PROJECT FINAL REPORT

Grant Agreement number: 261980

Project acronym: CAMEL-MCG

Project title: “Development of Highly Efficient and Environmentally Friendly Grinding Technology Through a Minimum coolant approach

Funding Scheme: Research for the Benefit of SMEs

Period covered: **from** 1st November 2010 **to** 31st October 2012

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[1]

Declaration by the scientific representative of the project coordinator

I, as scientific representative of the coordinator of this project and in line with the obligations as stated in Article II.2.3 of the Grant Agreement declare that:

- The attached periodic report represents an accurate description of the work carried out in this project for this reporting period;

- The project (tick as appropriate)[2]:

  X has fully achieved its objectives and technical goals for the period;
  ☐ has achieved most of its objectives and technical goals for the period with relatively minor deviations.
  ☐ has failed to achieve critical objectives and/or is not at all on schedule.

- The public website, if applicable
  X is up to date
  ☐ is not up to date

- To my best knowledge, the financial statements which are being submitted as part of this report are in line with the actual work carried out and are consistent with the report on the resources used for the project (section 3.4) and if applicable with the certificate on financial statement.

- All beneficiaries, in particular non-profit public bodies, secondary and higher education establishments, research organisations and SMEs, have declared to have verified their legal status. Any changes have been reported under section 3.2.3 (Project Management) in accordance with Article II.3.f of the Grant Agreement.

Name of scientific representative of the Coordinator: ..Juanan Arrieta.

Date: ..11../ December / .2012.

For most of the projects, the signature of this declaration could be done directly via the IT reporting tool through an adapted IT mechanism.

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[2] If either of these boxes below is ticked, the report should reflect these and any remedial actions taken.

4.1 Final publishable summary report (40 pages)

4.1.2 Executive summary

Grinding plays an important role in the development of tools and in the production of steam engines, internal combustion engines, bearings, transmissions, and ultimately, jet engines, astronomical instruments, and micro-electronic devices. This process requires very high input of energy per unit volume of work-material removed. Virtually all the energy is converted to heat, which can cause high work-piece temperature and related thermal damage such as grinding burn, phase transformation, tensile residual stresses, surface cracks, reduced fatigue strength, thermal distortion and inaccuracies. Normally, a large amount of cutting fluids is applied to improve the grinding performance. Most of the cutting fluids used are formulated from mineral oils, which are one of the most unsustainable elements of grinding processes. In addition, the chronic inhalation of oil-based mist has been shown to be responsible for serious health risks. As the environmental regulations become firmer, the cost of disposal or recycling also continues rising. As a consequence, there is a requirement to develop environmentally aware and cost-effective near dry or MQL (Minimum Quantity Lubrication) grinding processes.

MQL grinding has several key technical barriers, including the high wheel wear, limited material removal rate, work-piece thermal damage, generation of fumes, and accumulation of chips both in the grinding wheel and the machine enclosure. In the Figure 1 is shown how the consortium partners have joined their efforts to develop a new approach that improve the efficiency of the near dry methods developed till now, the MCG: **Minimum Coolant for Grinding**. MCG technique would provide to all cutting grains the required cooling fluid, in a minimal quantity but without losing effectiveness. The technique is based on the use of two nozzles, not necessarily placed very close to the grinding wheel. The first nozzle will launch an oil spray which will enter through the wheel pores. Then, the second nozzle will launch a gas which will freeze the oil or transforms it in a viscose substance in order to facilitate the adherence to the grains. In the cutting area, the frozen or adhered oil is liquefied progressively by the heat generated. In that manner, the amount of oil in the grinding zone will be higher than MQL techniques increasing the efficiency of the process.

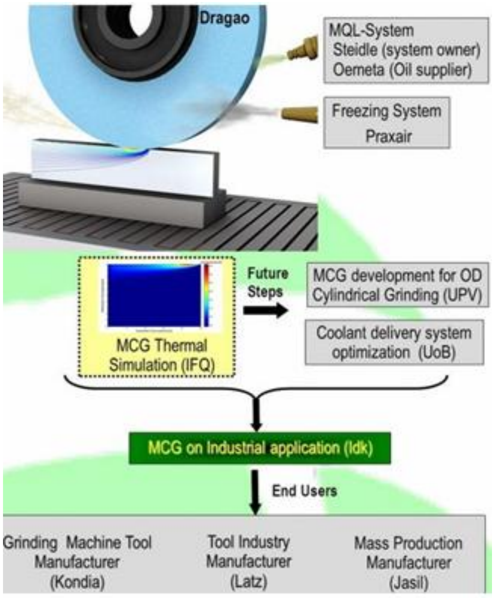


Figure 1: MCG technology description

In the first part of this project, besides the development of the MCG prototypes for different grinding operations in the RTDs facilities, simulation software able to predict the optimal MCG grinding process parameters were developed. During the trials, the forces, surface roughness, grinding wheel wear, temperatures and residual stresses were assessed for MQL, MCG and flood cooling with conventional 5% soluble oil. The experiments showed the best performance in terms of surface roughness, power consumption and wheel life was achieved by MCG. In the case of residual stresses compressive values were obtained in the MCG and MQL ground parts but with lower values than conventional flood cooling. Therefore the best surface quality was obtained with conventional techniques. In the second part of this project an intensive work was done in the industrialization of the MCG. An exhausting system composed by an industrial vacuum cleaner connected to a special nozzle able to clean both the grinding wheel and the machine closure was developed. Once the technology was optimized it was established in the end users facilities showing that MCG has a high potential to diminish production costs and improve competitiveness by dropping resource consumption and generating less waste.

4.1.3 Project context and main objectives description

Grinding is the common collective name for machining processes which utilize hard abrasive particles as the cutting medium. Nowadays, grinding is a major manufacturing process which accounts for 20-25% of the total expenditures on machining operation in industrialized countries. Society, as we know it, would be quite impossible without grinding. Almost everything that we use has either been machined by grinding at some stage of its production, or has been processed by machines which owe their precision to abrasive operations. Grinding is traditionally regarded as a final machining process in the production of extreme hardness of brittleness components requiring smooth surfaces and fine tolerances.

The grinding process requires extremely **high energy expenditure** per unit volume of material removed. These energy levels are much higher than those in machining operations. This difference can be attributed to factors such as the presence of a wear flat and chips produced with a high negative rake angle. Nearly, all of this energy is converted to heat which is concentrated within the contact zone. In fact, the production rates are often limited by grinding temperatures and their deleterious influence on workpiece. Therefore, to improve the performance the vast majority of the grinding operations are performed with the aid of a grinding fluid.

Grinding fluids are generally considered to have two main roles: lubrication and cooling. Grinding fluids can also help to keep the wheel surface clean and provide corrosion protection for newly machined surfaces. Lubrication by grinding fluids reduces the friction and wear associated with the grinding process, thereby allowing for more efficient operation with less consumption of the abrasive. Bulk cooling of the work piece by applied fluid decreases the inaccuracies associated with thermal expansion and distortion of the workpiece.

On the other hand the cost of grinding fluids is approximately 15 percent of the life-cycle operational cost of a grinding process. It includes the costs associated with procurement, filtration, separation and disposal. Already the costs for disposal of coolant are higher than the initial cost of the coolant, and they are still rising. Even stricter regulations are under consideration for coolant usage, disposal and worker protection. As a result of all of this, coolant in wet grinding operations is a **crucial economic issue**.

The **MQL** (minimum quantity lubrication) technique is gaining acceptance as a cost-saving and environmentally friendly option in place of some wet machining processes like turning and drilling. This technique is based on the avoidance of the emergence of heat by reducing the friction between tool and work piece by providing the working zone with minimum amounts of lubricant. MQL permits dramatic cuts in coolant costs: 10 – 40 ml/h in MQL vs. 30 – 200 l/min in flood cooling, while protecting workers and the environment. It also delivers improved tool life and surface finish - even though tool life is often the reason why wet machining is applied. MQL can deliver better life for two reasons: (1) the optimum concentration of lubrication can be specified for a given operation, and (2) silicon particle contamination suspended in the cutting fluid is eliminated.

MQL technique has had a very **low application in grinding** processes, since it is necessary to traverse the grinding wheel pores and these constitute a real labyrinth in a random way. This specific feature of the grinding process makes traditional MQL systems used in turning and drilling not feasible for grinding, and nowadays there are not industrial applications in this field. Throwing a small spray of lubricant over the wheel (as in MQL techniques) does not reach all the contact area and it is impossible to have proper lubrication.

The attempt of the **MCG** system (Minimum Coolant for Grinding) which will be developed in this project **solves this problem**, taking up the wheel pores with frozen lubricant. The oil is thrown by a nozzle and after a cryogenic gas from a second nozzle freezes this oil. This lubricant is fixed in the pores, close to the grains and the conglomerate, and liquefies when it arrives to the contact zone,

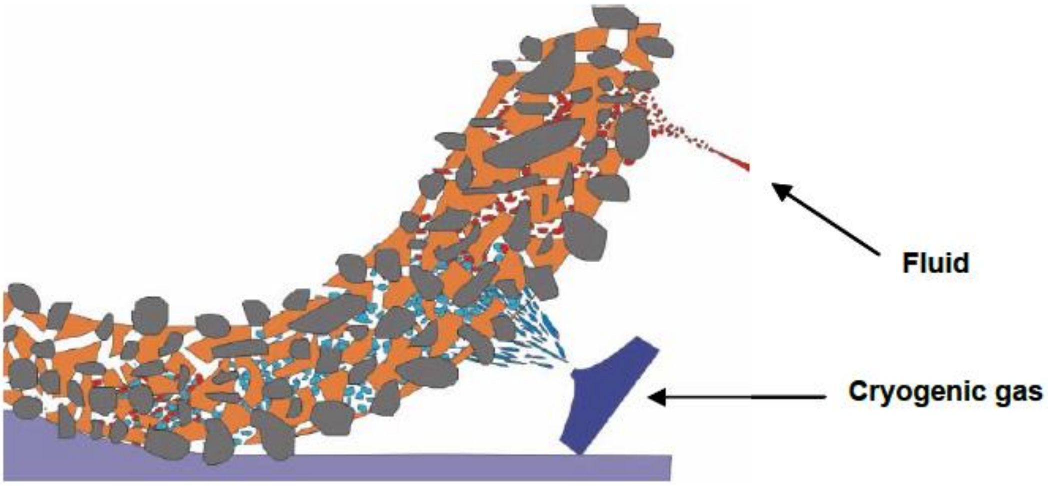


Figure 1: MCG approach; the frozen lubricant reaches efficiently the contact area between the wheel and the workpiece

cooling both the wheel and the workpiece. Lubricant freezing has not only the function of cooling, but also of fixing efficiently the lubricant to the contact area. In the figure, we can observe how the fluid enters into the pores. The cryogenic gas freezes the oil which is dragged until the cutting zone where it is liquefied again (s. Figure 1).

The **main objective** of the project is to prove that Minimum Coolant Grinding (MCG) is viable and sustainable technology in comparison to flood cooling in conventional grinding. For that an industrial case study will be evaluated in terms of the total production cost per part, covering all sustainability measures.

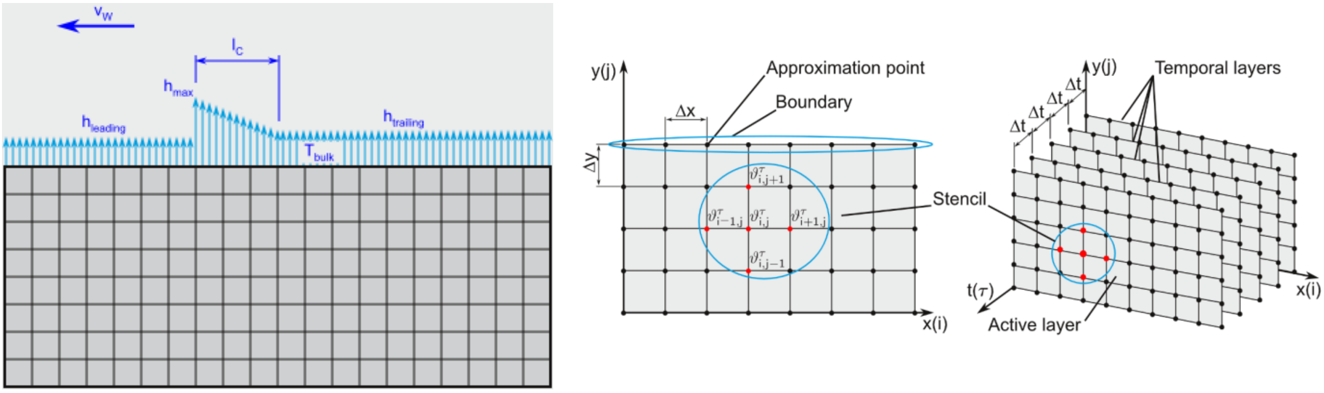
The MCG technique is conceptually simple, but the success of its application depends on several factors that must be independently analyzed, although all of them are at the end jointly implemented on the industrial prototype:

- ✓ Nozzles, both are different; one is for gas and the other for oil spray.
- ✓ Gas flow, speed and temperature.
- ✓ Grinding wheel features. The bonding system of the grains must be adequate.
- ✓ Lubricant. Coolant speed, characteristics at high and low temperatures, freezing point, and facility to be adhered with the abrasive grains and the bonding.
- ✓ Exhausting system to eliminate the waste generated during grinding in near dry conditions.

4 Main S&T results/foregrounds (25 pages)

Along the CAMEL-MCG project life, the research performed by the partners has both theoretical and experimental activities, supported by industrial evaluations at the beneficiaries' shop floor and production systems.

For the first period of the project (Month 0 to Month 9), performed activity had a big component of **theoretical analysis of the heat transmission on the grinding zone**, as it is critical to characterize appropriately the technology. The wrong selection of setting parameters can cause thermal damage of the workpiece surface and significant rise of manufacturing costs. For this reason, fundamental understanding of the grinding process, especially the physical phenomena in the contact zone, is a key factor for a productive machining with grinding wheels.



(a) (b)

Figure 2: (a) Model of the heat transfer coefficient used for the simulation; (b) Spatial (left) and temporal (right) discretization of continua for two dimensions.

The **finite difference model** developed by **Magdeburg University** represents a flexible solution of different combinations of boundary conditions for the analysis of the thermal phenomena in the workpiece during a grinding process. For the solution of the heat equation, the finite difference method (FDM) has been used. In direct comparison of FDM with the analytical model by Carslaw and Jaeger, the FDM is more flexible and allows solving of the problem on finite domain. The basic scheme of the FDM model is shown in Figure 2a. The principle of the model is very similar to the analytical model by Carslaw and Jager, however the dimensions of the workpiece are finite and the boundary conditions can be easily implemented.

The developed model is based on the replacement of the partial derivatives in the heat equation 1 by finite differences.

$$\frac{\partial\vartheta}{\partial t} = \frac{k}{\rho c_p}\left(\frac{\partial^2\vartheta}{\partial x^2}+\frac{\partial^2\vartheta}{\partial z^2}\right)=\kappa\left(\frac{\partial^2\vartheta}{\partial x^2}+\frac{\partial^2\vartheta}{\partial z^2}\right) \tag{1}$$

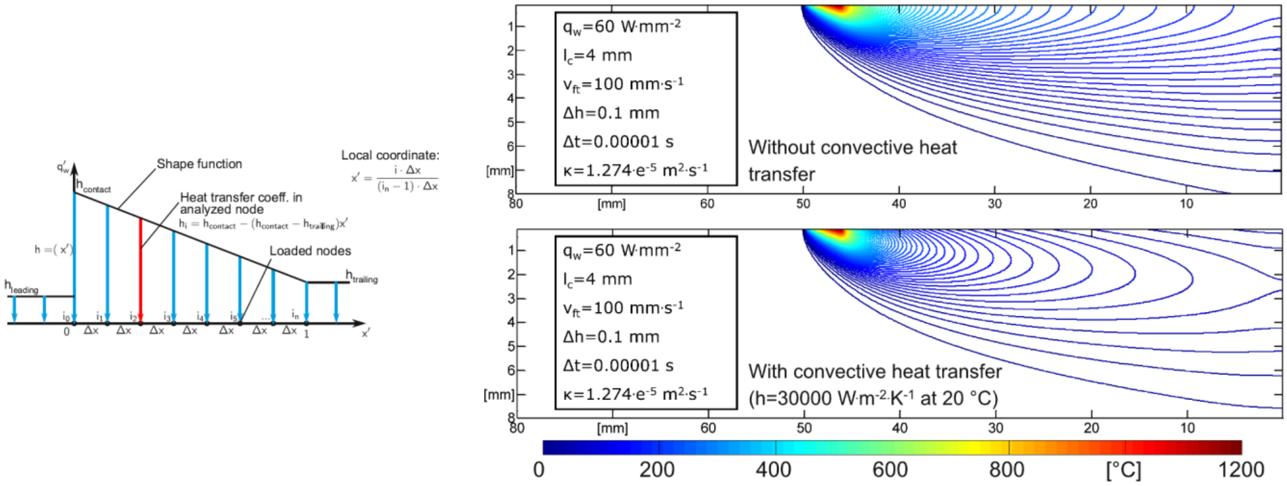
Geometrical representation of FCTS scheme is shown in Figure 2b. The computation is realized by a stepwise movement of a five-point stencil in parallel oriented time layers. An advantage of this computation scheme is a simple implementation, because none system of algebraic equation must be solved.

The forward time central space differentiation (FCTS) scheme has been used for the discretization of the heat equation (s. Figure 2b). This scheme represents a basic FDM principle, where the forward difference is used for the replacement of the partial derivation of the time. The spatial partial derivations are replaced by centred finite differences as follows (2). Geometrical representation of FCTS scheme is shown in Figure 2b. The computation is realized by a stepwise movement of a five-point stencil in parallel oriented time layers.

$$\vartheta^{\tau+1}_{i,j} = \vartheta^{\tau}_{i,j}+\Delta t\kappa\left[\left(\frac{\vartheta^{\tau}_{i-1,j}-2\vartheta^{\tau}_{i,j}+\vartheta^{\tau}_{i+1,j}}{\Delta x^2}\right)+\left(\frac{\vartheta^{\tau}_{i,j-1}-2\vartheta^{\tau}_{i,j}+\vartheta^{\tau}_{i,j+1}}{\Delta y^2}\right)\right] \tag{2}$$

For the modeling of entering heat flux, the rectangular and triangular distribution can be used. The different values of coefficient of the heat transfer for leading and trailing edge of the contact zone can be used for the modeling of **convective cooling**. The incorporation of the refrigeration parameters in developed model has been realized by application of the linear interpolated coefficient of the heat transfer within the contact zone allows the precise control of the maximal achievable temperature (s. Figure 3a).

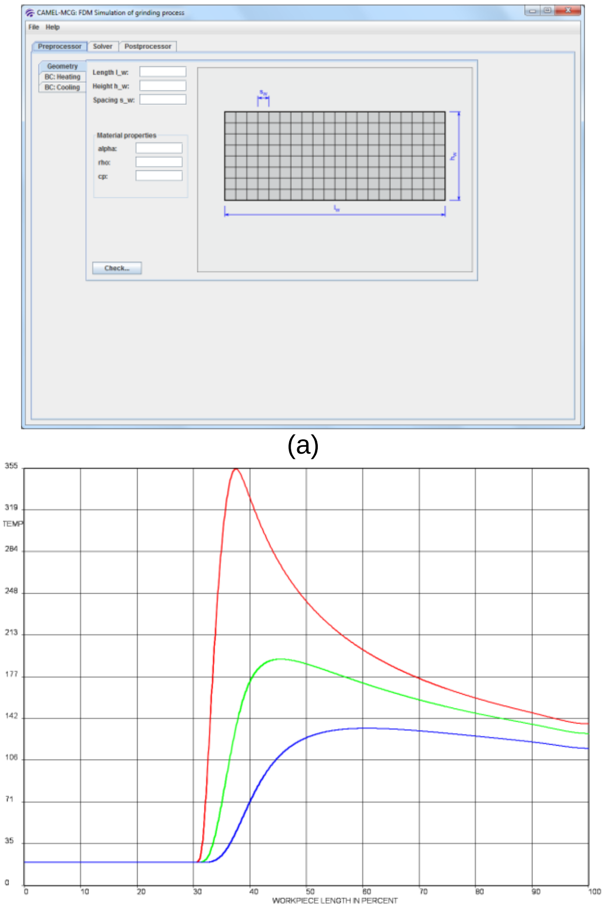
From the experimental data has been found that the heat transfer coefficient is about 25000 $W\cdot m^{-2}\cdot K^{-1}$, for the MQL grinding process and 40000 $W\cdot m^{-2}\cdot K^{-1}$ for the wet grinding. In the Figure 3b is possible to see the influence of the refrigeration on the temperatures field.



(a) (b)

Figure 3: Influence of the heat transfer coefficient in the contact zone on the temperature field in workpiece.

The algorithm for solving the heat equation by the finite difference method has been programming in JAVA language and can run on any java virtual machine regardless of computer architecture. In the Figure 4a-b the Graphical User Interface (GUI) developed to introduce the input parameters like geometry and material properties of the workpiece simplify the utilization of the solution algorithms is presented. On the other hand the visualization data where can be visualized the maximum temperatures achievable is shown in the Figure 4c.



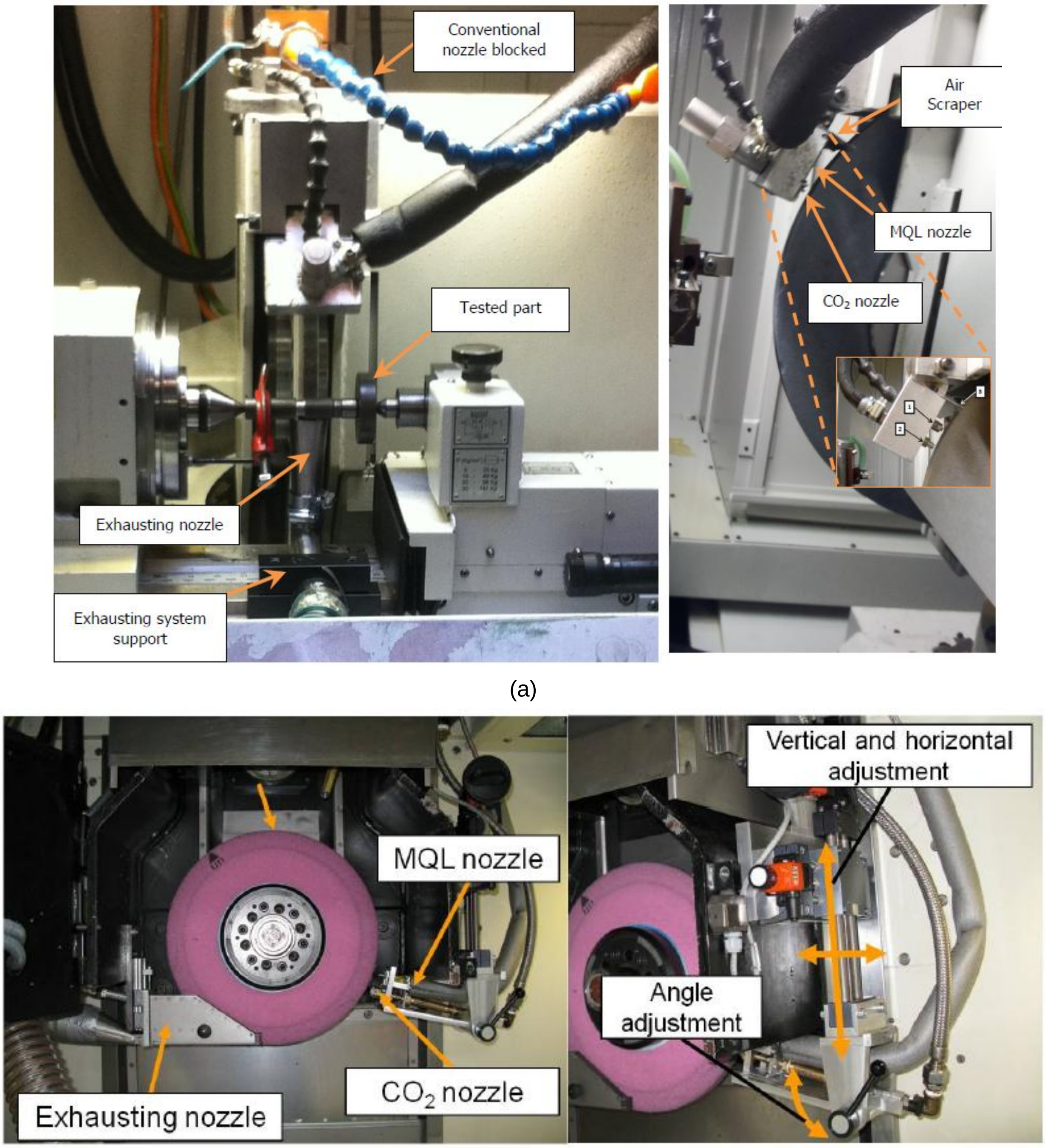
(a)

(b)

Figure 4: Java programming Graphical User Interface for the simulation software developed: (a) assistant to define the geometry of the workpiece; (b) 2D simple graph with the temperatures in different depth of the workpiece.

The second main objective for this first period has been the setting up of the different mechanical elements that will be fundamental on the optimum performance of the MCG process. In the following figures are shown the MCG prototypes set up in the cylindrical grinder located at Basque Coutry University and ready to assess the maximum performance of the new technology. The prototype for the surface grinding evaluation was installed in Bremen University.

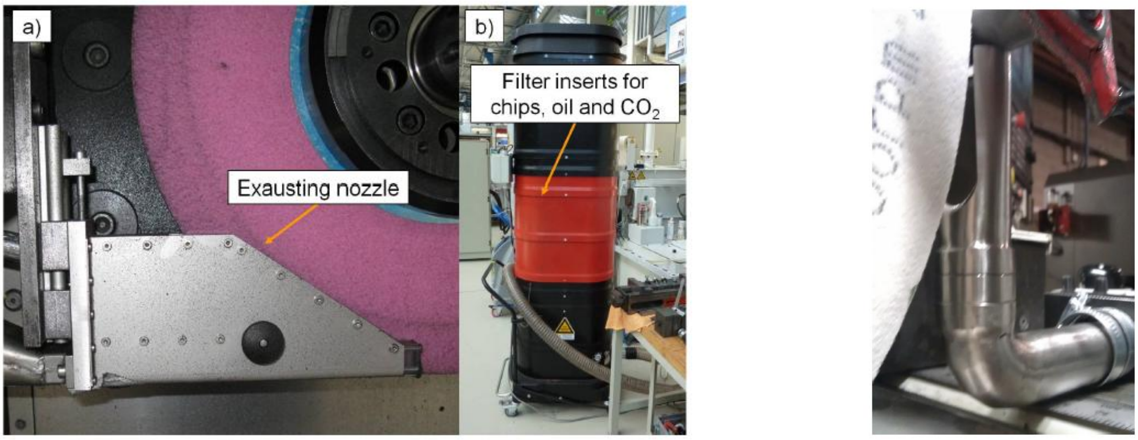
Prior to analyze the performance of the technology another important role must be solved: how to remove the metallic chips and the dust generated by the wheels wear. The solution developed by Ideko and Bremen for cylindrical and surface grinding respectively has the same principle that consists in connect a special nozzle to an industrial vacuum cleaner equipped with filter inserts for extracting chips, oil mist and CO_2 out of the working room (s. Figure 6a-b).



(a)

(b)

Figure 5: (a) Implementation of the MCG on the OD grinder (UPV); (b) MCG in the surface grinder (UoB).

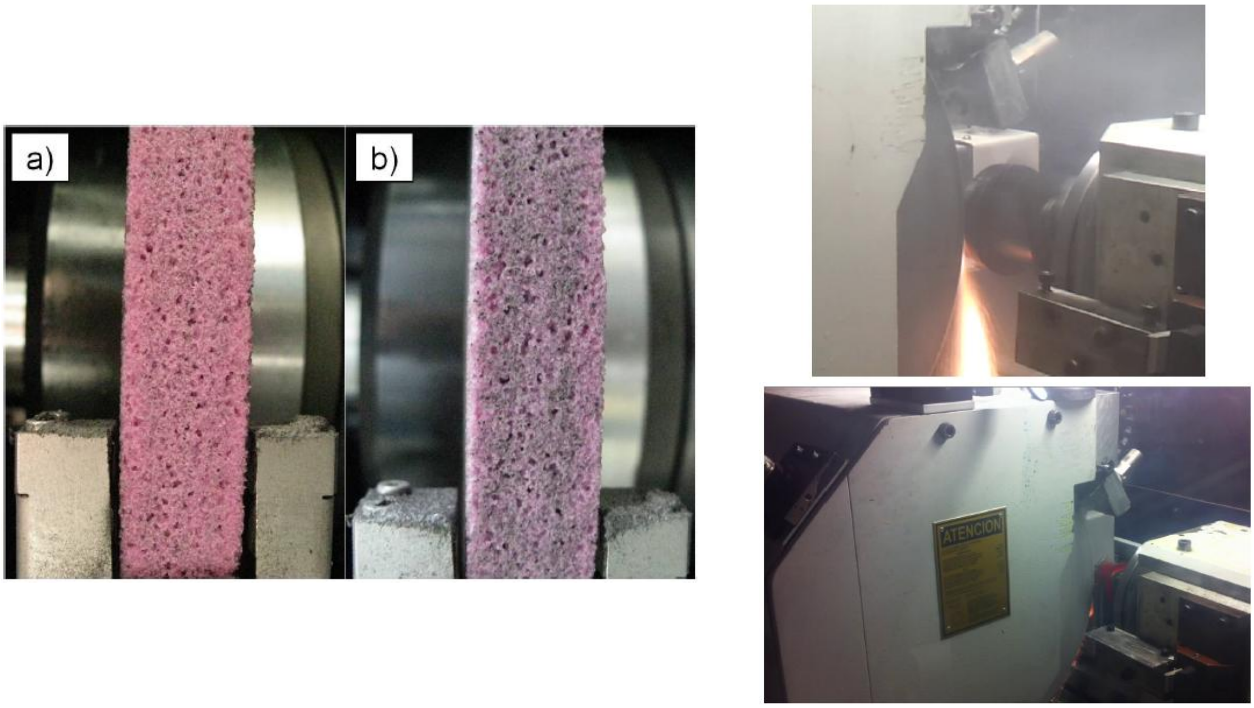


(a) (b)

Figure 6: (a) Wheel loading after grinding with and without exhausting system activated; (b) The same case during the cylindrical grinding operation.

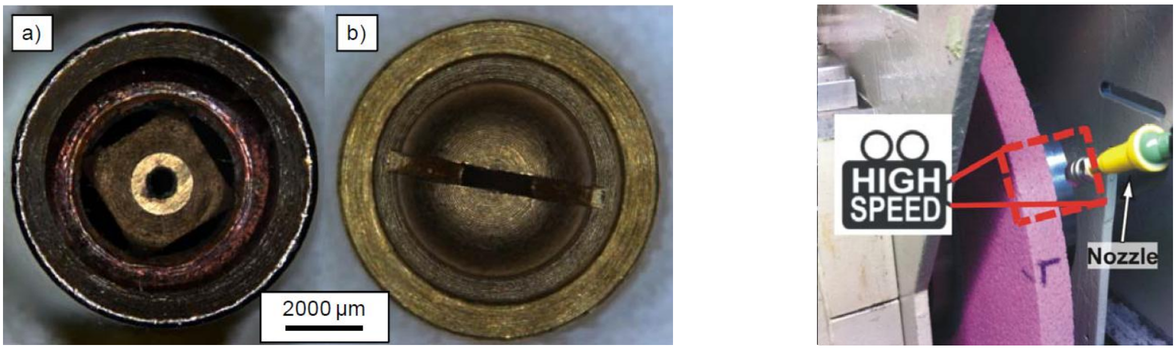
To evaluate the cleaning effect of the exhausting system, grinding tests with and without vacuum cleaning have been performed and the wheel load has been assessed (s. figure 7a-b). It can be taken from the pictures that after grinding without using the exhausting system a high amount of chips can be detected on the wheel surface.

Once the complete prototypes with the MGC technology have been developed for both cylindrical and surface grinding, they were ready to assess the maximum ability of the process. The first task developed in that field was the selection of the best shape for the MQL and the CO_2 supply nozzles. The shape of the coolant jet and the spray behaivour for the differente nozzles have been investigated by high speed videos (s. Figure 8). Furthermore, the CO_2 flowrate dependent on the gas pressure was examined as well as the temperature for certain distances after the nozzle orifice



(a) (b)

Figure 7: (a) Wheel loading after grinding with and without exhausting system activated; (b) The same case during the cylindrical grinding operation.



(a) (b)

Figure 8: (a) Different shapes of the nozzle tested for the supply of the MQL oil; (b) Scheme of the setting up with the high speed camera for assessing the best shape of the oil sprayed.

For the determination of jet shape and spray behavior the air supply and the air pressure at the MQL supply system were varied. An investigation by STEIDLE regarding the influence of the air supply and air pressure adjusted by a regulating valve has shown that with increasing air supply and pressure the flowrate of air also increases. An almost steady state of the flowrate is reached with 1.25 turns of the regulation valve for air supply independent from air pressure.

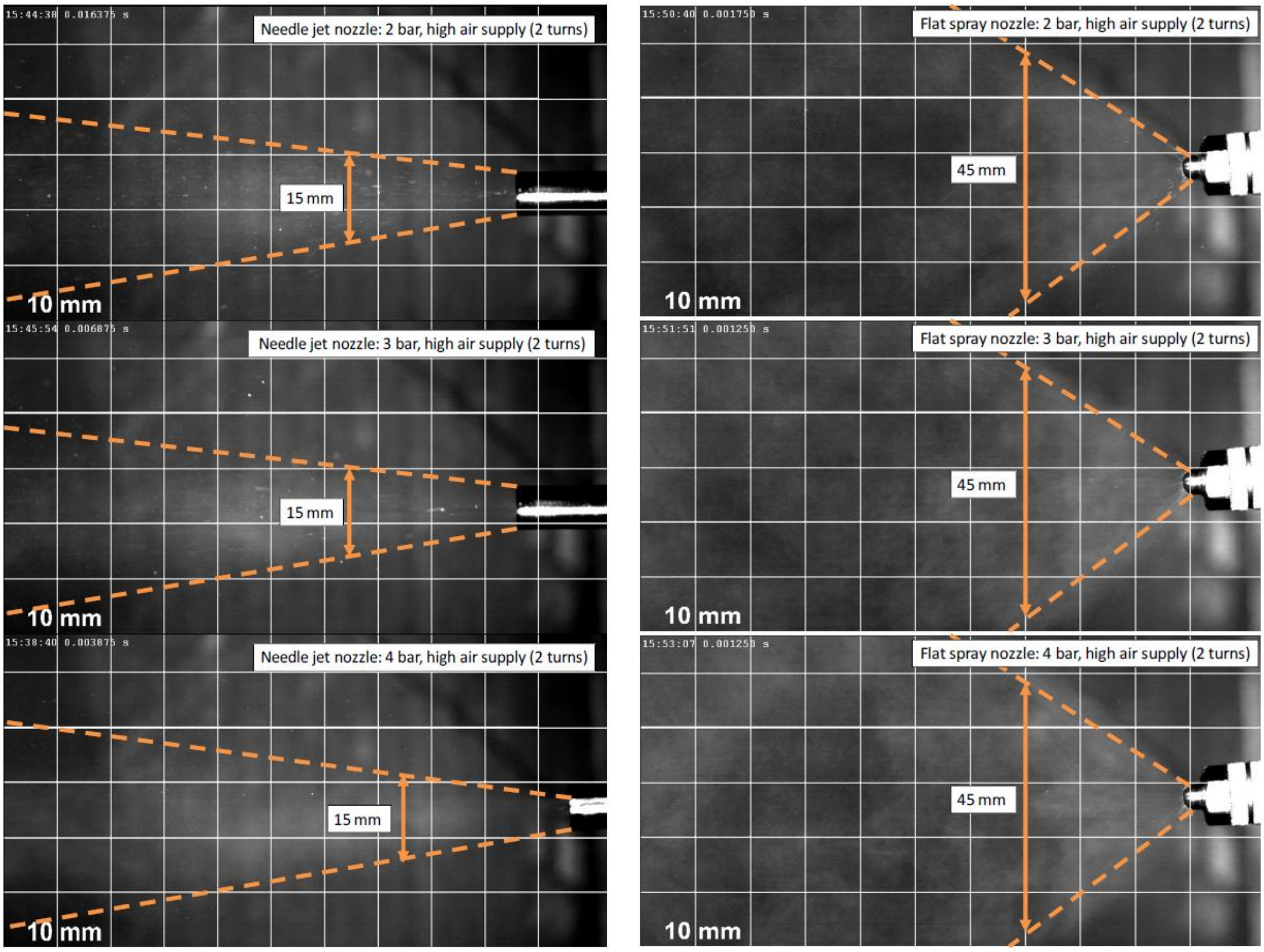
At low air supply of the MQL system a constant oil supply over the cross section of the oil spray cannot be achieved. Drop sizes of up to 1 mm for the needle jet nozzle and 0.8 mm for the flat spray nozzle have been observed at what the drop velocity was quite low. Thus, for both nozzles a low air supply has been considered to lead to a non-uniform moistening of the grinding wheel during the process. A jet width of 15 mm in a distance of 30 mm after the nozzle orifice can be determined for the needle jet nozzle, for the flat spray nozzle a width of 45 mm of the jet has been measured.

In the following, the results for a high air supply with varying air pressure will be discussed. In Figure 9 exemplary high-speed images of the needle jet nozzle are illustrated. The high-speed videos have shown that with increasing air pressure a uniform aerosol generation and a smaller drop size can be noticed which can also be seen in Figure 9. Furthermore, with increasing air pressure the jet speed is also increasing, but a determination of the jet speed according to the air pressure was not possible due to the small drop size.

In contrast to the findings regarding the needle jet nozzle, the high-speed videos of the flat spray nozzle have shown that the jet speed is nearly independent from the air pressure. In addition to that, a nearly uniform aerosol generation, with few bigger drops occurring, can be determined with an air pressure of 2 bar. In the case of an air pressure of 3 bar a higher amount of bigger drops have been detected within the oil spray.

In the case of MQL oil supply nozzles the jet needle nozzle has been chosen for the following grinding tests in work package 3. This nozzle enables a long distance between the nozzle orifice and the impact of the oil on the grinding wheel, especially in the case of surface grinding. In this regard, the flat spray nozzle generates the loss of a high amount of overspray due to the spray width of 45 mm in a distance of 30 mm after the orifice. With regard to environmental aspects, the flat spray nozzle has the advantage of decreased air consumption during the process due to the fact that an adequate and uniform aerosol generation can be achieved by adjusting an air pressure of 3 bar. This would lead to a reduction of up to 18% regarding the air consumption. However, the flat spray nozzle is more suitable for outer-diameter grinding processes due to a shorter distance between the grinding wheel and the MQL oil supply nozzle.

Comparable to the investigation of the MQL oil supply nozzles, different nozzles for CO2 supply have been assessed using high-speed videos. Two nozzles have been analyzed the GAM 1190



(a) (b)

Figure 9: (a) Different shapes of the nozzle tested for the supply of the MQL oil; (b) Scheme of the setting up with the high speed camera.

from the company PNR suggested by PRAXAIR and the nozzle type 2507 from the company Lechler.

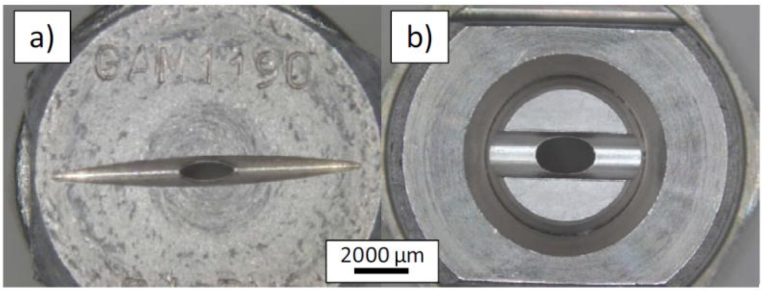


Figure 10: Different shapes of the nozzle tested for the supply of the CO_2: (a) GAM 1190; (b) Lechler 2507.

As can be seen in the following figure the nozzle Lechler 2507 is characterized by a strong jet expansion in a distance of up to 30 mm. Considering a grinding wheel width of 20 mm and a distance between the grinding wheel and the CO_2 supply nozzle of more than 20 mm during the surface grinding tests, the nozzle Lechler 2507 is rather applicable against the nozzle GAM 1190 despite a high amount of overspray.

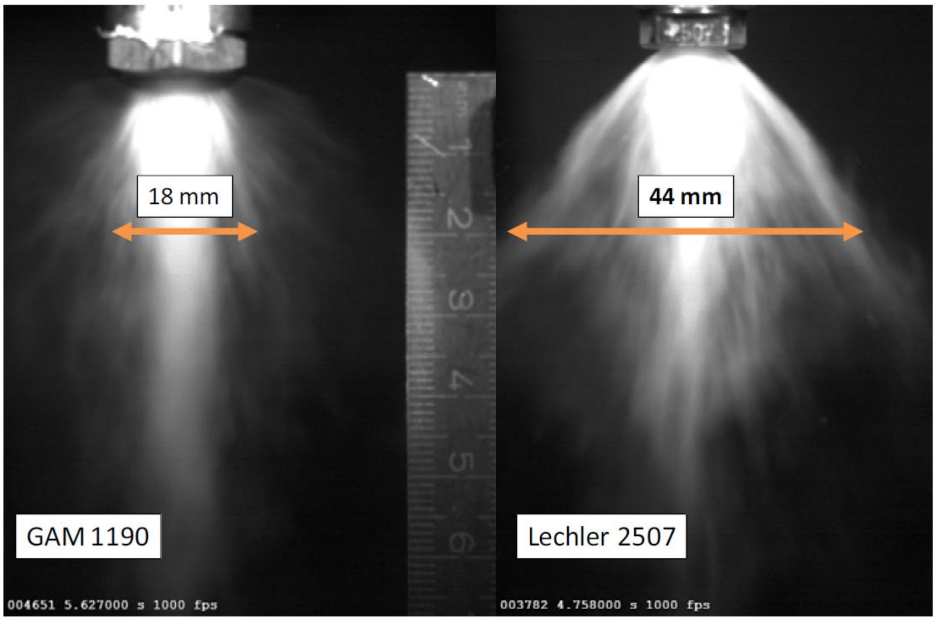


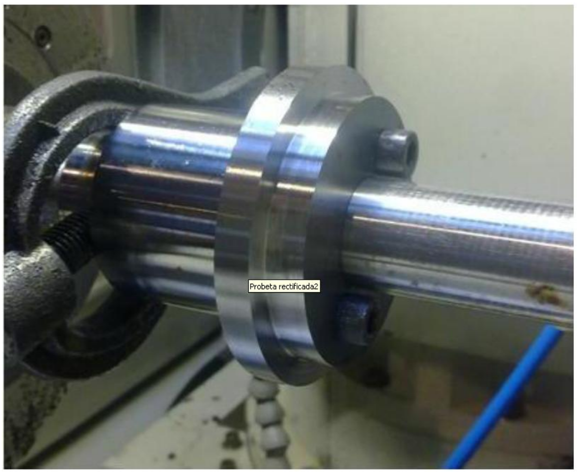
Figure 11: Shape of the oil sprayed with the GAM and Lechler nozzles.

In the next section a summary of the work done by the UPV to find the optimal MCG grinding parameters for outer diameter cylindrical parts is presented. Characterization of performance of a given grinding configuration involves studying aspects such as wheel wear and specific grinding energy.

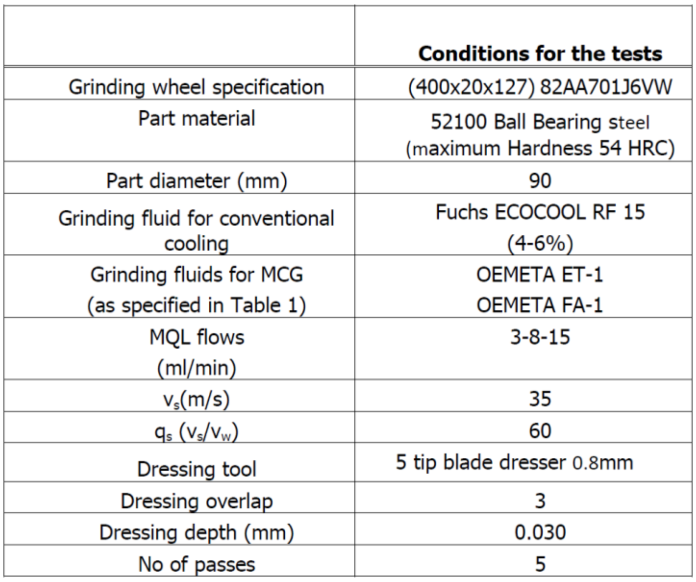
The diameter of the specimen was 90mm. In order to find the limits of the technology tests roughing grinding test were performed with differents specific material removal rates Q'_W of 3 and 5 $mm^3/s \cdot mm$.

Using these parameters the influence of the following variables has been analyzed:

- The nature of the MQL oil provide by OEMETA: FA1 and ET1.
- MQL flow: fl1=3 ml/min; fl2=8 ml/min; fl3=15 ml/min.
- CO_2 consumption: fl1=1 Kg/min; fl2=0.6 Kg/min; fl3=0.4 Kg/min; fl4=0.2 Kg/min.



(a)



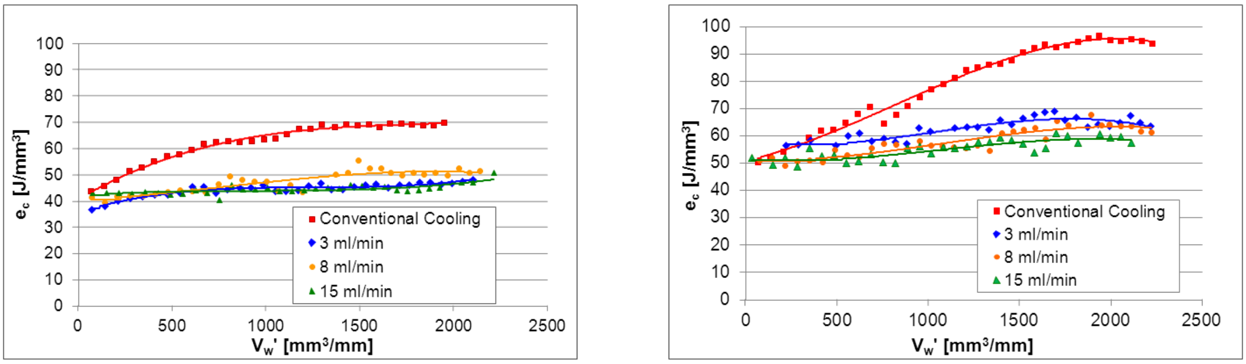
	Conditions for the tests
Grinding wheel specification	(400x20x127) 82AA701J6VW
Part material	52100 Ball Bearing steel (maximum Hardness 54 HRC)
Part diameter (mm)	90
Grinding fluid for conventional cooling	Fuchs ECOCOOL RF 15 (4-6%)
Grinding fluids for MCG (as specified in Table 1)	OEMETA ET-1 OEMETA FA-1
MQL flows (ml/min)	3-8-15
v_s(m/s)	35
q_s (v_s/v_w)	60
Dressing tool	5 tip blade dresser 0.8mm
Dressing overlap	3
Dressing depth (mm)	0.030
No of passes	5

(b)

Figure 12: (a) Outer diameter cylindrical part ground; (b) Grinding test data.

Radial wheel wear was measured after each set of 5 experiments, so that the evolution of wheel material lost V'_s(mm^3/min) vs part material removed V'_w(mm^3/min) has been obtained. From these curves the grinding ratio G for each parameter combination has been calculated, from which comparison of wheel life between the different lubrication conditions can be established. The efficiency of the removal mechanism has also been addressed in terms of specific grinding energy e_s(J/mm^3) vs part material removed V'_w(mm^3/min). For doing so, power measurements during the grinding experiments have been carried out using a Load Controls Inc. Model UPC adjustable capacity power sensor.

In the following figures its showed the main results obtained. In the figure 13 is analyzed the influence of the MQL flow in the efficiency of the process. From these charts a lower values of specific energy for MCG compared to flood Cooling has been noticed. This difference is bigger as the oil flow is increased. On the other hand higher severity of the process implies better performance of the MCG.

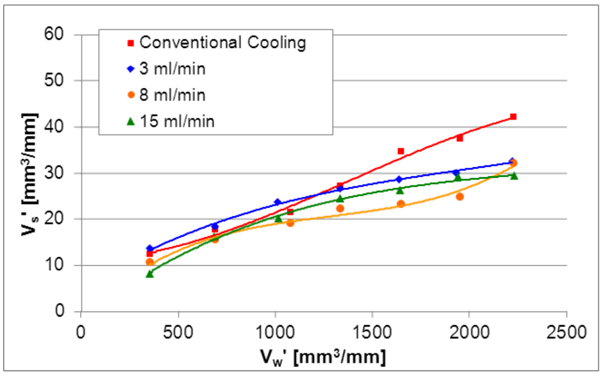


(a) (b)

Figure 13: Specific energy vs. number of workpieces ground for: (a) FA1 oil type, f_{CO2}=1kg/min, Q’= 5mm^3/mm·s; (b) FA1, f_{CO2}=1kg/min, Q’= 3mm^3/mm·s.

In the figure 14 differents values of G-ratio are presented for a Q'_w of 3 mm^3/mm·s concluding higher wear is observed with flood cooling. The best G ratio was achieved with a oil flow of 8ml/min. As can be seen in the Figure 14 b lower G-ratios are obtained but with similar tendency.

In order to analyse the influence of the formulation of two oils provided by OEMETA: FA1 (fatty alcohol) and ET (ester oil) the same previous analysed has been done. In the figure 15 the grinding ratio comparison shows that OEMETA ET-1 produces an impressive improvement not only with respect to conventional cooling, but also with respect to OEMETA FA-1.



G-ratios

Q'_w=3	
Conv. Cooling	60
fl_1 = 3ml/min	100
fl_2 = 8ml/min	120
fl_3= 15ml/min	120

Q'_w=5	
Conv. Cooling	32
fl_1 = 3ml/min	37
fl_2 = 8ml/min	50
fl_3= 15ml/min	50

Figure 14: Grinding wear results with the following MCG conditionsFA1 oil type, f_{CO2}=1kg/min, Q’= 3mm^3/mm·s

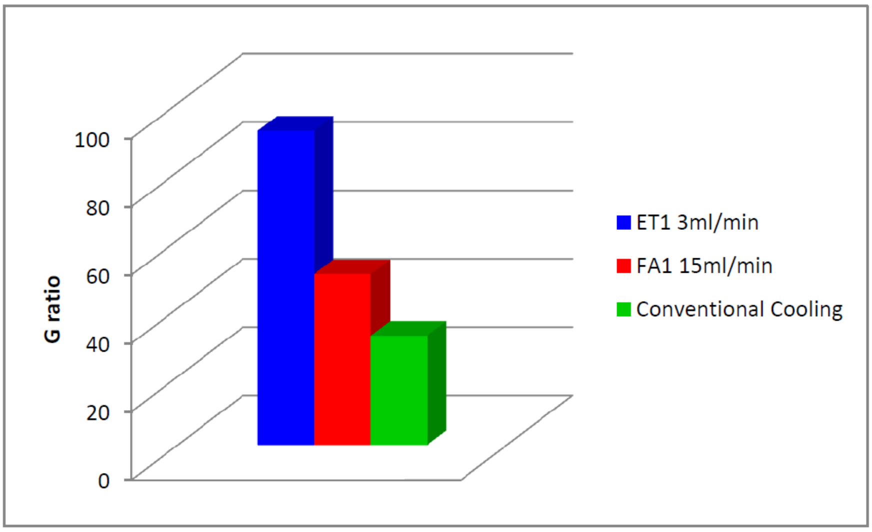
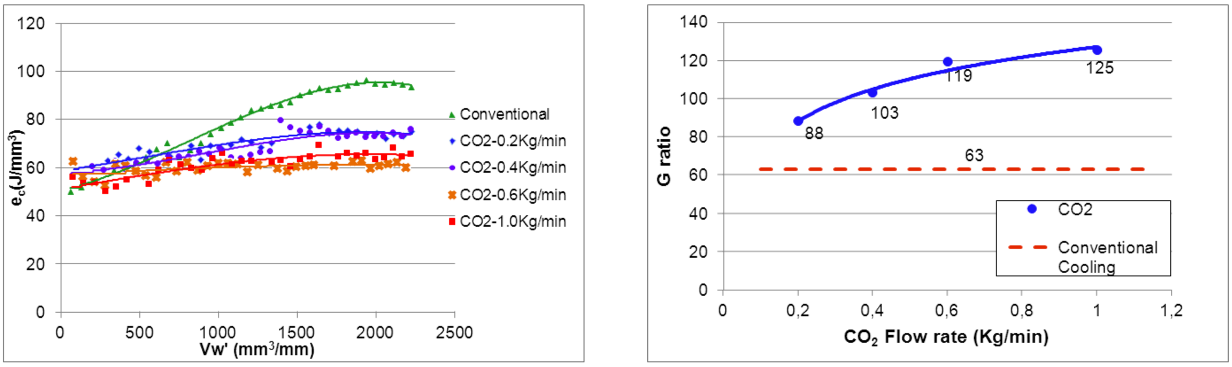


Figure 14: Grinding ratio of the MCG system when using OEMETA FA-1 (8ml/min) and OEMETA ET-1 (3ml/min) and grinding ratio with conventional cooling. Results for Q’=5mm$_3$/s·mm.

Another important variable to depict is the flow of the CO_2 for that similar results have been done varying the flow rate from 1 to only 0.2 Kg/min. The best results as can be extracted from the figure 15 has been obtained with a flow rate of 0.6 Kg/min.



(a) (b)

Figure 14: Grinding results for different CO_2 flow rates: OEMETA FA-1 (8ml/min) for Q’=3mm$_3$/s·mm.

Finally, the drastic reduction of coolant has the risk of an excessive increase of temperatures which could cause thermal damage. In order to see if the worpieces have suffered from burning, it has measured residual stresses on specimen surfaces using X-Ray difractometry.

The results are shown in Figure 15. It can be seen that in the case of the parts ground using conventional cooling the main stress σ_2 is clearly compressive, whilst σ_1 is near zero. In the case of the parts ground using the MCG technology, σ_2 is always compressive but of a lower value than in conventional grinding. Although σ_1 is positive (tensile), a clear trend can be observed that correlates the nature of this main residual stress with the flow of CO_2. When increasing the gas flow the value of the tensile stress is reduced. In other words, the deleterious effect of grinding temperatures decreases when gas flow is increased. That means the process is not valid for roughing operations.

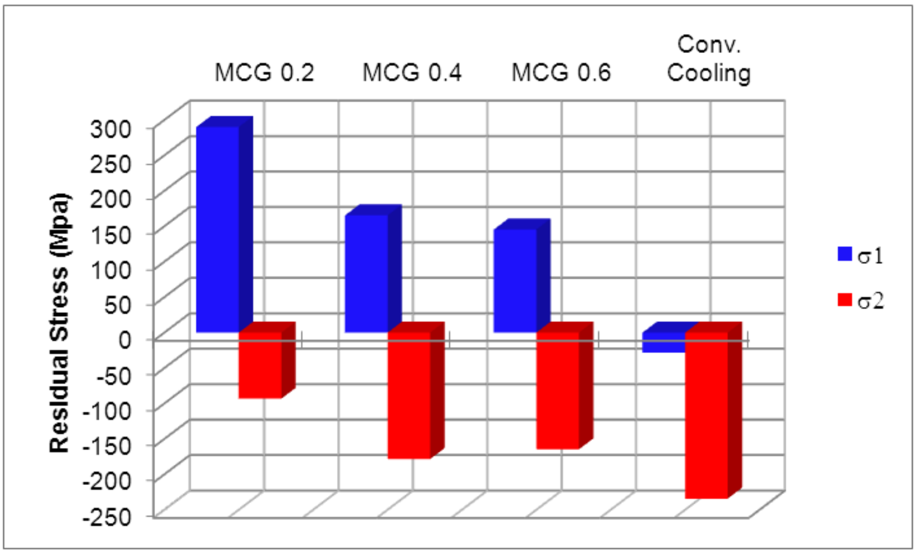


Figure 15: Residual stresses Measurements on ground surfaces with 8ml/min oil flow and variable CO2 flow. Q'_w = 3 mm3/s·mm.

After this analysis the optimal MCG conditions are:

- Oil Type: OEMETA ET1.
- MQL flow: fl2=8 ml/min.
- CO_2 consumption: fl2=0.6 Kg/min.
- Only valid for **fine finishing operations** with Q'_w lower than 3 $mm^3/s·mm$.

Similar methodology was followed by UoB to define the optimal setting parameters of the MCG for surface grinding. In the Figures 16-17 is recorded the main results that reflects damage free grinding when the part is down-ground with lower depth of cuts and high feed speeds. In the surface operation similar performance in terms of surface finish and power consumption of both coolant supply methods has been achieved

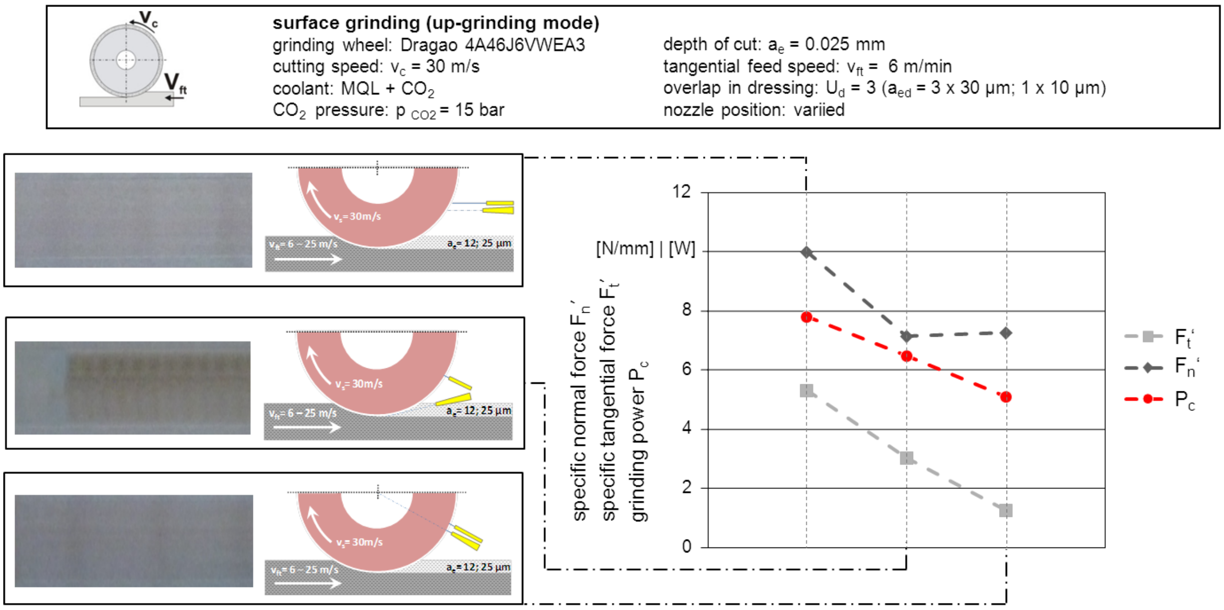
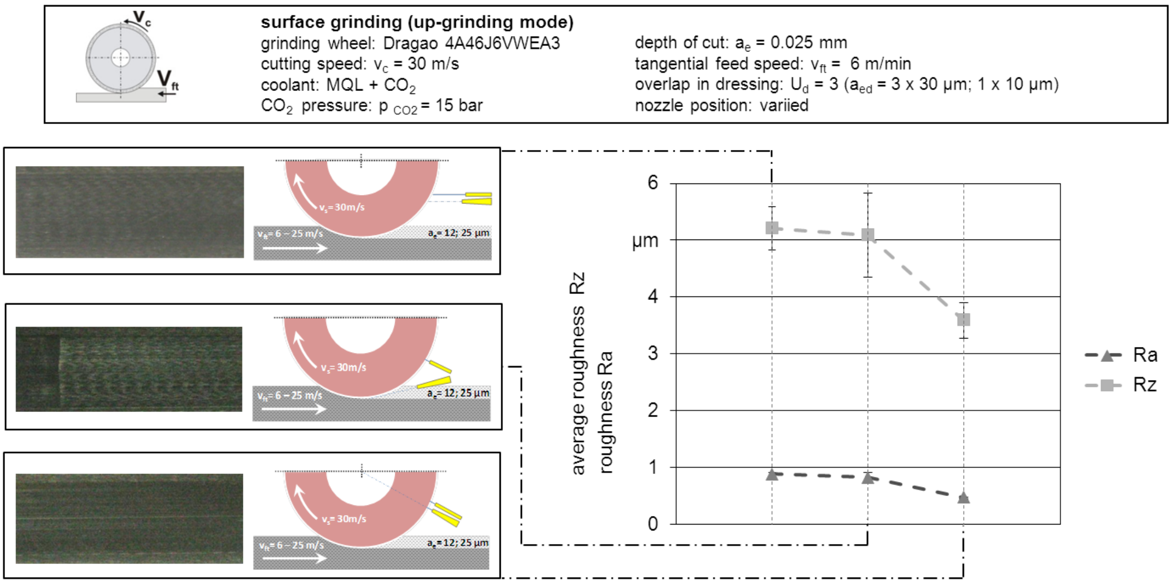

surface grinding (up-grinding mode)
grinding wheel: Dragao 4A46J6VWEA3
cutting speed: v_c = 30 m/s
coolant: MQL + CO_2
CO_2 pressure: p_{CO2} = 15 bar
depth of cut: a_e = 0.025 mm
tangential feed speed: v_{ft} = 6 m/min
overlap in dressing: U_d = 3 (a_{ed} = 3 x 30 µm; 1 x 10 µm)
nozzle position: variied

Figure 16: Impact of the MCG on the grinding forces.



surface grinding (up-grinding mode)
grinding wheel: Dragao 4A46J6VWEA3
cutting speed: v_c = 30 m/s
coolant: MQL + CO_2
CO_2 pressure: p_{CO2} = 15 bar
depth of cut: a_e = 0.025 mm
tangential feed speed: v_{ft} = 6 m/min
overlap in dressing: U_d = 3 (a_{ed} = 3 x 30 µm; 1 x 10 µm)
nozzle position: variied

Figure 17: Impact of the MCG on the roughness and the surface integrity by nital etching.

The final technical step of the project has been the industrial validation done in the Jasil facilities. In the Figure 18 appears the part ground with the new technology. The OD part was ground in the cylindrical grinder of Jasil in Portugal whereas the connecting rod was ground in the facilities of Bremen University.

The first step was the installation of the MCG equipment: MQL, CO2 injection system, exhausting nozzle to clean both the wheel and the machine and the industrial vacuum cleaner in the grinder located in Jasil (See Figure 19).

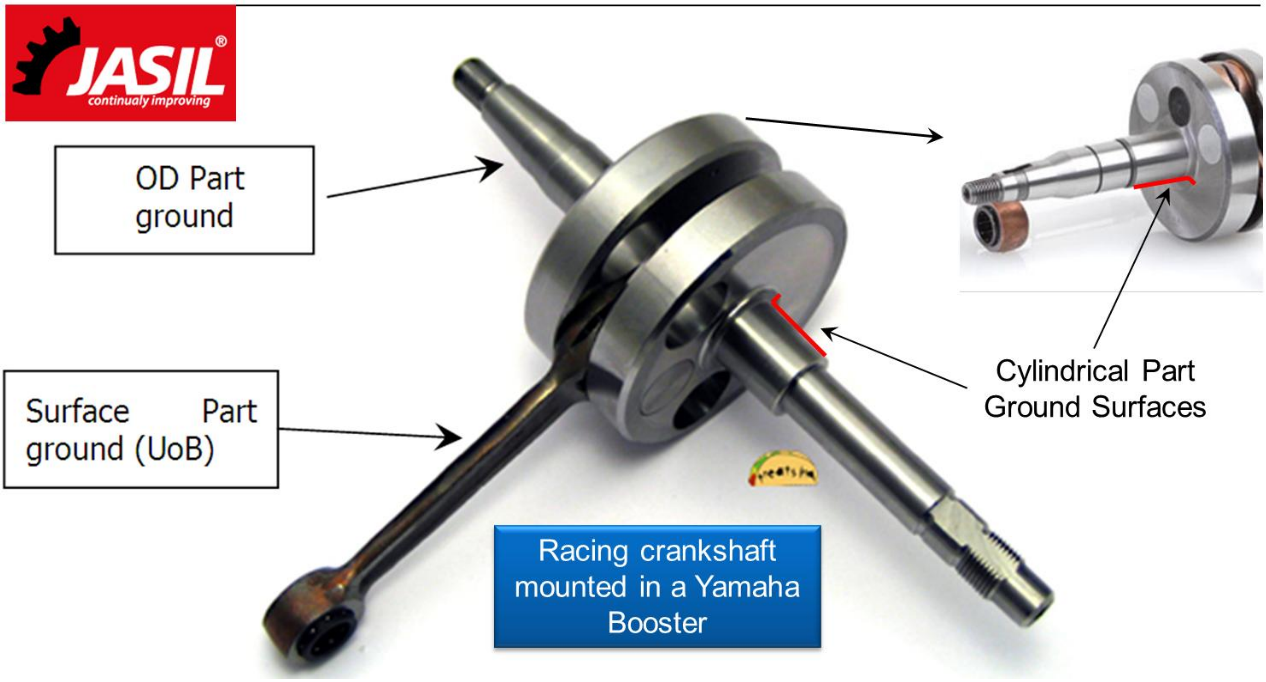


Figure 18: Description of part selected for the industrial validation of the Camel-MCG technology

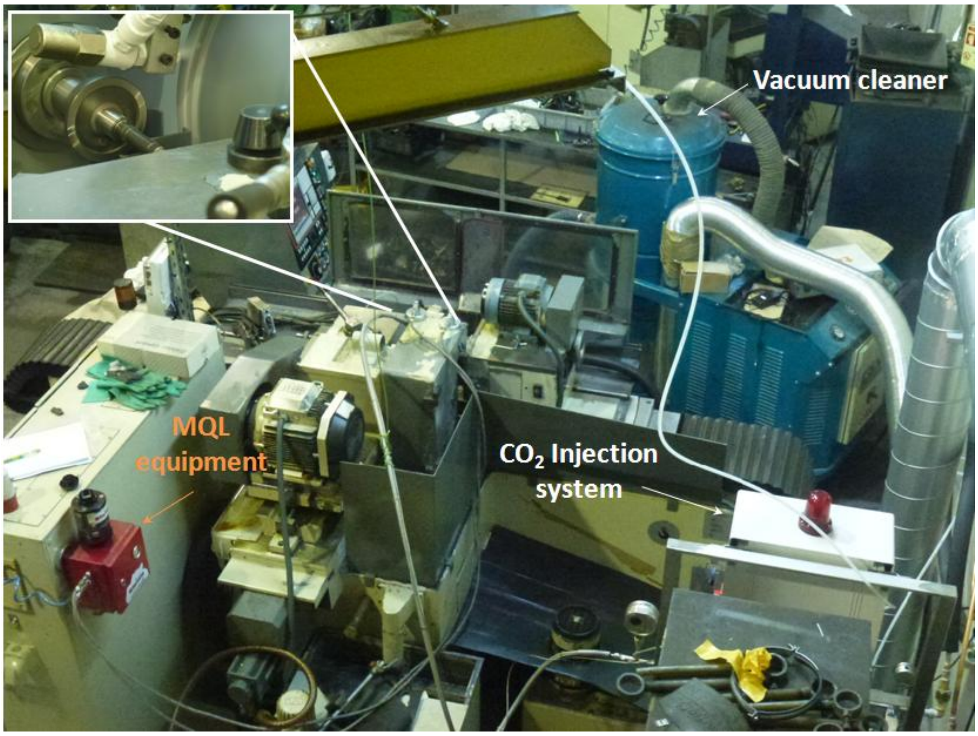
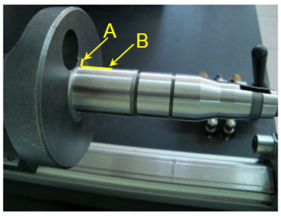


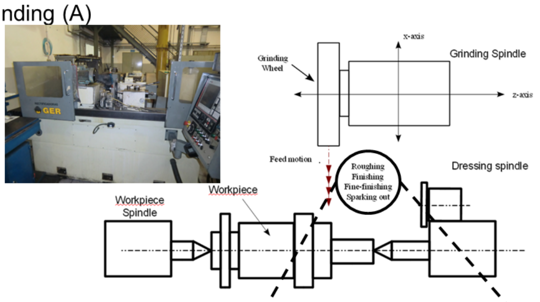
Figure 19: Plant view of the MCG technology installed in the GER machine ready to grind the shaft.

In the figure 20 a description of the grinding operation and machine used is presented. The grinding operation consists in a plunge grinding of the 20 mm outer diameter (surface A). The material ground is a case hardening steel 18CrMo4 and the grinding cycle involves three stages: one roughing operation with a Q'_w of 1 mm3/s/mm leaving 4 μm for finishing with a Q'_w of 0.1 mm3/s/mm. Finally, in order to improve the roundness and surface finish a sparking out of 1 second was left.

A friable Aluminum Oxide grit (2A) from DRAGAO with a special induced open structure to retain the highest amount of oil was designed for the MCG grinding. The grit size (60) and the hardness of the wheel (M) were selected in function to the roughness tolerances and stock removal rate specifications. Finally, a vitrified bond was used with the aim of supporting both the high level of the porosity and high temperature stability needed for this process.

- **Op 1:** External cylindrical peripheral plunge grinding (A)
- **Op 2:** External Face Grinding (B)





Grinding Wheel	2A60M5VB2 ∅450x203.2x20 mm v_S = 32 m/s
Workpiece	Case hardening steel 18CrMo4 (1.7243) → 44 HRc Grinding diameter = 21 mm Grinding width = 14 mm Revolutions per minute of the Workpiece = 400
Dressing plate parameters	Traverse Feed rate = 100 mm/min Dressing depth of cut = 1pass of 0.02 mm + 1 pass of 0.01 mm in radius
Overstock	0.2 mm in diameter

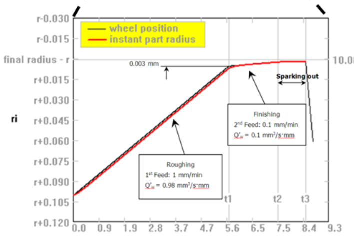
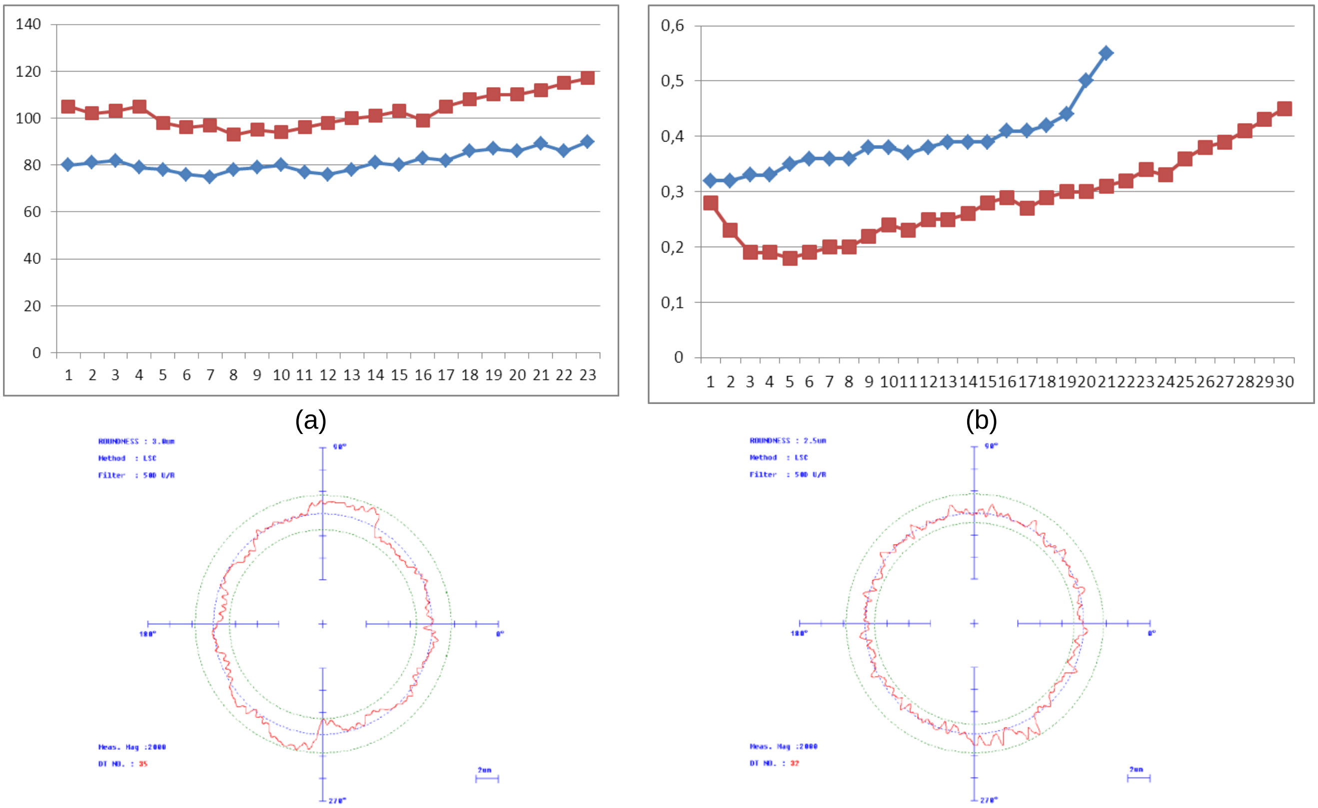


Figure 20: Description of the grinding cycle and workpiece material description for the industrial validation.

Conventional grinding employed vegetable based coolant liquid fluid (6.7% emulsion), with a flow rate of 100 l/min. The MCG grinding was performed by applying CO2 under a pressure of 16 bar and a flow of 0.6 Kg/min. On the other hand, the flow used for the MQL system was 8 ml/min.

In the figure 21 are shown a comparison between the MCG and Flood cooling for the crankshaft grinding. The main conclusions are that MCG consume less power (figure 21a) and produce better surface finish (figure 21b) but worse roundness than flood cooling.



(a) (b)

(c) (d)

Figure 21: Description of the grinding cycle and workpiece material description for the industrial validation.

Finally, in order to analyze the surface integrity of the ground surfaces a measurement of the residual stresses has been carried out using the X-Ray Difractometer technique (Figure 22). Three workpieces from the overall batch have been analysed: the first, the tenth and the latest. Besides two measurements have been done per part: points A and B. Point B is located 180º away from point A.

(a) (b)

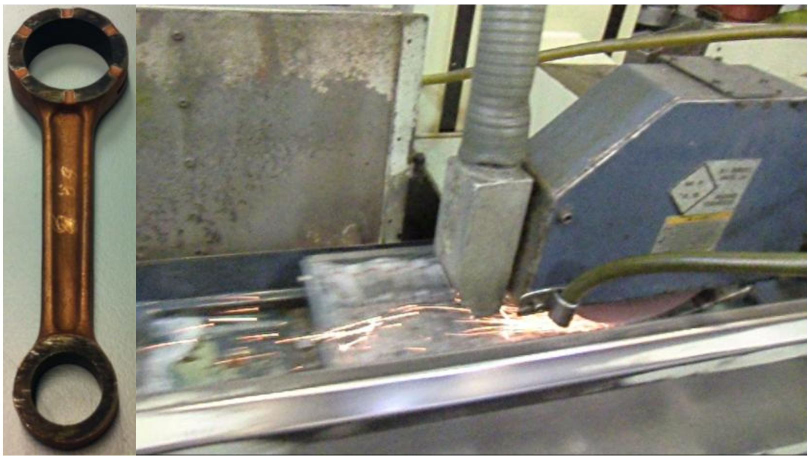
Figure 22: XRD measurement: (a) Axial direction; (b) Circumferential direction.

Table 1: Residual Stresses of the parts ground with MCG and flood Cooling.

Part	Measuring Point	**Residual Stresses**				**FWHM**			
		Axial		**Circumferential**		**Axial**		**Circumferential**	
		MPa	**+/- MPa**	**MPa**	**+/- MPa**	**Deg**	**+/- Deg**	**Grados**	**+/- Deg**
MCG-1	A	**-345,2**	39,6	**-549,3**	44,4	**3,578**	0,021	**3,215**	0,026
MCG-1	B	**-452,8**	34,7	**-429,3**	48,5	**3,589**	0,025	**3,282**	0,038
MCG-10	A	**-405,3**	57,1	**-555,5**	44,5	**3,357**	0,035	**3,106**	0,025
MCG-10	B	**-334,2**	32,7	**-502,8**	36,2	**3,521**	0,021	**3,233**	0,036
MCG-20	A	**-179,5**	33,5	**-269,1**	59,7	**3,807**	0,028	**3,477**	0,024
MCG-20	B	**-277,9**	34,4	**-377,0**	52,1	**3,801**	0,020	**3,452**	0,043
Flood -1	A	**-418,1**	24,0	**-533,2**	64,8	**3,527**	0,007	**3,260**	0,031
Flood -1	B	**-415,6**	21,3	**-520,0**	37,7	**3,552**	0,018	**3,256**	0,036
Flood-10	A	**-405,0**	24,3	**-436,2**	16,7	**3,565**	0,018	**3,258**	0,038
Flood-10	B	**-369,4**	25,2	**-463,4**	36,0	**3,521**	0,013	**3,254**	0,031
Flood-20	A	**-401,2**	21,7	**-371,0**	53,5	**3,538**	0,027	**3,258**	0,033
Flood-20	B	**-442,0**	23,2	**-468,9**	45,0	**3,552**	0,035	**3,225**	0,036

The results of the table 1 show that the surface integrity of both technogies are correct with better compressive stresses for the conventional cooling. After that we can conclude that MCG grinding for this kind of parts is technically viable.

Now the results for the connecting rod is presented. In the figure 23 the con rod grinding is presented. In the next table the methodology followed to optimize the industrial application is presented. To evaluate the limits of the MCG technology four test series have been designed and performed with the aim to reduce the cycle time for the grinding operation (s. figure 2). The test series were performed under usage of the MCG system and conventional coolant supply as well. The grinding strategy in terms of depth of cut, cutting sequence and the overlap rate in dressing were varied while the tangential feed speed vft = 25 m/min and the cutting speed vc =30 m/s have been kept constant. Furthermore, two different grinding wheels with a grit size of 46 and 80 mesh have been used. During the grinding tests, the energy consumption of the machine tool has been measured. For the assessment of the surface integrity of the ground parts, surface roughness has been evaluated as well as thermal damage of the workpiece by nital etching.



process
pendular grinding

grinding wheel
355x26x127
4A46J6VWEA3

workpiece
con rod
18CrMo4
(case hardenend 62 – 64 HRc)

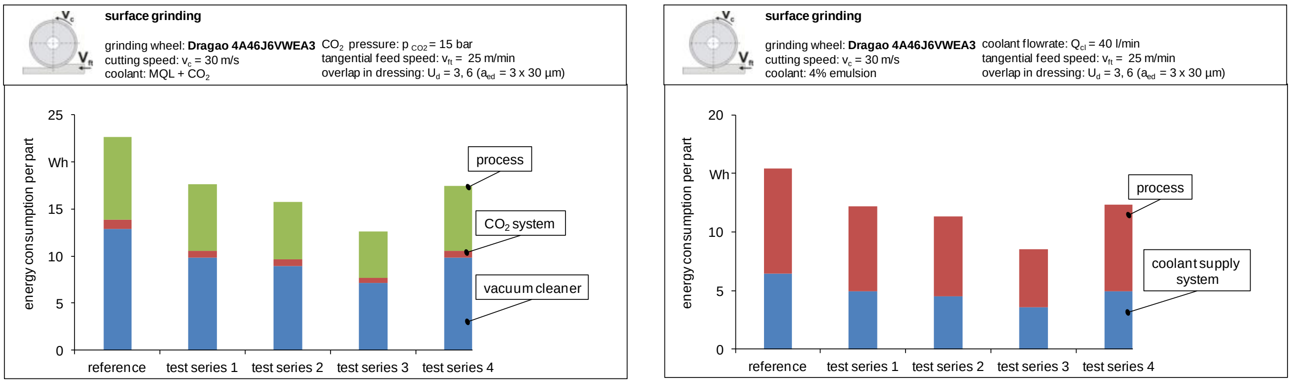
process parameters
v_s = 30 m/s
v_{ft} = 25 m/min
a_e = 6 x 30 µm
2 x 10 µm
2 x 0 µm (spark out)

coolant
flooding coolant supply

Table 2: Con rod grinding conditions

test series 1	**test series 2**	**test series 3**	**test series 4**
pendular grinding	pendular grinding	pendular grinding	pendular grinding
workpiece con rod	**workpiece** con rod	**workpiece** con rod	**workpiece** con rod
process parameters U_d = 3 a_e = 3 x 50 µm 1 x 30 µm 2 x 10 µm 1 x 0 µm (spark out)	**process parameters** U_d = 3 a_e = 3 x 50 µm 2 x 25 µm 1 x 0 µm (spark out)	**process parameters** U_d = 3 a_e = 3 x 60 µm 1 x 20 µm 1 x 0 µm (spark out)	**process parameters** **U_d = 6** a_e = 3 x 50 µm 1 x 30 µm 2 x 10 µm 1 x 0 µm (spark out)

To assess and to compare the energy consumption of the grinding tests with the MCG system and conventional coolant supply the consumed energy per part has been calculated. Figure 23a-b give an overview of the energy consumption per part for the different test series with respect to different specific consumers.

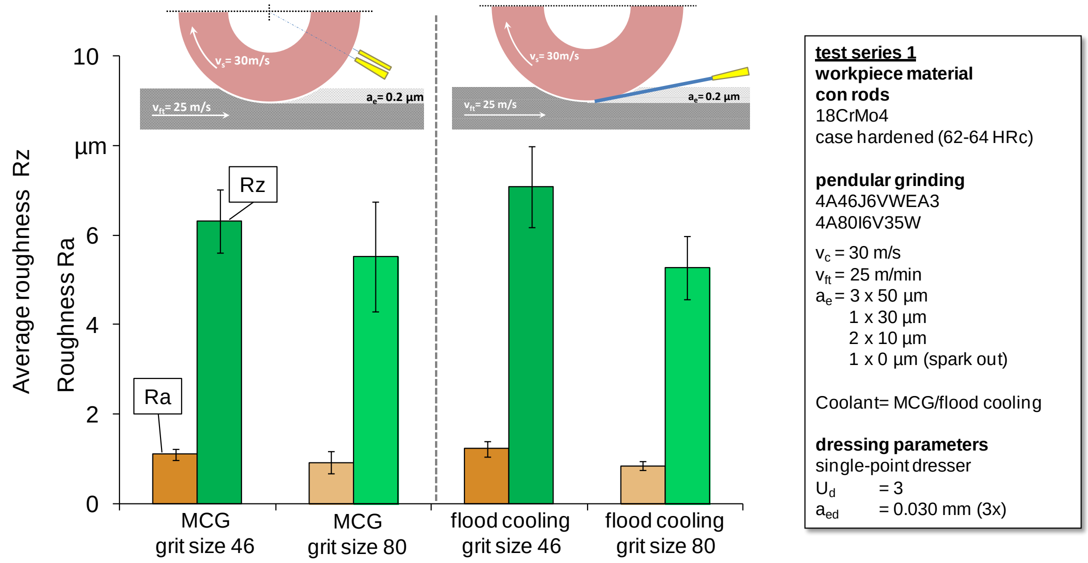


(a) (b)

Figure 23: Energy consumption per part during surface grinding a grit size of 46 mesh with: (a) conventional coolant supply and (b) flood cooling.

It can be taken from the figures above that the energy consumption per part decreases with decreasing cycle time. Also, the influence of the dressing process on the used energy can be seen. A higher overlap in dressing leads to higher energy consumption per part due to the extended duration of the dressing process. The comparison between the CAMEL system and the conventional coolant supply shows clearly that the CAMEL system generally causes a higher energy consumption. This can be explained by the high demand for energy of the supporting equipment (exhausting and CO2 system).

In general, the surface roughness values show that the MCG approach leads to less surface roughness values. Furthermore, the reduction of the cycle time by increased depth of cut causes higher roughness values for both coolant supply approaches. This effect can be explained by a change of the wheel topography due to increasing stress of the grinding wheel at higher depths of cut a_e resulting in higher wear and roughness of the grinding wheel surface.



test series 1
workpiece material
con rods
18CrMo4
case hardened (62-64 HRc)

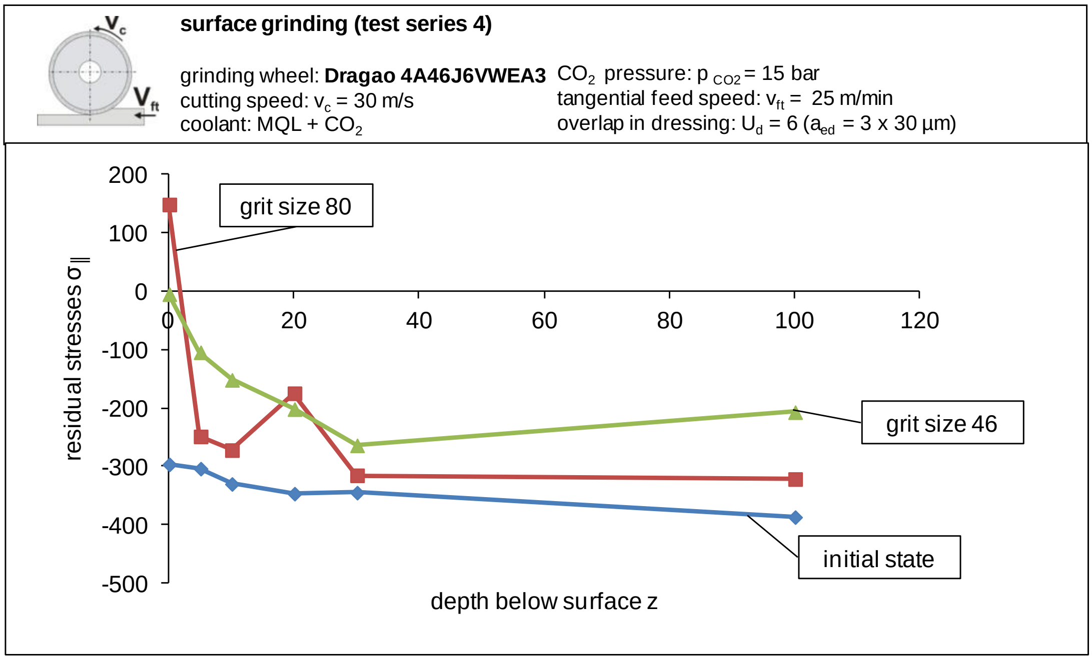
pendular grinding
4A46J6VWEA3
4A80I6V35W
v_c = 30 m/s
v_{ft} = 25 m/min
a_e = 3 x 50 µm
1 x 30 µm
2 x 10 µm
1 x 0 µm (spark out)

Coolant= MCG/flood cooling

dressing parameters
single-point dresser
U_d = 3
a_{ed} = 0.030 mm (3x)

Figure 24: Surface roughness of ground parts after test series 4 with the MCG system and conventional coolant supply

The residual stress depth profiles show a change from compressive residual stresses of the initial state of about 300 MPa to almost tensile residual stresses at the surface. This indicates a thermal influence on the ground workpiece during grinding with the MCG system and supports the results after nital etching. Furthermore, the influence of the grit size is obvious: Due to the higher friction caused by the less grain size of 80 mesh the increasing thermal effect leads to higher tensile residual stresses at the surface of the ground parts.



surface grinding (test series 4)

grinding wheel: **Dragao 4A46J6VWEA3**
cutting speed: v_c = 30 m/s
coolant: MQL + CO_2
CO_2 pressure: p_{CO2} = 15 bar
tangential feed speed: v_{ft} = 25 m/min
overlap in dressing: U_d = 6 (a_{ed} = 3 x 30 µm)

Figure 25: Residual stress profile of ground parts after test series 4 with the MCG system

In the following lines summarize of the industrial application results are presented.

- Regarding the energy consumption the usage of the MCG system during surface grinding and cylindrical grinding leads generally to a higher consumption (appr. 20 up to 30%). This effect is resulting from the supporting equipment (exhauster, CO2 system) of the MCG approach.
- The surface and subsurface properties of the ground workpieces after surface grinding with the MCG system are characterized by lower roughness values.
- For the con rod grinding both coolant supply strategies (MCG and conventional coolant supply) slight thermal damage of the ground surfaces has been detected. If the low grade of thermal damage affects the mechanical properties and the operational behaviour of the parts could not be verified. However in the case of cylindrical grinding operation due to the kinematics of the process and the fine finishing grinding conditions no thermal damage has been detected.

To convince of the potential of the new technology a production cost analysis and Life cycle assessment have to be done. Costs in precision cylindrical grinding are compared for different technologies and grinding conditions. The analysis is for repeated batch production with the methodology and conditions showed in the Deliverable 4.1. Account is taken of machine cost, abrasive cost and fluid lubricant cooling cost. Cost comparisons were based on extensive trials to assess re-dress life against workpiece quality requirements. Easy-to-grind hardened steel was ground at conventional speeds.

The total production cost per part is given in Table 3. As can be seen in the equation 3 the grinding cost represents the expenses of the machining hourly rate C_{mth}, the labor cost C_{wag} and cooling usage cost hourly rate C_{coo}. During grinding tool-wear occurs, therefore tool cost per part, C_{tow}, is added as well.

$$C_{sin} = t_s \cdot (C_{mth} + C_{wag} + C_{coo}) + C_{tow} \tag{3}$$

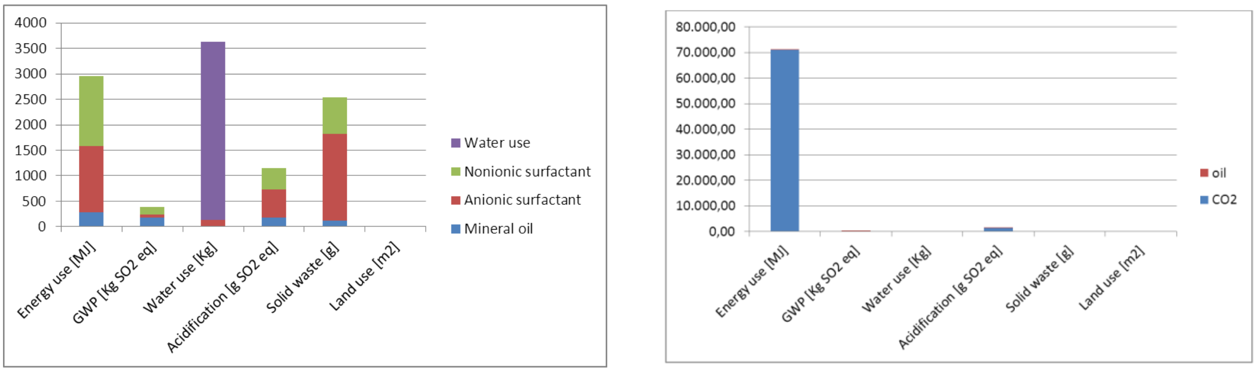
where the t_s is manufacturing time in hours.

Despite of the cost of the machine rate and the coolant cost is higher for the MCG the lower consume of the grinding wheels and higher production rates makes the total production cost saving of 16 %, for the crankshaft grinding.

Table 3: Manufacturing single cost per piece

	Conventional	**MCG**
Machine hourly rate C_{mth} (€/h)	46	50
Wages C_{wag} (€/h)	50	50
Tooling cost (€/p)	0,04	0,03
Coolant cost (€/h)	2,55	10,08
Manufacturing time (min)	0,36	0,27
Manufacturing single cost per piece (€)	**0,63**	**0,53**

In order to evaluate the environmental effect of a process, the impact resulting from each stage of its life cycle has to be considered. A quantitative assessment of the environmental impact is evaluated with an additional health semi quantitative assessment associated with MCG process in comparison to conventional flooding. A comparison of material production impacts broken down by component is shown in Figures 26-27. The results suggest that surfactants dominate the emissions for three of the six impact categories: energy use, acidification, and solid waste.



Flood cooling MCG

Figure 26: Life cycle assessment of: Flood cooling and MCG

Based on LCA, it can be observed that for MCG, in comparison to conventional flooding, a switch to a lower emulsion concentration can yield reductions in GWP, acidification, and solid waste, while these reductions are associated with an increase in energy use. In short, in cryogenic machining there is a compromise as regards higher energy use and a cleaner machining process. As we know that the production of Carbon Dioxide requires electrical energy consumption, we can talk about such being a sustainable machining process only when using a renewable energy source (wind, solar, hydro, etc.).

When the Coolant Fluid is at the end of its useful life, it has to be disposed of. In MCG, the fluids immediately evaporate after being delivered to the cutting zone, leaving no residuals, and there is no need for recycling. On the other hand, in the conventional the Coolant Fluid has to be removed from the workpiece, chips, etc. after the grinding process, and then collected and recycled. All this represents additional processes, costs, and environmental burdens. The usual procedure for oil based CLF disposal consists of drying the emulsion and its subsequent combustion. In contrast to oils, emulsions do not have high energetic values; therefore the combustion process must take into account the high potential for additional environmental burdens. Although combustion does recover some energy from the waste Coolant Fluid, it additionally highly impacts GWP and acidification.

Including recycling requirements, the conclusion that MCG has drastically lower environmental emissions in comparison to oil-based Coolant Fluids, in most impact categories, is robust with regard to different end of life cycle options, e.g. combustion, etc.

With regard to worker health and safety chronic inhalation of oil-based mists has been shown to be responsible for serious health risks. Such emulsion mists can harbor bacteria, and contain surfactants, biocides, chlorinated fatty, chelating agents and defoamers, all of which are harmful to health. This is notable since surfactants and biocides have been found to impair lung functioning [1, 2]. None of these materials are present in evaporated CO2. More importantly, it has been proven that machining mist can be eliminated in MCG grinding. In addition to mists, oil-based Coolants can cause dermatitis and other skin irritations. They also tend to result in the accumulation of an oily sludge on and around the production plant over time. Spills can also be a rather regular workplace hazard, but can be eliminated by using MCG cooling. On the other hand, in MCG grinding less likely but more serious safety issues are required, related to the extremely low temperature of the pipes delivering the CO2, which can cause physical burns in the event of contact.

Therefore can be conclude that the challenges in production with regard to the economy and the environment taking into account the overall life cycle of the Coolant fluid have been discussed in this deliverable. In that sense, MCG is presented as **viable** and **sustainable grinding technology** in comparison to flood cooling. For both technologies a comparative LCA was conducted. The LCA demonstrated that moving from oil-based CLFs to MCG grinding is a move towards more sustainable grinding process. Changing from oil-based to Minimum Coolant Grinding (MCG) can reduce the solid waste, water usage, global warming potential, acidification, and in an increased energy use for Coolant Fluid production. While oil-based emulsions are highly developed after decades of research and development in this field, MCG grinding has only just recently been studied in depth in this work. With knowledge of their relative capabilities, it is believed that sustainable alternative machining performance improvements are likely possible.

4.1.5 Potential impact and dissemination activities

The potential economic impact of the project is high and the consortium quantifies it according to the following benefits:

- ✓ 40% reduction in the generation of waste and energy consumption.
- ✓ 20% of reduction of cost associated of each workpiece, due to respective reductions in energetic cost, lubricant and coolant cost, cutting fluid recycling cost, required floor space and wheel consumption.
- ✓ Promising application opportunities in Fine Finishing Grinding in many industrial sectors as automotive parts, cutting tool production, aerospace components, etc.

Apart from the general benefits taken from the results of the project, partners will profit from specific products resulting from the project.

STEIDLE

Exploitable Knowledge	**Exploitable product(s) or measure(s)**	**Sector(s) of application**	**Timetable for commercial use**	**Patents or other IPR protection**	**Owner & Other Partners involved**
MQL systems for MCG processes	New nozzles for oil application on grinding wheels	Automotive, aerospace, grinding mill-shops	2013	TBD	STEIDLE

MQL system for MCG Processes
The MQL systems require an adaptation for MCG processes. The main difference between grinding and defined edge machining, is the big contact length for grinding. Oil droplets from MQL systems have to cover a bigger surface, length and wide. More open oil jets and flow rates of oil and pressurized air are required.

Devices in MQL system have to be revised, nozzles, pneumatic pumps and other components have to be modified

ABRASIVOS DRAGAO.

Exploitable Knowledge	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable for commercial use	Patents or other IPR protection	Owner & Other Partners involved
Grinding wheels for MCG processes	Grinding wheels with new abrasive grits and wheel porosity	Automotive, aerospace, grinding mill-shops	2014	TBD	DRAGAO

Grinding wheels.
New grinding wheels adapted for MCG machining need improved capacity to carry frozen oil to grinding point, wheel porosity, conglomerate material and grit size have to modified in order to achieve the best oil carrying conditions.
Abrasive grits, as well as conglomerate grits, are modified to meet the new thermal and dynamic conditions of cutting.

LATZ S.COOP:

Exploitable Knowledge	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable for commercial use	Patents or other IPR protection	Owner & Other Partners involved
MCG optimized process	New grinding techniques efficient from economic, ecological, and energetic points of view	Automotive, aerospace, grinding mill-shops	2014	TBD	LATZ & JASIL

MCG optimized process.
The implementation of optimized processes for Minimal Coolant Grinding will decrease costs in grinding operations. Energy costs, grinding waste disposal costs, liquids and sludge, are drastically reduced.
Another improvement for the company will be the reduction on floor occupation, big conventional cooling liquid tanks are no longer necessary. As land cost is high, reductions of occupied land are important..

OEMETA.

Exploitable Knowledge	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable for commercial use	Patents or other IPR protection	Owner & Other Partners involved
MCG lubricating oil	New oil types able to MCG processes	Automotive, aerospace, grinding mill-shops	2013	TBD	OEMETA

Lubricant oil
Oil for MCG demands the qualities common to all MQL oils, as well as new specific properties for MCG, particularly improvement of capacity to be easily frozen without an excessive amount of cooling energy.

New lubrication oil formulations have to be prepared for the MCG process.

JASIL-J. ANTONIO DA SILVA.

Exploitable Knowledge	**Exploitable product(s) or measure(s)**	**Sector(s) of application**	**Timetable for commercial use**	**Patents or other IPR protection**	**Owner & Other Partners involved**
MCG optimized process	New grinding techniques efficient from economic, ecological, and energetic points of view	Automotive, aerospace, grinding mill-shops	2014	TBD	JASIL & LATZ

MCG optimized process.
The implementation of optimized processes for Minimal Coolant Grinding will reduce costs in grinding operations. Energy costs, grinding waste disposal costs, liquids and sludge, are drastically decreased.

Another improvement for the company will be the reduction on floor occupation, big conventional cooling liquid tanks are no longer necessary. As land cost is high, reductions of occupied land are important.

Finally a new, efficient, and ecological process will be a clear commercial advantage for the company.

KONDIA M.E. TALDEA S.L.U.

Exploitable Knowledge	**Exploitable product(s) or measure(s)**	**Sector(s) of application**	**Timetable for commercial use**	**Patents or other IPR protection**	**Owner & Other Partners involved**
Machine equipment	Grinding machine equipped for theMCG process.	Automotive, aerospace, grinding shops	2014	TBD	KONDIA
Components	Chip extraction system, machine adaptation for oil and cryogenic application	Automotive, aerospace, grinding mill-shops	2013	TBD	KONDIA

Machine equipment

The main result for KONDIA will be the design and development of a grinding machine tool specially equipped for grinding parts using the Minimal Coolant Grinding technique, eliminating conventional coolant equipment.
This machine will have a great impact mainly in automotive industries, as well as all companies using grinding processes. Cost of coolant is drastically disminished, grinding sludge and filters disposal costs are eliminated, grinding machine footprint is decreased as coolant tank is no necessary, power consumption is reduced.
The machine performance is ameliorated, machining cost are reduced and ecological impact is improved.

Components
The implementation of the complete system will also mean the development of specific devices for the grinding machines: chip extraction system, connections to external aspiration pump, grinding wheel headstock adaptation to MQL and Cryogenic gas implementation, working table and work piece headstock modifications.

These components could also be installed on grinding machines retrofitted for MCG machining. Machine adaptation for MCG will open a new market for Kondia

Dissemination activities

Several dissemination activities have been performed by the CAME-MCG consortium. These actions include preparing materials for dissemination, attending relevant fairs and congresses related to grinding activities, publishing papers in scientific journals and developing, and continuously updating, a website for the project.

Material for dissemination.

Different items for dissemination were prepared. Among them a poster and leaflets depicting the main activities and results obtained in the project.
This material, poster and leaflets, was used for several dissemination activities carried out by partners attending exhibition fairs related to grinding activities.

Finally a movie depicting MCG technology was created, showing the main advantages of the process. This movie was uploaded to the project website for public access.

O.D. Cylindrical Grinding

Grinding wheel: Drag o 2A60M6VB3
Cutting speed: Vc = 30m/s
Coolant: MCG (CO2+MQL)
CO2 pressure: 15 bar
Rough pass : 20.2--> 20.03 mm Vf 1 mm/min
Finish pass : 20.03--> 20 mm Vf 0.1 mm/min
Sparking-out time: 1 sec.
Dressing conditions: 2x0.01mm F250 mm/min.

Industrial Fair and exhibitions.

CAMEL- MCG project was disseminated through the most important exhibitions related to machine tool and for grinding in Europe and outside Europe.

Events on which the CAMEL project was disseminated is as follows:

- GRINDTEC exhibition (Augsburg, March 2012): DRAGAO presented the project to visitors, showed a poster and delivered CAMEL-MCG leaflets. UoB had a presentation of the CAMEL-MCG poster
- METAV exhibition (Düsseldorf, March 2012): OEMETA and STEIDLE showed CAMEL-MCG poster, delivered leaflets, and discussed the project idea with (potential) customers.
- AMB exhibition (Stuttgart, September 2012): OEMETA and STEIDLE showed CAMEL-MCG poster, delivered leaflets, and discussed the project idea with (potential) customers.
- AMB China (Nanjing, October 2012): OEMETA showed CAMEL-MCG poster, delivered leaflets, and discussed the project idea with (potential) customers.

Project Nº 261980

CAMEL-MCG

Development of Highly Efficient and Environmentally Friendly Grinding Technology Through a Minimum Coolant Approach

MCG concept.

Minimal Coolant Grinding is an alternative process to conventional grinding eliminating the flood cooling usual approach. Oil droplets are thrown into the grinding wheel by a MQL nozzle, this oil is frozen, by means of a cryogenic gas, sticking them to wheel pores and enabling the oil to be carried to the wheel-part contact zone lubricating the cutting process.

MCG Approach. Main advantages.

The main purpose of MCG is to **substitute current cooling and lubrication system,** emulsion or oil, using a 1000 to 2000 times lower quantity of oil.

Advantages of MCG process from technical, economic and environmental points of view.

- Elimination of expensive current **coolant and filtering systems**.
- Reduction of a 40-50% of the total **energy required.** MCG cooling system consumption is almost zero.
- Dramatic reduction of liquid **coolant waste** from 2500 litres in a 6 months period to 100 -150 litres.
- Used filtrating paper and other sources of **pollutant waste disappear.**
- Reduction of 30% in **floor plant occupation**, as coolant systems are no longer necessary.

Conventional flood cooling.

MCG lubrication . MQL oil frozen by cryogenic gas.

CAMEL-MCG Project. Partner´s roles.

MQL-System
Steidle (system owner)
Oemeta (Oil supplier)

Freezing System
Praxair

MCG Thermal Simulation (IFQ)

Future Steps

MCG development for OD Cylindrical Grinding (UPV)

Coolant delivery system optimization (UoB)

MCG on Industrial application (Idk)

End Users

Grinding Machine Tool Manufacturer (Kondia)	Tool Industry Manufacturer (Latz)	Mass Production Manufacturer (Jasil)

Scope of MCG applications:

- Surface grinding.
- Cylindrical grinding.
- Centerless grinding.

Project cutting tests carried on pilot systems for surface and cylindrical grinding.

Cutting parameters improved by MCG cooling.

❑ Cutting forces.
❑ Specific energy.
❑ Wheel wear.
❑ Surface finish roughness.

Project Current activities.

❑ **Optimization of CO_2 application.** Efficiency of the system, minimum gas flow rate.
❑ Design of new elements to facilitate **evacuation of chips** from grinding area.
❑ **Cleaning of the wheel** to prevent clogging.
❑ Cutting parameters in order to enhance MCG properties.

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Beneficiaries attended the fair, presenting on their booths, Camel-MCG Project development, objectives and results were presented in different ways.

1. A poster describing the topics of the project, all beneficiaries and their role in the project was exhibited. The CAMEL poster is shown up on the left.
2. People from project beneficiaries attended the fair answering questions set up by interested visitors on MCG technology.
3. Leaflets depicting MCG principles and advantages, project summary and activities were exhibited.

Scientific dissemination

Scientific dissemination was carried out by RTD partners in two ways, presentation of CAMEL-MCG technology in scientific congresses and publishing of technical papers on indexed journals.

.A presentation on MCG technology was given at the most influent scientific congresses related to grinding and machining processes

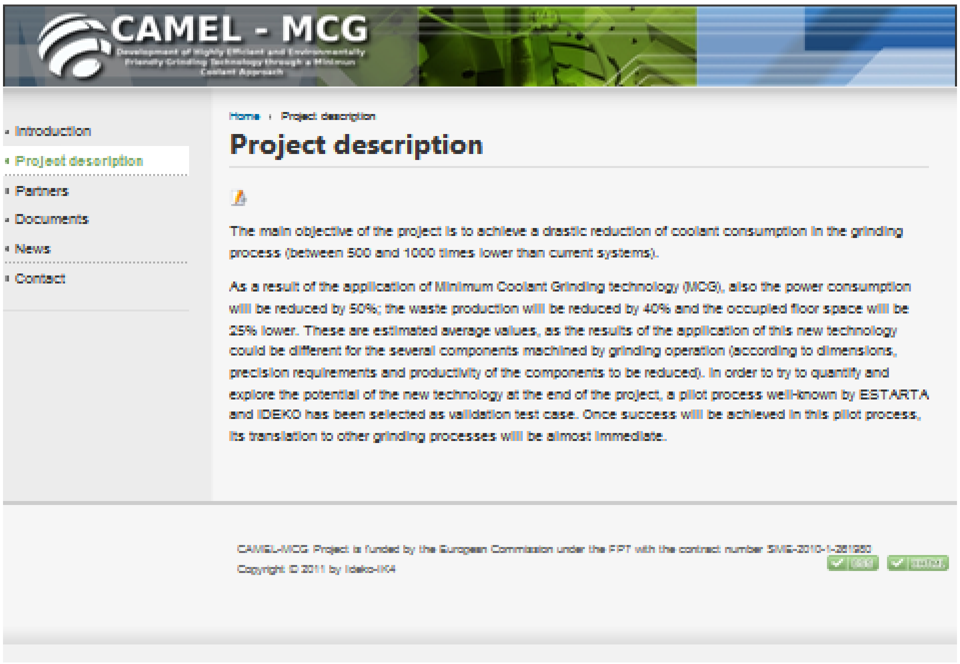
- CIRP General Assembly (Hong-Kong, August 2012): UoB and OVGU shared the presentation of a technical paper.
- ISAAT XV (International Symposium on Advanced Abrasive Technologies, Singapore, September 2012): UPV carried out a presentation.

Two scientific papers related to MCG technology were prepared and accepted for publication in scientific journals.

- Strategies for optimal use of fluids in grinding R.Alberdi, J.A.Sanchez, I.Pombo, N.Ortega, B.Izquierdo, S.Plaza, D.Barrenetxea. International Journal of Machine Tools & Manufacture, 2011, Vol 51 issue 6 pag.491-499
- Reduction of oil and gas consumption in grinding technology using high pour-point lubricants E.Garcia, I.Pombo, J.A. Sanchez, N.Ortega, B.Izquierdo, S.Plaza, J.I. Marquinez, C.Heinzel, D.Mourek, Journal of Cleaner Production, 2013; Vol.3 issue 3 Pag.300-307

Project Website.

From the beginning of the project a website was created. Along the development of the project, the site has been, and will be, regularly updated until the end of the project.
The site is divided in two areas, a private area for project partners, which is used for circulating all information corresponding to the project, and to store important documents (deliverables, Description of Work, Consortium Agreement , etc...). The other area is public and it is used as dissemination tool for the project.



Project description

The main objective of the project is to achieve a drastic reduction of coolant consumption in the grinding process (between 500 and 1000 times lower than current systems).

As a result of the application of Minimum Coolant Grinding technology (MCG), also the power consumption will be reduced by 50%; the waste production will be reduced by 40% and the occupied floor space will be 25% lower. These are estimated average values, as the results of the application of this new technology could be different for the several components machined by grinding operation (according to dimensions, precision requirements and productivity of the components to be reduced). In order to try to quantify and explore the potential of the new technology at the end of the project, a pilot process well-known by ESTARTA and IDEKO has been selected as validation test case. Once success will be achieved in this pilot process, its translation to other grinding processes will be almost immediate.

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4.1.6 Website

More information, pictures and news from the project can be accessed through the project’s website: http://www.camel-project.eu.