of new technological approaches. One innovative approach for this purpose is laser-assisted metal spinning because the formability of materials can be enhanced when a laser is used to apply localized heat. Like that laser-assisted metal spinning will contribute to overcome the industries' challenge to process materials like nickel- and titanium-based alloys and other hard to form materials efficiently. Deformation degree and deformation rate will be improved significantly by using the new technology. Moreover an enormous step towards process automation can be taken by eliminating intermediate heat treatments which are conventionally used. This will improve process efficiency even further and reduce throughput times significantly. Additionally, the production quality can be enhanced, as spring back of the material can be reduced, and thus, accuracy in dimension and shape will be increased significantly. In addition, higher surface qualities of the components can be achieved. Thus, finishing work and re-work can be reduced to a minimum. By adoption of laser-assisted metal spinning the metal spinning SMEs will be able to expand markets because they can meet the increasing market demand for challenging materials.

Concluding laser-assisted metal spinning will enable SMEs to decrease production time and costs by increasing the process capability and efficiency. At the same time, product quality will be improved. Thus SMEs' competitiveness will be improved and existing markets will be expanded as SMEs will be able to augment their production capacity. In specific terms, participating SMEs indicate to expect following direct economic benefits for metal spinning industry by adoption of laser-assisted metal spinning:

- Significant reduction in manufacturing costs and throughput times
- 15 – 25 per cent increase in turnover
- 25 per cent increase in orders, which have to be rejected today

Beneath the technological improvements specified before an adoption of the new technology laser-assisted metal spinning will also have an important socio-economic impact: The European metal spinning industry will improve its stage of development drastically. With regard to new competitors in China, Russia, Brazil, India and other countries, which are able to manufacture at lower costs, European SMEs will be able to sustainably secure jobs by creating higher qualified jobs. Like that also employees benefit directly from the implementation of an innovative technology like laser-assisted metal spinning by increasing their technological knowledge. Like this the company internal knowhow is enhanced clearly.

The possibility to process new challenging materials which they have not been able to process until now, SMEs will enter new markets. Consequently they will have a need of additional staff and will therefore create further jobs. Thus innovations induced by the project EasyForm resulting in a positive economic development will help to sustainably reduce unemployment.

Taking into account the aforementioned benefits and potentials of laser-assisted metal spinning the technology will be the starting point for further developments in the future. Thus companies will have the possibility to come up with the development of new innovative products because new materials can be processed with high efficiency thus complex component shapes can be realized. SMEs have the possibility to serve their customers' needs and at the same time facilitating a high degree of freedom regarding product design. Furthermore, for many companies which have not used laser technologies in their production further fields of development arise. Beneath the benefits in production achieved by the

¹ FWC Sector Competitiveness Studies – Competitiveness of the EU Metalworking and Metal Articles Industries (2009)

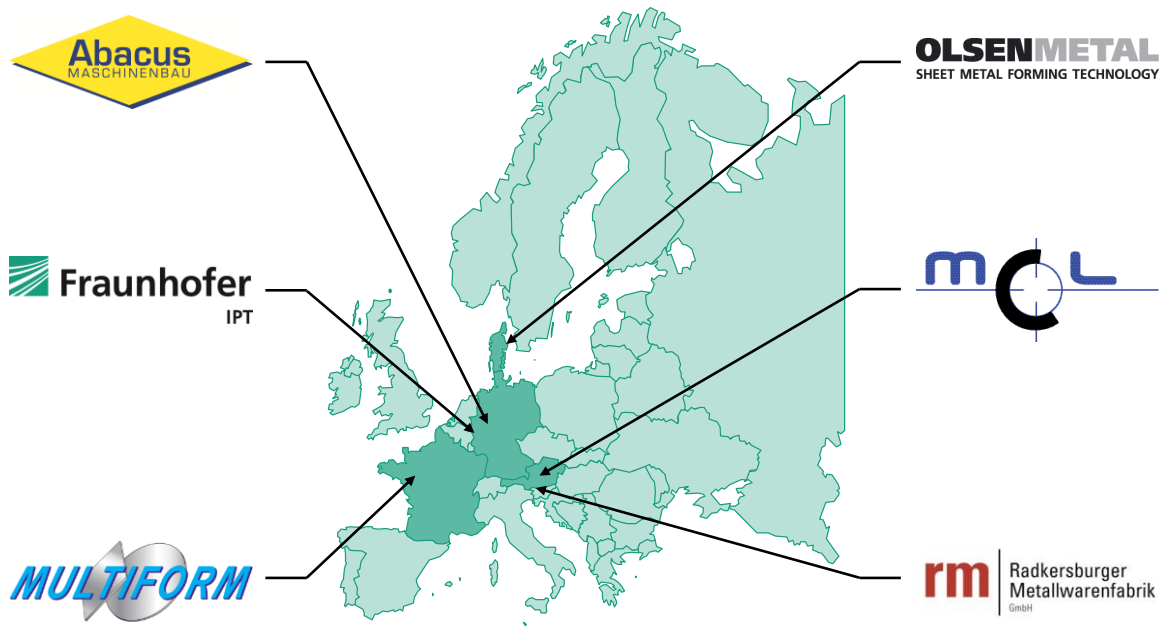
implementation of laser-assisted metal spinning the availability of a laser source offers the potential to include further processes of laser materials processing in the SMEs' production. Examples are welding, cutting or surface treatment as well as any combinations of the different processes. Like that SMEs can enhance their portfolio thus they can offer a broad service to their customers.

With regard to dissemination the project website www.easyform-project.eu has been updated. In order to communicate with a wider industrial and scientific community, non-confidential project results have been published. In order to do so, Olsen attended »Material Innovativ 2014« conference and fair in Fürth, Germany in order to promote the project. A further presentation has been realized on »International Conference on Technology of Plasticity, ICTP 2014« in Nagoya, Japan. The developed laser integration and selected project results have furthermore been presented at »Aachener Werkzeugmaschinen Kolloquium AWK 2014« and »International Conference on Turbomachinery Manufacturing ICTM 2015« in Aachen, Germany. After the end of the project a further presentation at the »International Conference on Materials Processing and Product Engineering MPPE 2015« in Leoben, Austria is planned. Beneath presentations further publications have been realized. Thus in reporting period 2 project overview has been published in the annual report of Fraunhofer IPT. Furthermore, a publication has been realized in the journal »Procedia Engineering«. A further publication is planned in the journal »IOP Conference Series: Material Science and Engineering«. Therefore an abstract has already been accepted by the scientific chair of the conference. Both journal publications are published open access in order to ensure a good visibility in the international community.

In addition the SMEs promoted the project on the international trade fairs »Midest 2013« in Paris, France, »Industrie Nantes« in Nantes, France, »ESEF« in Utrecht, Netherlands, »Hannover Messe« and »Euroblech 2014« in Hannover, Germany. After the end of the project participations on the trade fairs »Industrie Lyon« in Lyon, France and »Blechexpo« in Stuttgart, Germany are planned.

At the end of the project a project technology flyer has been created to summarize the achievements of the project for further dissemination activities. Furthermore, the industrial partners created exploitation plans for their exploitation of the project results.

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