Resin Bonded Diamond grinding wheels conditioning using SiC rotary dresser

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Abstract: Superabrasive grinding of advanced materials parts with complex geometry is a critical issue for aerospace or energy industry. Likewise, conditioning of superabrasive is a key process in order to obtain the most effective grinding. While from industrial point of view the conditioning parameters and dressers are designed from the experience, from scientific point of view the last works are focused on achieving guidelines for optimising conditioning process. In this sense, the present work is focussed on the conditioning process of diamond resin bonded grinding wheels. To this end, SiC rotary dressers of different hardness and applying down-cut and up-cut are tested in order to achieve the best conditions. On the one hand, the wheel surface is deeply analyse. A software is developed in order to analyse the grain pull out, the new abrasive grains and the size evolution and grain concentration during conditioning. On the other hand, the wheel geometry is also measured due to the importance of geometry loss during the conditioning process on profile grinding wheels. The results shown that down-cut conditions are more aggressive obtaining a better wheel surface recovery and the wheel geometry of the incidence edge is lost, requiring a subsequent truing process to obtain the wheel profile. Finally, it is noteworthy that the methodology developed for the analysis of the diamond resin bonded grinding wheels is suitable for all types of grinding wheels even rotary dressers.

Keywords: Grinding, Dressing, Truing, Diamond wheels, Wheel surface analysis.

1. Introduction

Aerospace, automotive and energy industry are increasingly demanding advanced materials parts with high precision and complex geometry [1,2]. Likewise, the superabrasive grinding wheel is a type of high-efficiency, high-precision and long-life fixed abrasive tool, being the best choice to achieve those stringent requirements [3,4]. Moreover, dressing process is a critical issue for grinding optimization [5]. In this sense, dressing of superabrasive grinding wheels is a key to achieve precision grinding of complex geometry parts.

One of the characteristics of superabrasive grinding wheels is the hardness. However, once the wheel is worn the hardness and strength of this type of wheel hinder the dressing process in order to regenerate wheel profile and wheel cutting ability. Depending on the nature of dressing process, common (also called mechanical) dressing, electrical discharge dressing even laser dressing can be found [4]. Regardless the process, the conditioning process of profile grinding wheels is divided in two steps: truing, to re-establish the wheel profile, as it is shown in figure 1(a), and dressing, to achieve optimum wheel surface conditions (figure 1(b)).
From the different superabrasive grinding wheels that can be found in the industry, the present work is focused on resin-bonded diamond wheels. The first work addressing this issue is carried out by Inasaki [5], establishing the minimum time for truing and dressing and highlighting the dressing conditions. Likewise, in the last years different dressing methods have been developed. On the one hand, W.K. Chen et al. [6] developed a loose abrasive lapping method for dressing resin bond diamond wheel achieving better wheel topography with more exposes grains and reducing the grain pull-out. However, this method is only valid for wheel diameters in the order of Ø20mm being not immediate to apply this method on industrial application using grinding wheels of about Ø300mm. Moreover, wheel surface analysis is carried out using SEM technique, which is of great added value from a research point of view but not useful from an industrial point of view.

On the other hand, W Deng et al. [7] have developed one of the latest study focused on dressing resin-bonded diamond wheels. They have used laser-dressing method, which is of high precision, differentiating between laser profiling and laser ablation and sharpening, which correspond to truing and dressing processes respectively. Combining two processes they provide a theoretical guidance to avoid damage in the wheel, however, the process optimization is not taken into account and the result hardly can be applied to the industrial process. Moreover, especial attention has to be paid to the degree of graphitization of the diamond controlling the energy transmitted to the inside of the diamond grits. This issue together with the absence of optimum methodology hinder the industrial application of laser-dressing of resin bonded diamond grits.

One of the limitations of conditioning resin-bonded diamond wheels is the analysis of wheel surface. It is necessary to control the surface obtained in the first truing steps in order to design dressing steps. As it is mentioned above, SEM technique is used to analyse the surface, however it is not feasible from an industrial point of view. Likewise, Lefebvre et al. [8] carried out a complete analysis of wheel surface after truing and dressing obtaining the wheel topography. Both macro and micro geometry using wheel replicas and measuring these replicas with a non-contact interference microscope and specific software. This work establishes threshold values of 3D roughness parameters in order to determine the efficiency of truing and dressing process. However, one of the industrial limitations of the present work is the difficulty of implement the analysis methodology on the real industrial application. The microscope cannot be used in the grinding machine and the method is time consuming.

Although the most recent works addressing conditioning process of resin-bonded diamond wheels are focused on the development of new technologies, these are not easy to implement in the industry. Therefore, the optimization of conditioning process of resin-bonded diamond wheels using conventional tools is still the most widely used. In general, conditioning process is usually carried out in 2 steps, firstly truing process, in which SiC rotary dressers are used to remove the worn surface and to obtain the adequate wheel geometry. Secondly, the dressing process is carried out in order to achieve the abrasive capacity of the grinding wheel using Al₂O₃ sticks. The present work is focused on the optimization of truing process using SiC rotary dressers, which are nowadays implemented in the
industry. Different SiC hardness and process parameters are evaluated to determine the optimum conditions. Likewise, the wheel geometry and topography are carefully characterized during wheel conditioning. To this end, different states of wheel surface for the different truing strategies are analysed using a developed software in Python to quantify the grain concentration on the active surface through grain tracking. Grain pull-out and the protrusion of new sharp grains are taken into account. The proposed methodology combines the use of conventional SiC with a quick and automated analysis of the wheel surface, leading to a low-cost methodology to determine the optimum resin-bonded diamond wheels truing conditions using SiC rotary dresser. Results show efficient grinding ability and shape recovery of resin-bonded diamond wheel for industrial conditions.

2. Material and Methodology

2.1. Materials and instruments
The experimental work is carried out on a cylindrical grinding machine DANOBAT FG600S. A resin bonded diamond grinding wheel RD D252R100BG10 with dimensions Ø400 mm × 6.25 mm is analyzed during the study. The diamond grain size is about 252µm with a high grain concentration (100) on wheel surface and the bonding agent is phenolic resin of hardness R. As it is previously mentioned, in the present work truing process with vitrified SiC rotary dressers is optimized. To this end, an external rotor of 1.5kW and frequency changer is mounted on the grinding machine as shows figure 2(a). SiC rotary dressers of different hardness (H and J) are analysed. The specifications of rotary dressers are shown in figure 2(b).

![Figure 2. (a) Set up of dressing with SiC rotary dresser and (b) SiC rotary dresser specification.](image)

![Figure 3. Wheel geometry acquisition set up (a) grinding graphite (b) microscope to acquire the wheel shape and (c) graphite shape measurement and (d) wheel surface acquisition set up.](image)
The diamond resin bonded wheel is analyzed before, during and after dressing in order to determine the efficiency of the process. To this end, both the wheel geometry and the wheel surface are measured and analyzed. A graphite billet is used to measure the wheel shape. Thus, the graphite is ground and the negative of the wheel is obtained, as it is shown in figure 3 (a) and (b). Optical microscope Dino-Lite with x140 increases and its software DinoCapture 2.0 are used to measure the wheel edges (figure 3 (c)). Moreover, this microscope is also used to obtain wheel surface images. This portable microscope allows the online measurement of the wheel surface, reducing operating times and the error due to the assembly and disassembly of grinding wheel during the tests. Figure 3(d) shows the set up to acquire wheels surface images.

### 2.2. Diamond Resin Bonded Wheel Truing Methodology

This work is focused on truing resin-bonded diamond wheel using SiC rotary dressers of different hardness and using different parameters. Table 1 compiles the parameters used for both hardness, H and J, of SiC rotary dressers. Two truing conditions are set modifying only the rotation direction of the dresser, and thus obtaining down-cut (qd -) and up-cut (qd +).

**Table 1.** Wheel conditioning parameters for SiC rotary dresser.

|          | \( v_s \) [m/s] | \( v_f \) [mm/s] | \( a_d \) [mm] | \( n_d \) [rpm] | \( q_d \) [-] | \( U_T \) [-] |
|----------|----------------|----------------|--------------|---------------|----------------|-------------|
| SiC down-cut | 30             | 80             | 0.1          | 3000          | +0.628         | 122         |
| SiC up-cut  | 30             | 80             | 0.1          | 3000          | -0.628         | 122         |

**Figure 4.** Designed tests methodology.

The same methodology is designed regardless the parameters or dressers tested. Aggressive truing parameters are designed due to the hardness difference between diamond wheel and the dressers, assuming that the initial wheel geometry is lost. In order to quantify both the geometry lost and wheel surface changes, the wheel is measured before starting tests, each 10 passes and at the final state. In total 6 stages are measured; the methodology is detailed in figure 4. It is important to note that neither the wheel nor the dresser are disassembled during the complete tests, being an advantage over other methodologies in the literature as no error is introduced into the process due to the loss of zeros and references. Moreover, to ensure the same wheel microscope positioning, sectors are marked in the wheel and the last adjustment is done manually, finding previously recognized abrasive grains. In order to measure the wheel geometry a plongée is done on a graphite billet being plongée parameters \( a_e = 2 \text{mm} \) and \( v_e = 5 \text{m/s} \) and 2D images are captured from negative of the geometry obtained in the graphite. In order to obtain accurate images, the only requisite is to position the camera perpendicular to the trace of the grinding wheel in the graphite. While the wheel geometry is analysed using DinoCapture 2.0 software, the wheel surface is analysed using a developed software in python. This software compares different states of the same area of wheel surface determining the grain concentration in the surface and the grain pull out. To ensure the analysis of the same area during the complete test, before starting the test a random \( 2.2 \times 2.8 \text{ mm}^2 \) is selected and marked in the wheel allowing to track the evolution of the
same diamond grains. It is important to clarify that the tests are done one after the other without dressing the wheel surface after each test. There is not a reference surface established. The order followed during the tests is: SiC H down-cut, SiC J down-cut, SiC H up-cut, SiC J up-cut. Therefore, the starting surface and starting geometry of each test is not the same for all the tests. This fact has to be borne in mind when the results are analysed. Although the analysed area is the same but the surface starting point no. Thus, the final state of surface and geometry of test 1(SiC-H down-cut) is going to be the starting state of surface and geometry of test 2 (SiC-J down-cut). Therefore, the results are presented consecutively and the variation from the initial to the final state is obtained.

3. Results

As it is previously mentioned, an optimum conditioning process involves the regeneration of both the geometry of the wheel, especially on profile grinding wheels, and the surface and abrasive capacity of the grinding wheel, as it is shown in figure 4. This analysis presents novel results of conditioning resin bonded diamond grinding wheel with SiC rotary dressers varying the hardness and speed ratio, showing the incidence of the process for each wear phenomenon. The designed methodology is applicable for different abrasive materials and conditioning parameters, even if stationary dresser is used, showing its versatility and suitability for different grinding and dressing analyses.

3.1. Wheel surface analysis

Regarding to the wheel surface analysis a software is developed in Python in order to simplify the testing methodology and to reduce the analysis time. This fact together with the simple optical microscope used leads to easy and quick implementation on real industrial process. Moreover, it is worthy of interest to note the different applications on wheel surface characterization. Although in the present work is developed to determine the efficiency of conditioning process, this powerful program also determine the wear flat evolution of grinding wheels.

The developed software present 3 modules in order to characterize the surface of diamond grinding wheel. The software is based on binary segmentation of 2D optical images detecting the resin bond and the diamond abrasive grains as it is shown in figure 5(a). The three steps of the analysis are represented. The first module quantifies the percentage of the abrasive grain concentration on each conditioning stages. The second module detect the grain pull out comparing different conditioning stages and the last module is able to follow each abrasive grain on different conditioning stages in order to determine the size variation during the complete test. In figure 5(a) the followed grains are marked in blue green and yellow before starting the test and at the final step.

In figure 6 the evolution of the abrasive grain concentration during conditioning process for the 4 cases of study are represented. It is shown that the SiC rotary dresser tends to stabilize the abrasive grain

![Figure 5](image_url)
concentration around 25% regardless the starting point of the test. Thus, for the case of $\text{SiC H down-cut}$ the starting point is of about 32% decreasing the concentration until 24% while the starting point of $\text{SiC H up-cut}$ is 19% presenting increasing tendency. The higher grain concentration implies a closer grinding wheel being a value of 25% relative to close grinding wheel structure.

![Figure 6. Evolution of diamond grain concentration depending on number of conditioning passes for different SiC hardness and parameters.](image)

**Table 2.** Variables to quantify the state of wheel surface after conditioning process.

|                  | SiC H down-cut | SiC J down-cut | SiC H up-cut | SiC J up-cut |
|------------------|----------------|----------------|--------------|--------------|
| Grains pull-out [number] | 8              | 7              | -            | 1            |
| New Grains [number]          | 1              | 3              | -            | -            |
| Grain Size variation [%]      | 28,45          | 26,43          | 7,67         | 12,5         |
| % of grains reduced [%]       | 53             | 45             | 45           | 55           |
| Grain Size reduction [%]      | -33,3          | -25,47         | -6,5         | -14,3        |

Not only the abrasive grain concentration reveals the conditioning efficiency, but also the grain pulls out and the new grains bring out in the wheels surface. On table 2 are built the analysed variables during conditioning. In general, down cut conditions are more aggressive than up cut conditions showing a greater variation on the wheel surface after conditioning. For down cut conditioning, regardless the SiC rotary hardness, worn abrasive grains are lost and new sharped abrasive grains are brought out, thus, the wheel surface is regenerated. There is not a surface regeneration using up-cut conditions. Moreover, a higher variation in the grain size is shown using down cut conditions. This effect is related to the new grains bring out because the abrasive grains that are embedded in the binder increase in size as they are brought out. Finally, the abrasive grains are broken during conditioning for all analysed cases. Although the number of reduced grains is similar in the 4 cases, using down cut conditions the grain size present higher reduction. Therefore, it is concluded that the hardness do not present high influence in the conditioning efficiency. However, in order to regenerate the wheel surface down cut parameters are required. In figure 5 (b) the life-cycle of an abrasive grain during the conditioning process is represented taking into account the wheel surface analysis and the parameters built on table 2.

**3.2. Wheel geometry analysis**

In addition to the cutting ability of the wheel surface, the geometry of the grinding wheel has to be maintained, especially for profile grinding wheels. To this end, after conditioning process, wheel geometry is analysed measuring both the incidence edge and the secondary edge as shown figure 7. The results are built on table 3. On the one hand, higher differences are measured on the incidence edge
regardless the case of study due to the initial impact. The difference measured in the secondary edge are lower than 6%, being almost insignificant. However, the incidence edge presents an increase of the angle of 48% in the case of SiC H up cut conditions and about 48% for SiC J down cut conditions. In both cases the right angle is lost, thus the wheel geometry is lost, therefore the conditioning process is not complete, and a subsequent conditioning process is required in order to re-establish the wheel profile.

Figure 7. Initial and final states of wheel geometry revealed in graphite block.

Table 3. Shape deviation on the incidence and secondary edge variation during conditioning.

|                | Incidence Edge | Secondary Edge |
|----------------|----------------|----------------|
|                | Initial state  | Final state    | Difference | Initial state | Final state | Difference |
| SiC H down-cut | 90             | 110.3          | 10.3       | 90           | 91.9        | 1.9        |
| SiC J down-cut | 100.3          | 131.58         | 31.28      | 91.9         | 93.46       | 1.56       |
| SiC H up-cut   | 97.86          | 140.86         | 43         | 90.98        | 94.42       | 3.44       |
| SiC J up-cut   | 140.86         | 147.26         | 6.4        | 94.42        | 99.87       | 5.45       |

4. Conclusions
The present work is focussed on address a real industrial problem when diamond resin bonded grinding has to be dressed. In general, conditioning process is divided in two steps, truing and dressing process. However, in the industry it is shown that the common techniques and abrasives do not work well when this type of grinding wheels are conditioned. Therefore, in the present work the efficiency of SiC rotary dresser is tested varying the hardness and using down and up cut. From the analysis carried out the following conclusions are taken:

- A methodology is designed to online analysis of wheel surface. The designed methodology is applicable for different abrasive materials and conditioning parameters, even if stationary dresser is used, showing its versatility and suitability for different grinding and dressing analysis.
- Down-cut conditions are more aggressive for the process allowing a better retrieval of abrasive capacity of diamond resin bonded grinding wheel. Higher grain pull out occur, removing the worn abrasive grains and a great number of new abrasive grains bring out.
- The hardness of the grinding wheel do not affect to the wheel surface results.
- The wheel geometry is lost regardless the SiC hardness and conditioning parameters. The secondary edge present low variation (6%), however, on the incidence edge the maximum variation measured is of 48%.
- These results show that conditioning with SiC is not enough to remove worn surface and re-establish abrasive capacity and wheel profile. Therefore, a subsequent truing process is required to obtain the adequate profile on diamond resin bonded grinding wheel.
Acknowledgements
The authors gratefully acknowledge the funding support received from the Basque Government in the HAZITEK operation program for funding the project PROWHEEL “Tailor-Made Grinding Solutions: una tecnología completa de muela/proceso para una respuesta óptima y customizada a las demandas del Mercado”. The authors also acknowledge the Basque Digital Innovation Hub (BDIH) initiative of the Basque Government allowing the collaboration with IDEKO research center.

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