Chapter 8

Drilling of composite: results and discussion

8.1 Al2009/SiC$_w$

8.1.1 FIMEC tests

The results about the FIMEC indentations here are showed, includes all the curves and the corresponding trends of yield tress and stiffness.

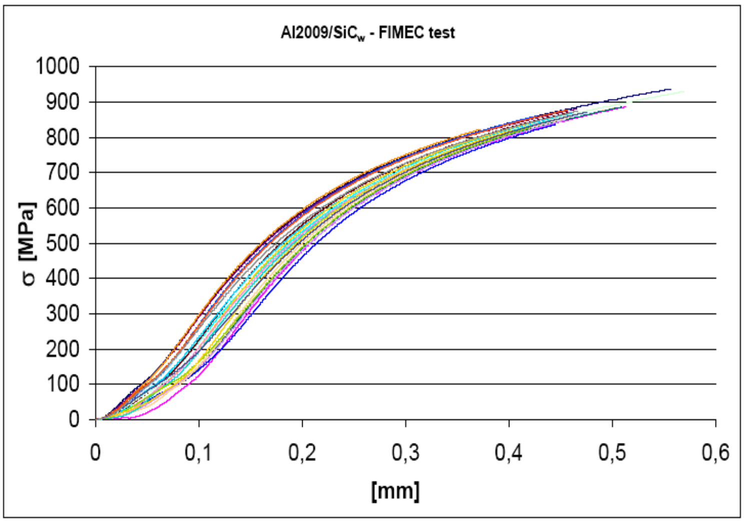


Fig.1 FIMEC curves obtained about the studied composite

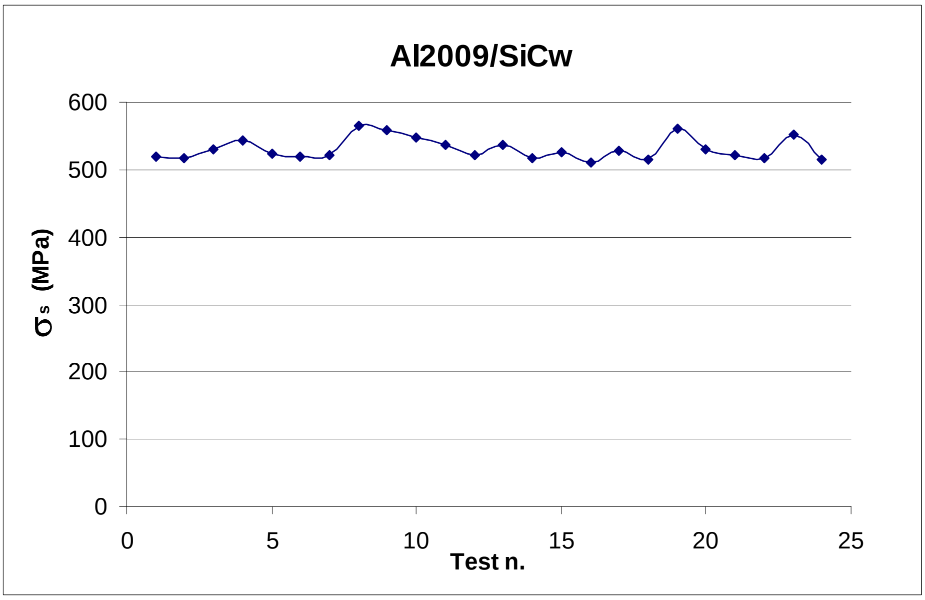


Fig.2 Yield stress calculated about the studied composite (average σ_s : 530.6 MPa)

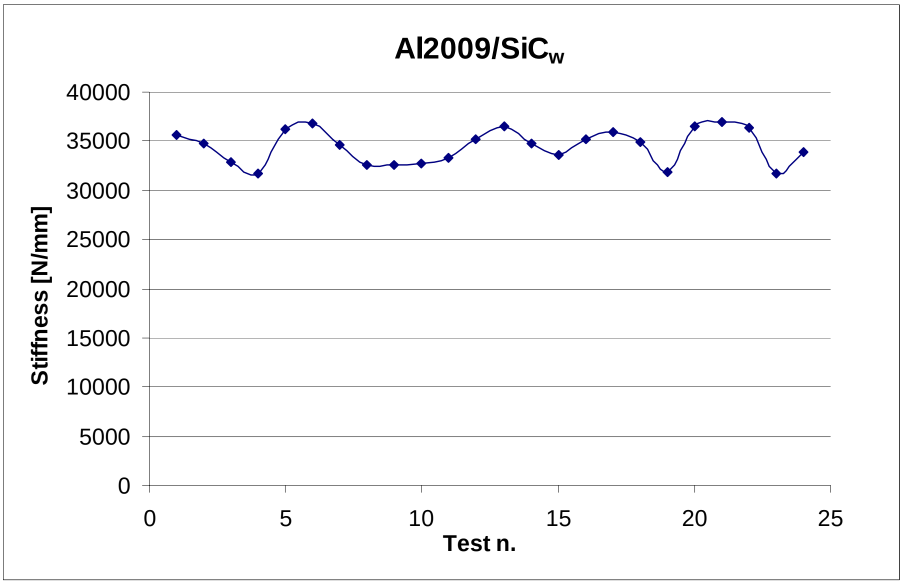


Fig.3 Stiffness calculated about the studied composite (average stiffness: 34464.4 N/mm)

8.1.2 Cutting forces vs. feed a_z

At first to quantify the influence of process parameters on the stresses, drilling tests at room temperature have been considered. In particular it will be showed as a function of feed a_z (where z axis coincides with the rotation axis drill rotation) as defined a_z *[mm / rev]* = v_{feed}/n, which is a fundamental analysis for a careful analysis based on the process productivity.

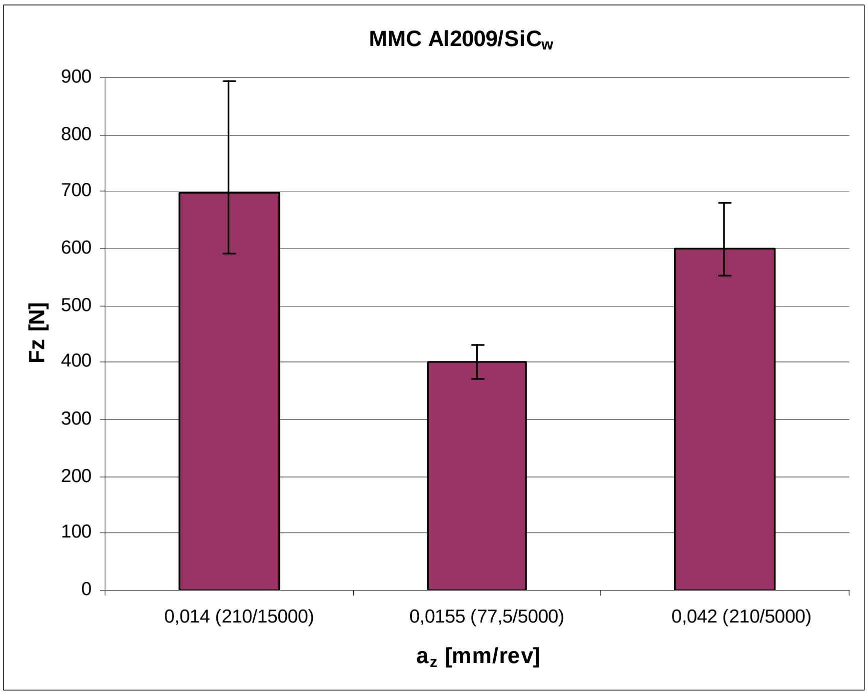


Fig.4 Al(2009)/SiC$_w$: F_z as function of a_z

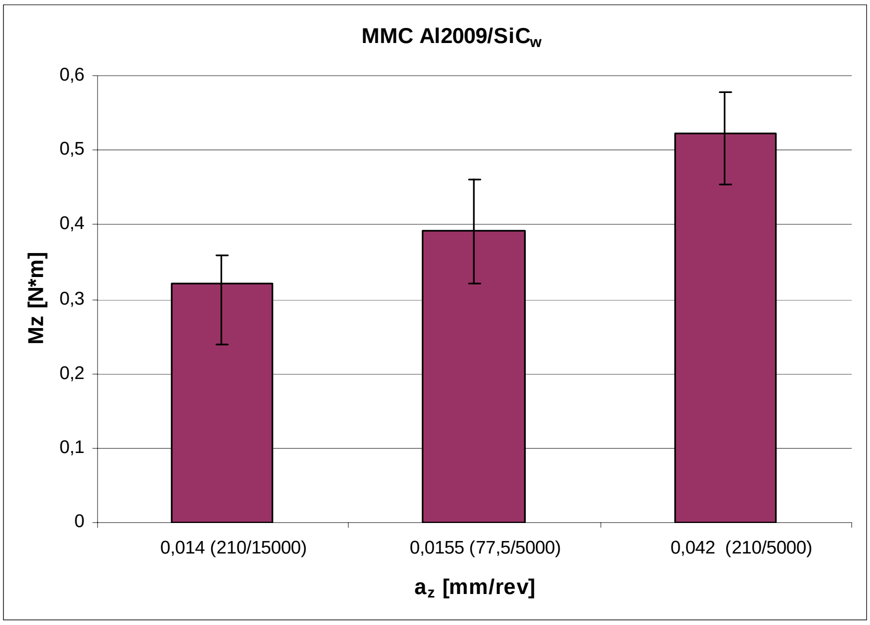


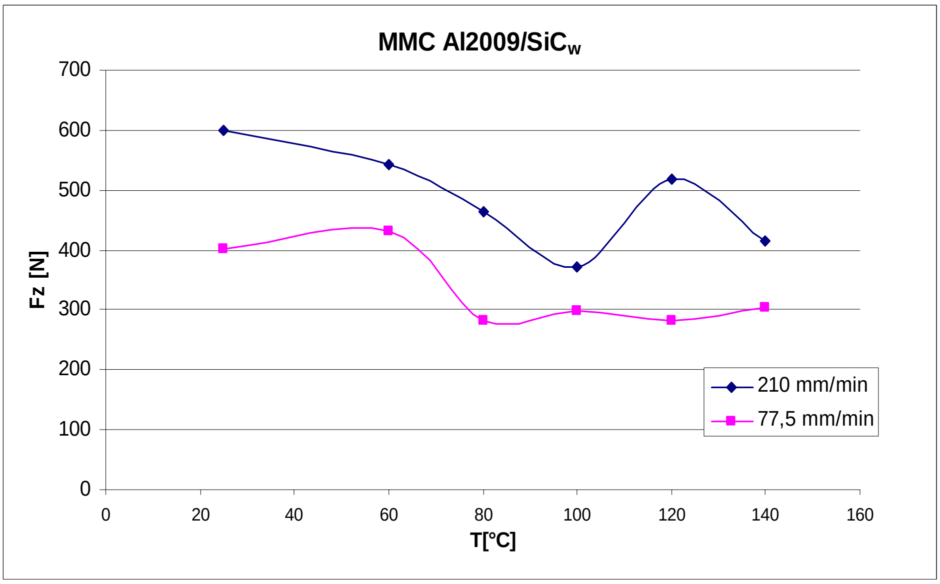
Fig.5 Al(2009)/SiC$_w$: M_z as function of a_z

By the results just showed, it can be seen as in the case of M_z theories relating to conventional materials are confirmed about the proportionality in a_z. So in this case working at high cutting rate (depending only by n) involves minor stresses for the cutting edges and thus higher quality and less wear. In addition the F_z situation seems more depending more v_{feed} because it depends especially by the central angle between the cutting edges and by the central chisel edge, considering that however for low a_z values some uncertainty about the result accuracy remains (see scale error bars for F_z).

8.1.3 Cutting forces vs. temperature *T*

The aim, that concerns the present work, mainly regards the drilling operations at "high speed" as rapid process implementation, so the focus has been about the influence of the workpiece heating and about the two highest values for a_z (0.015 and 0.042 mm/rev).

The considerations about the obtained results should regard not only trends and reliability (assessed by error bars, to verify also the process stability in specific conditions), but it is especially right compare in according to the variation of the aforesaid parameter test.



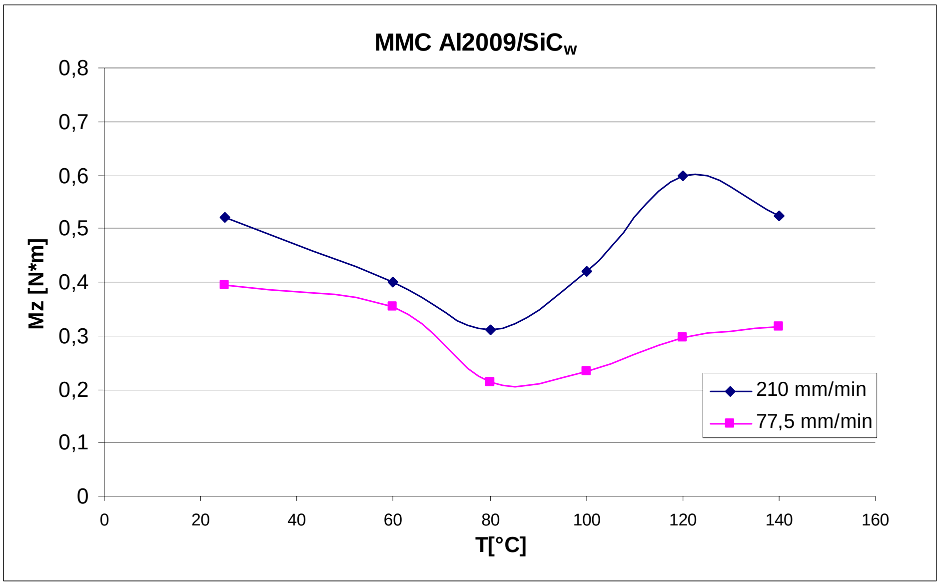


Fig.6 Al(2009)/SiC$_w$: F_z and M_z vs. T

	rid.% Fz	rid.% Mz
210 mm/min	38.33%	52.76%
77,5 mm/min	25.28%	45.85%

Tab.1 Cutting stress riduction % from r.t. to the minimum T

By the showed graphs, about the considered the material it is clear the presence of a minimum temperature for the all process conditions, both for M_z and for F_z (Fig.6). Particularly Tab.1 shows the percentage reductions of the forces as the minimal point compared to the values obtained at room temperature.

The reduction relative to M_z, with a minimum of 80°C, appears especially significant. This situation is positive in particular about the study of tool wear as M_z acts more than anyone else directly on the cutting edges. Regarding F_z, the reductions (with a T_{min} about 100 ° C) show a slightly smaller scale, reflecting the real effectiveness of the hot drilling concepts.

By analyzing the error bars on the individual obtained values (following Fig.7), if the result is good for the T_{min} and T_{amb} values and condition for each drilling, more uncertainty is found especially at “contour” temperatures to that of minimum, because evidently it is a certain instability in the cutting process in those conditions. In addition there is a greater uncertainty for M_z, where the acquired vibration signals are usually higher than in F_z. Note also the irregular but the steady decrease in the average of F_z with the temperature.

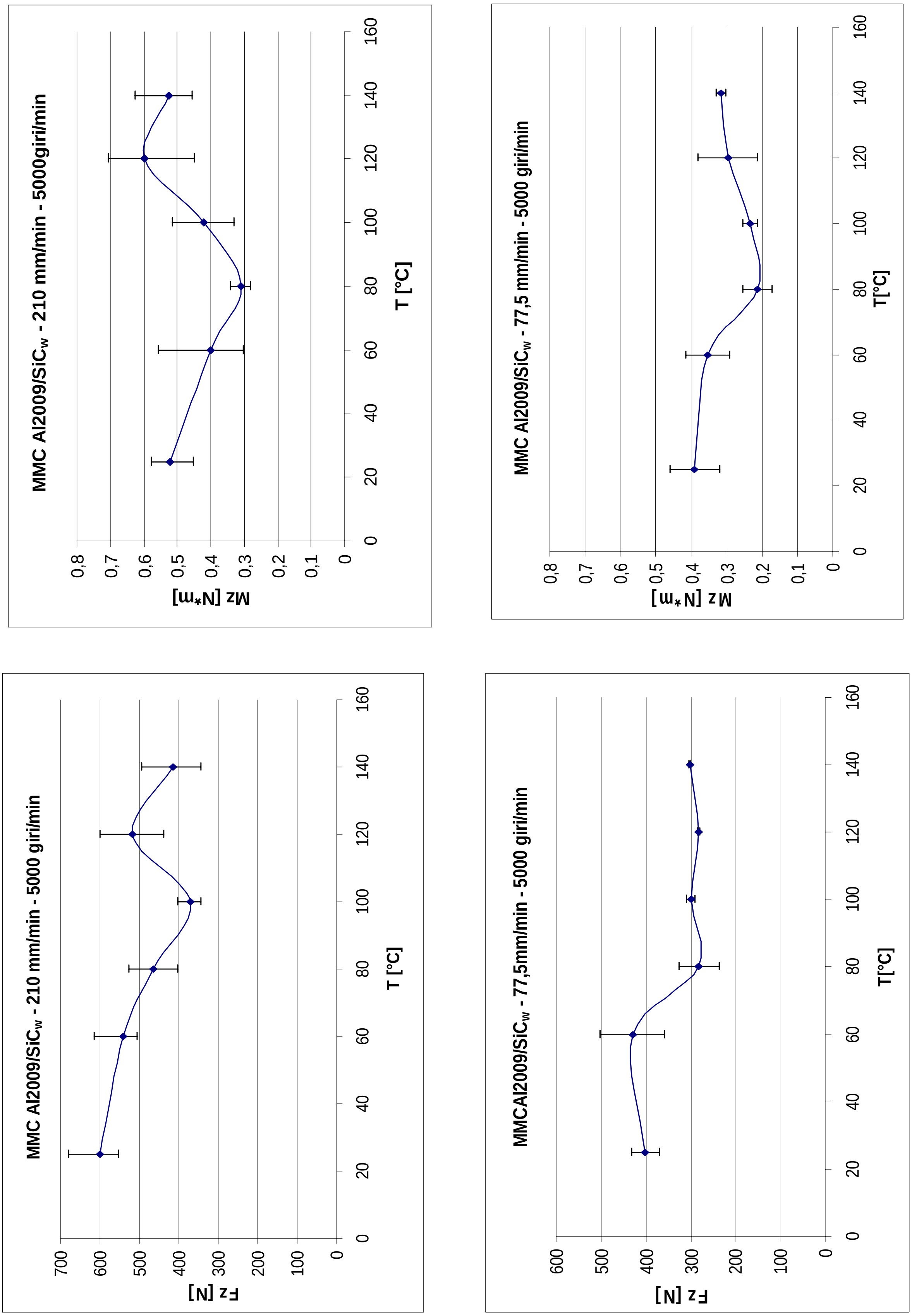
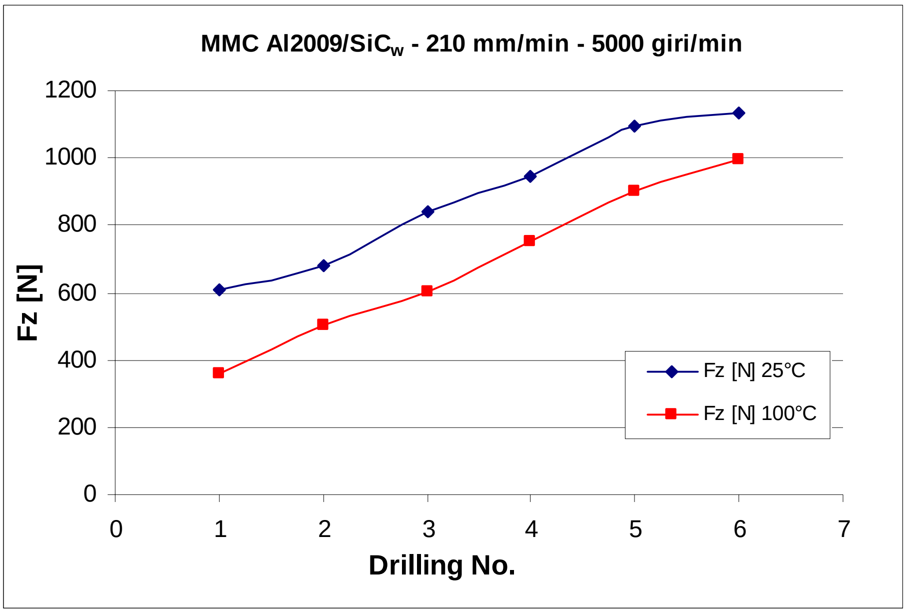


Fig.7 Al(2009)/SiC$_w$: F$_z$ and M$_z$ vs. T

According to the obtained results, it is useful to do a simple wear test concerning 6 holes carried out in succession with the same drill (to verify the wear first part as exhibited in Fig.5 of Cap.5), about the conditions of maximum feed a_z.



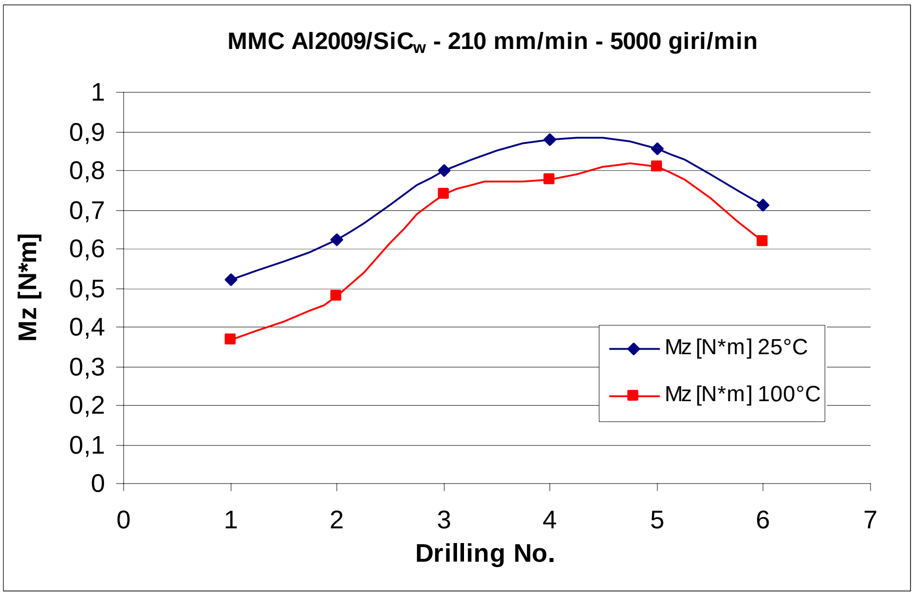


Fig.8 Al(2009)/SiC$_w$: F_z and M_z during the wear tool short experimentation

The stress reduction remains with the increase of drilling number, both for F_z and for M_z.

8.1.4 Micro-hardness

The study of stress has been followed by a first analysis, performed by HV micro hardness tests, about the effects of processing the material near the drilled holes. It has been measured as function of the distance from the realized drilling surface (Fig.9), at the T_{min} too.

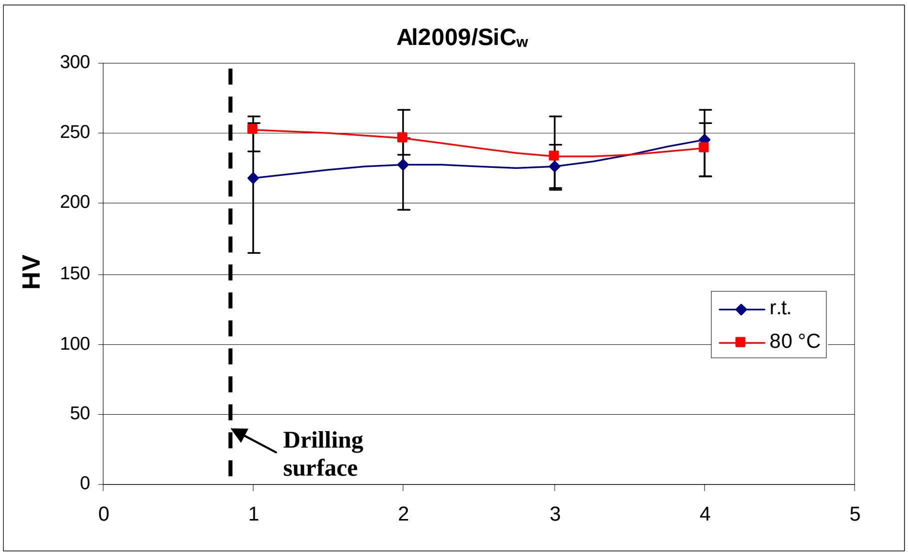


Fig.9 Al(2009)/SiC$_w$: Vickers hardness near the drilling surface

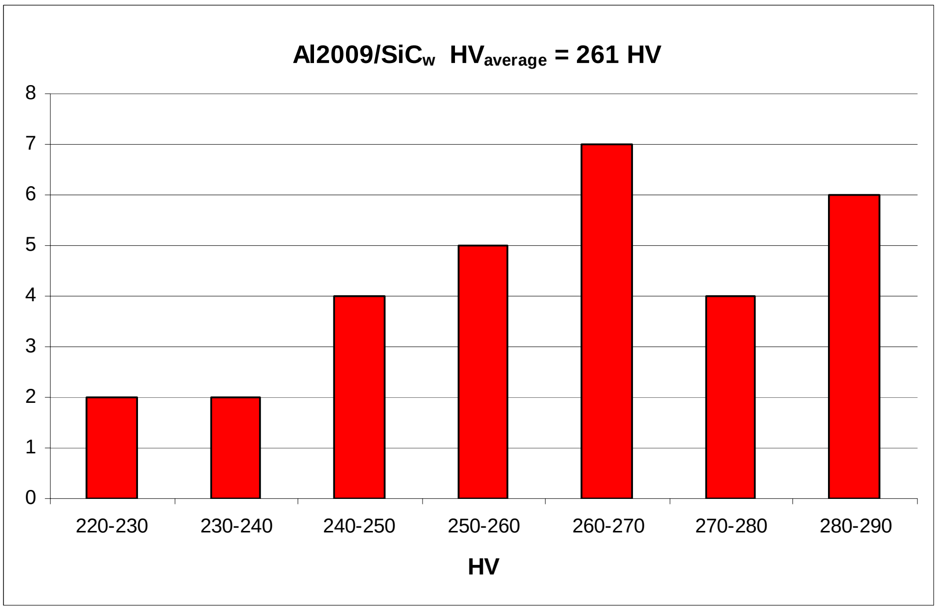
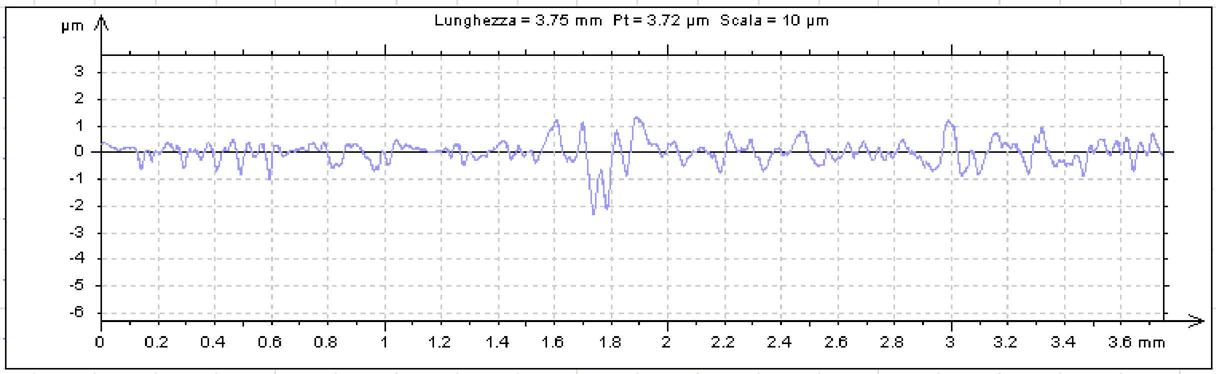


Fig.10 Experimental test to the microhardness evaluation

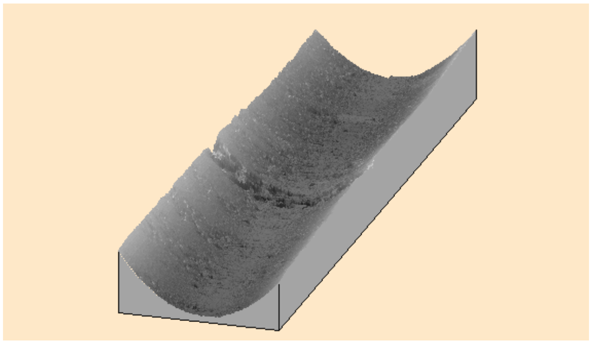
About that unfortunately there has not been a complete answer: a lowering of the values can be seen only in the immediate near the considered area, but it is not indicative. In fact, the experimentation tests adopted to verify the value the microhardness of the material (30 tests on the piece surface), which indicates 261 HV, is characterized by a too wide data dispersion data (Fig.10) .

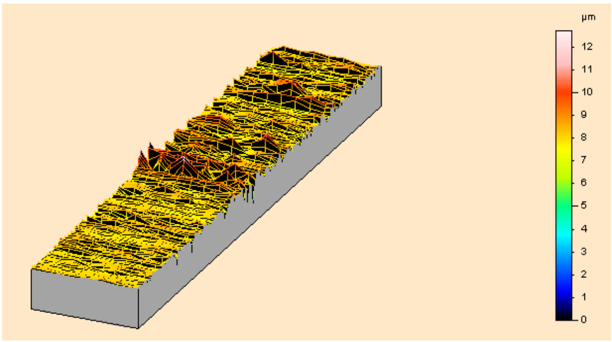
8.1.5 Surface roughness

About the numerical values of the parameter *Rq* (squared average deviation for the roughness profile), in the analyzed material, having an average value of 0.6 μm, no essential difference have been found between that at r.t. and at T_{min} (80°C). In particular you can see how at high workpiece temperature the drilling is characterized by more uniform surface (apart a central not uniformity probably due to accidental sliding of chip), where the peak-valley distance is less (Fig.11a) The situation is notable not only about the profile on average cross-section, but also in 3-D maps, properly cleaned by the hole curvature (Fig.11c).



a)

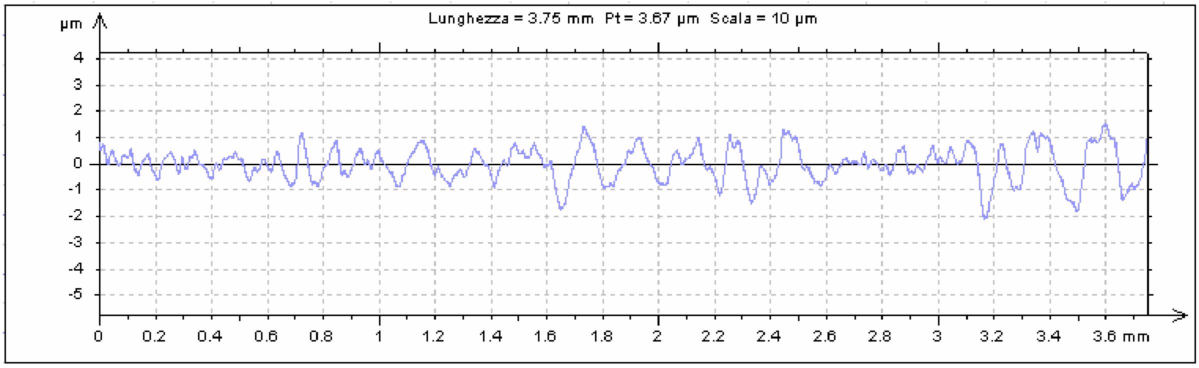




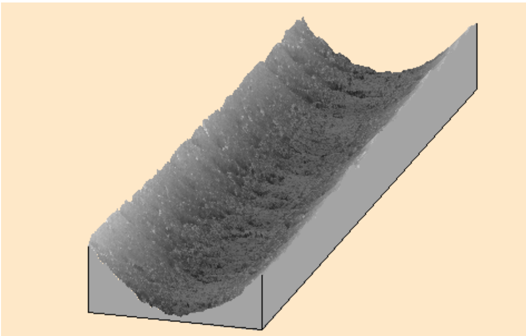
b) **c)**

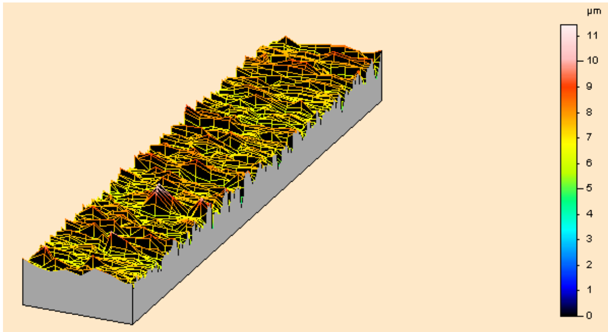
Fig.11 Al(2009)/SiC$_w$: roughness profiles for drilling at 80°C, a_z=0,04 mm/rev (Rq=0,4 μm)

In fact at room temperature both the average profile and the maps show less surface uniformity, especially in the exit side (right part of Fig.12a) of the drilling.



a)





b) **c)**

Fig.12 Al(2009)/SiC$_w$: roughness profiles for drilling at r.t., a_z=0,04 mm/rev (Rq=0,65 μm)

The fact that at temperatures higher than 80°C there was an increase in stress (and the greater dispersion than the average) it was explained as occurring propitious conditions could occur conducive to the formation of the cutting filling chip, with consequent increase of the forces necessary to remove it by the tool. Further evidence of this is certainly the roughness of the performed drilling at 140°C (Fig.13).

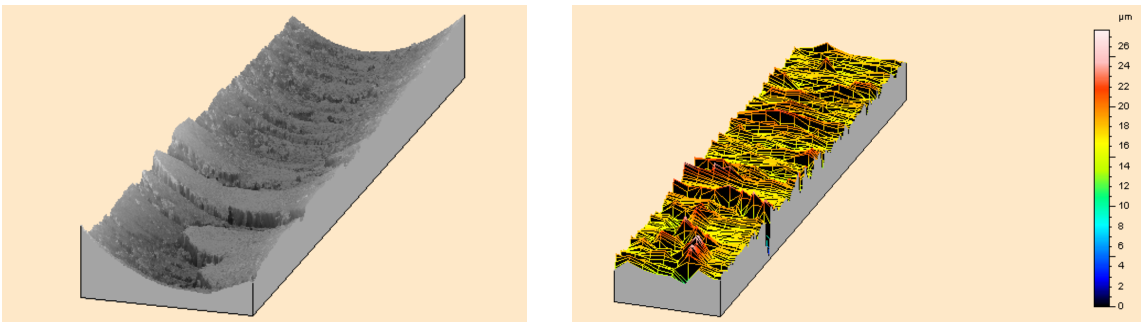


Fig.13 Al(2009)/SiC$_w$: roughness profiles for drilling at 140°C, a_z=0,04 mm/rev (Rq=0,95 μm)

By the 3-D maps it can be seen as part of chip attach on the surface, leading to an inevitable stress increase.

8.2 Al6061/SiC_w

8.2.1 FIMEC tests

Here are the results about the performed FIMEC tests are showed.

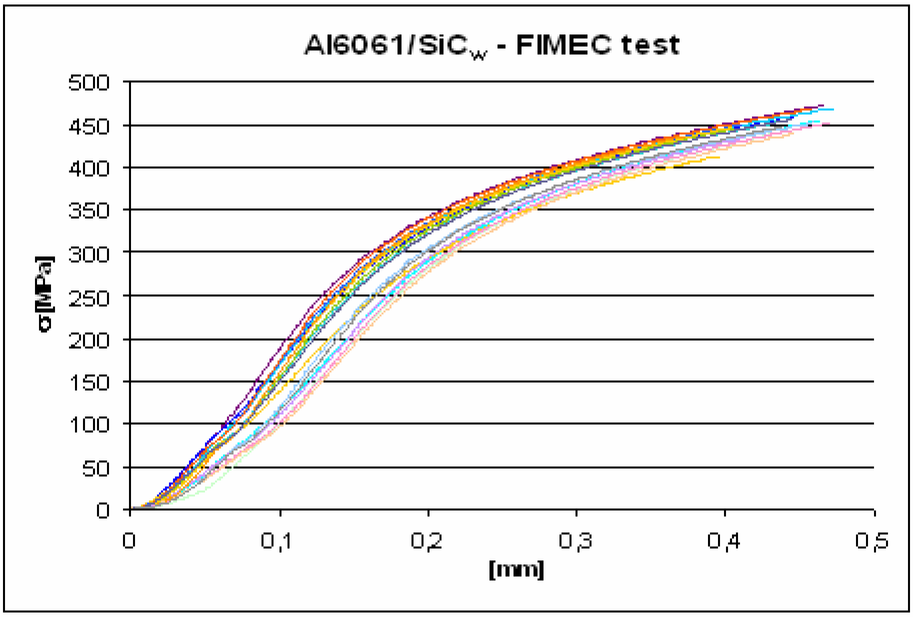


Fig.14 FIMEC curves obtained about the studied composite

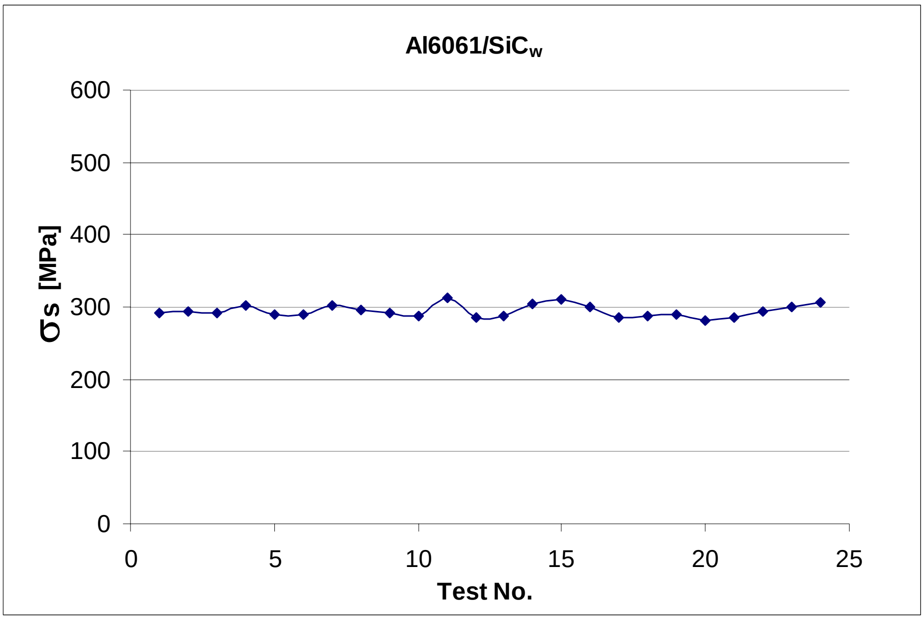


Fig.15 Yield stress calculated about the studied composite (average σ_S : 295.1 MPa)

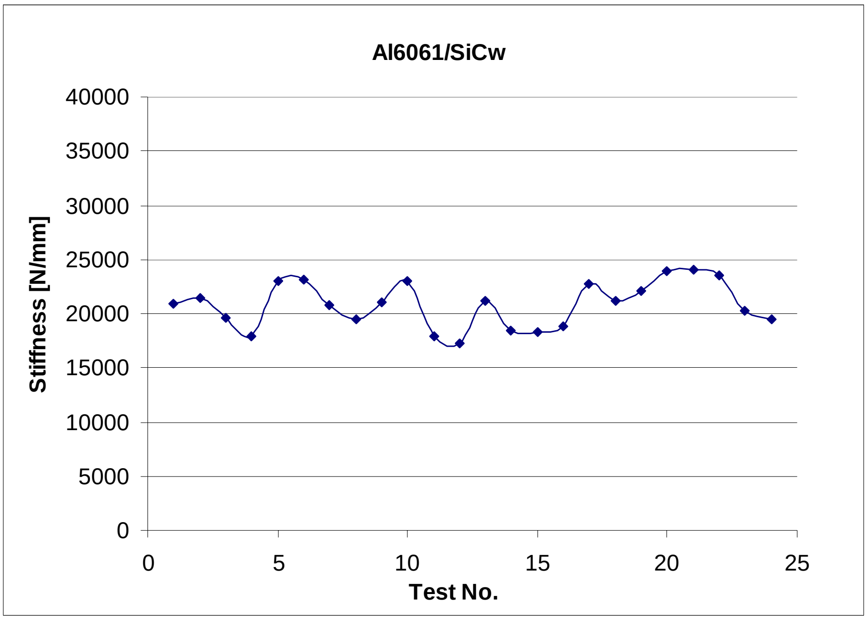


Fig.16 Stiffness calculated about the studied composite (average stiffness: 20815.9 N/mmm)

8.2.2 Cutting forces vs. feed a_z

In this case, while it is confirmed the proportionality of torque compared to feed, instead about the F_z trend seems to be the opposite of what we have seen before in Al2009/SiC_w. The reason may be in the low σ of the material (see carried out FIMEC tests in Fig.15), which involves, in addition to minor stress, more complex cutting process.

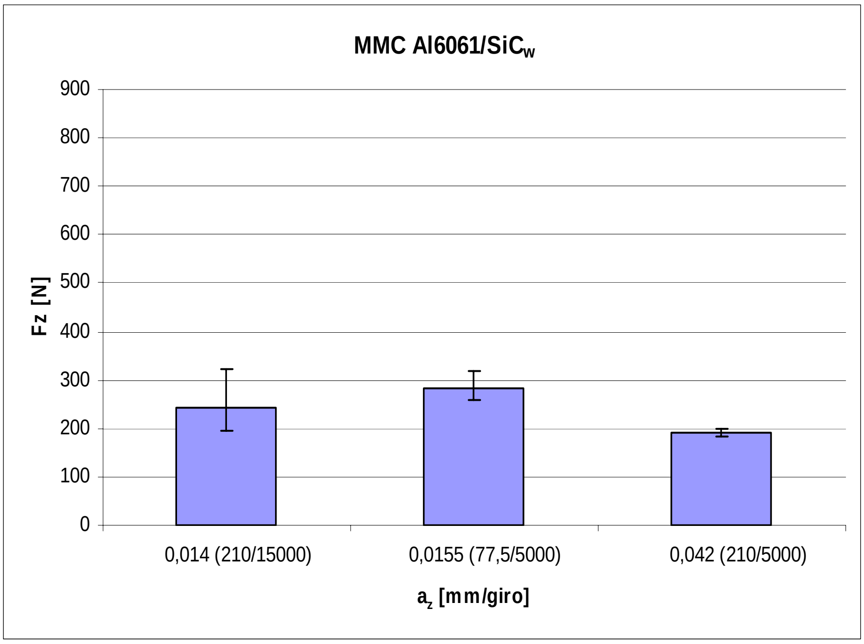


Fig.17 Al6061/SiC_w : F_z as function of a_z

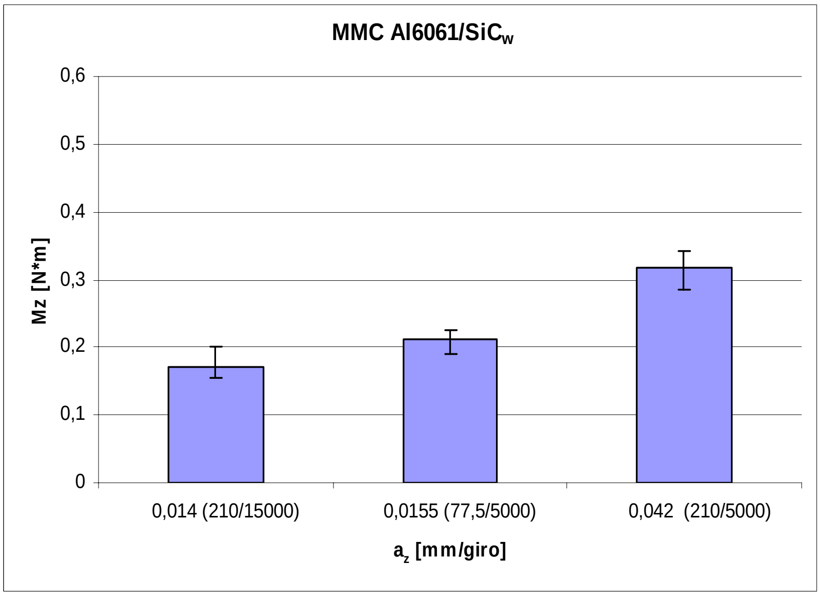


Fig.18 Al6061/SiC$_w$: M$_z$ as function of a$_z$

8.2.3 Cutting forces vs. temperature *T*

The properties for this material type means a very uncertain situation (Fig.19-20), apparently because the phenomenon of chip removal are more important than the usefulness obtained by the temperature increasing. Moreover this increase can certainly lead to an easier achievement of the conditions for the filling chip formation, cause of the scarce reductions in Fig.21, as well as at the highest level of error for the values at higher temperatures.

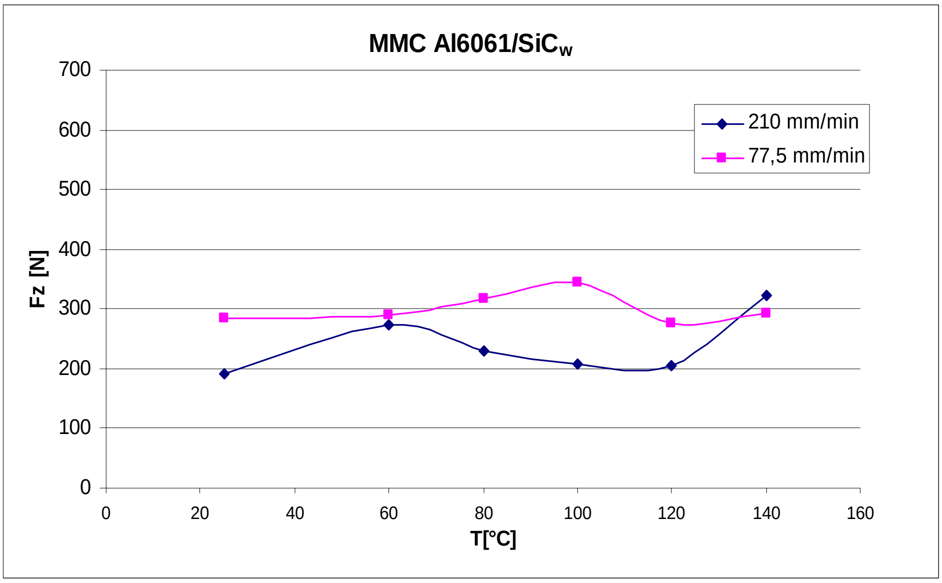


Fig.19 Al6061/SiC$_w$: F$_z$ vs. T

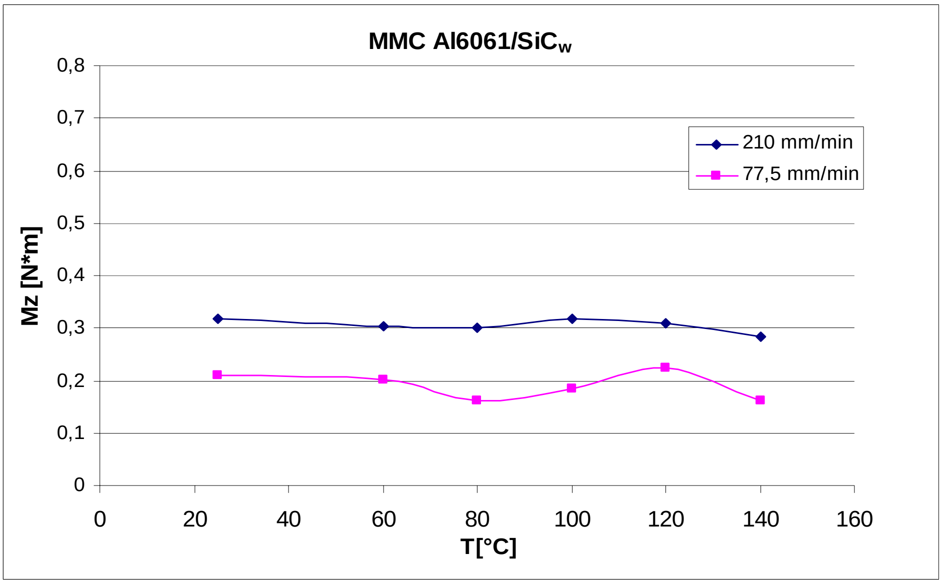


Fig.20 Al6061/SiC$_w$: M$_z$ vs. T

	rid.% Fz	rid.% Mz
210 mm/min	-	5,34%
77,5 mm/min	-	23,92%

Tab.2 Cutting stress riduction % from r.t. to the minimum T

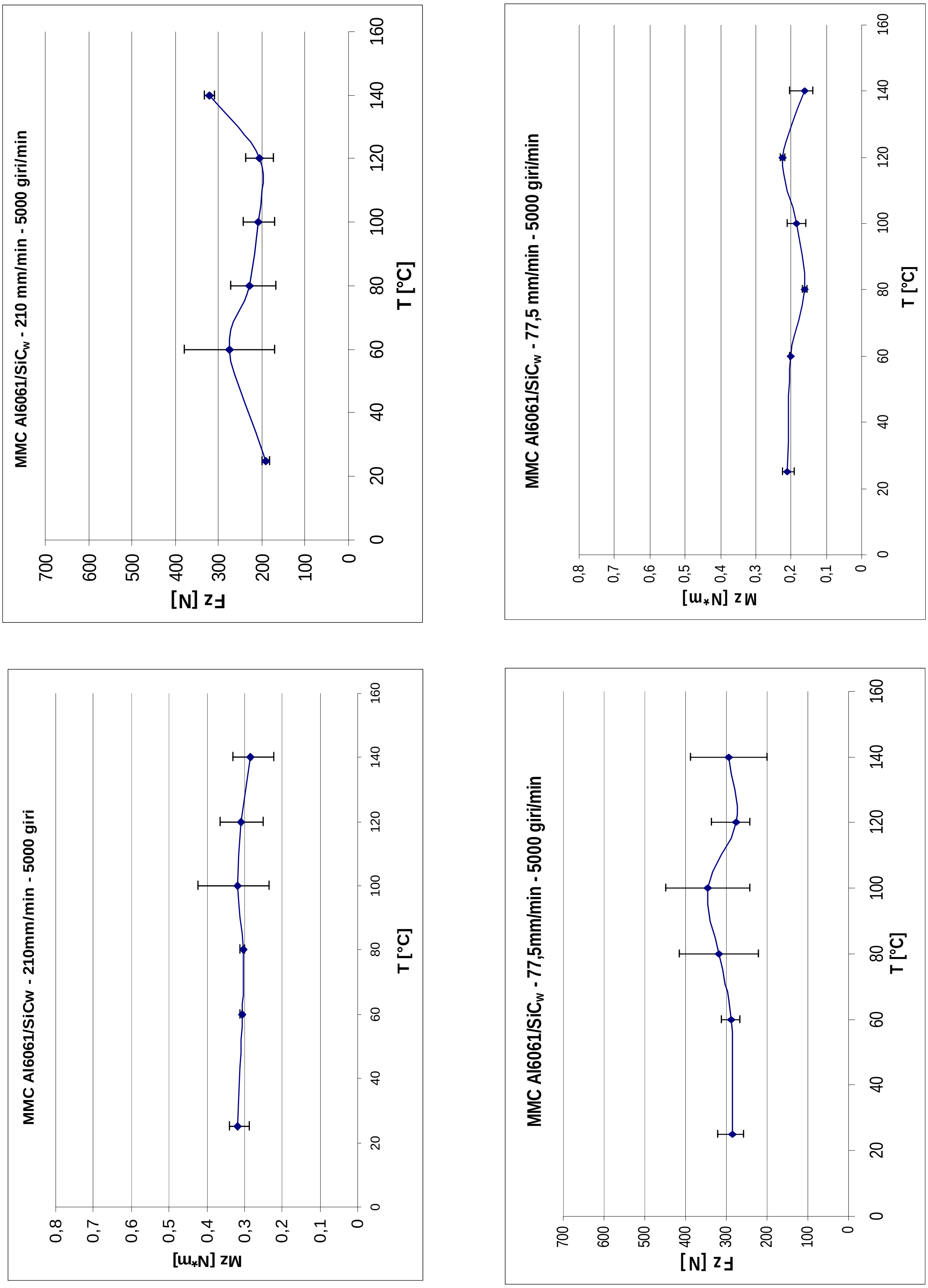


Fig.21 Al6061/SiC$_w$: F$_z$ and M$_z$ vs. T

8.2.4 Micro-hardness

The situation is more clear than in this composite respect to the previous. In fact, the experimental test to determine the actual value of this material can be included into a perfect Gaussian distribution for the data distribution, for that the average value is of 131,5 HV (Fig.22).

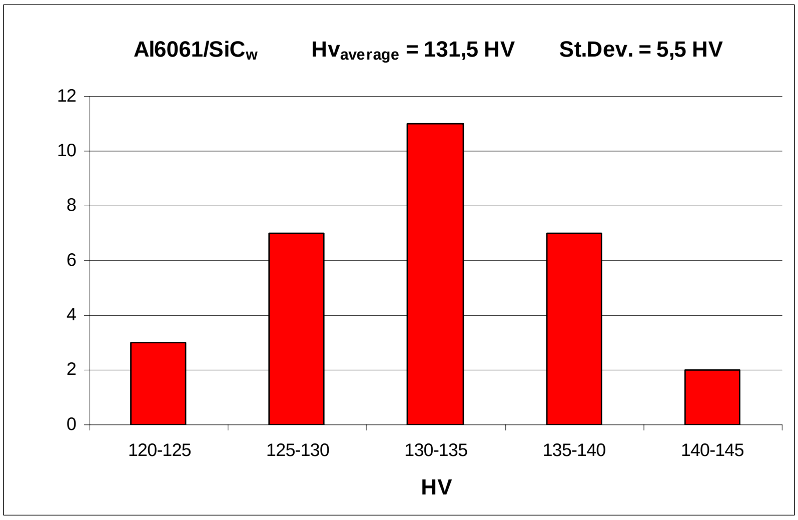


Fig.22 Experimental test to the micro-hardness evaluation

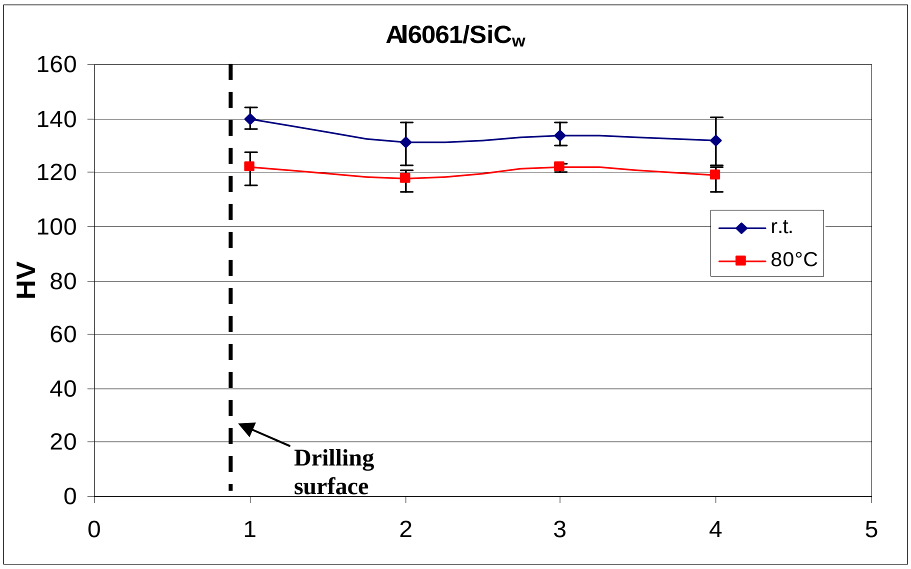


Fig.23 Al6061/SiC$_w$: Vickers hardness near the drilling surface

In particular by the hardness analysis near the drilling (Fig.23), it is possible to note as the heating causes a general lowering of values. A slight increase in the immediate vicinity of the drilling is observed, but generally a tension decrease (about 15%) is confirmed and so an improvement of the state of residual stress around the hole.

8.2.5 Surface roughness

About the carried roughness test very uncertainty is present for the drillings of this composite. A proof of this there is the trend about the same variable as function of temperature. This situation probably is due to the lower value of yield strength compared to that for the Al2000 alloy matrix.

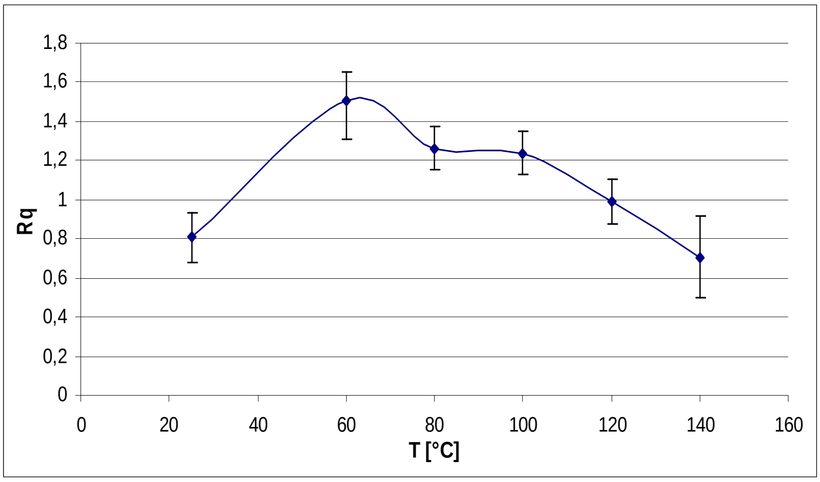
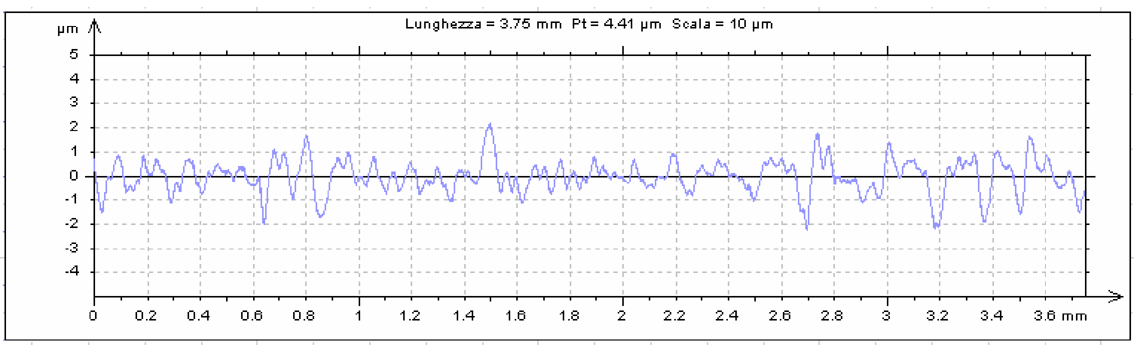
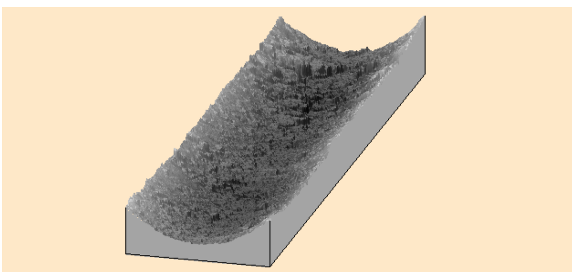


Fig.24 Al6061/SiC$_w$: Rq vs. T for a_z = 0,04 mm/rev

Now it is clear as in this case the workpiece heating facilitates the formation of the filling chip, finding at 60°C the beginning of a critical situation, which tends to decline with the resistance decrease of the material with temperature.



a)



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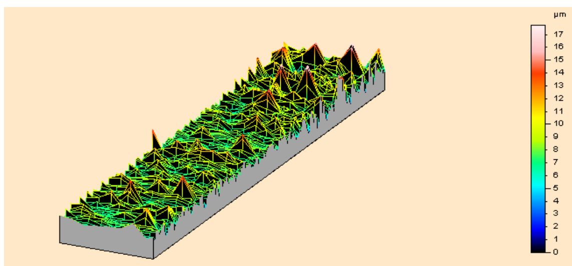


c)

Fig.25 Al6061/SiC$_w$: roughness profiles for drilling at r.t., a_z=0,04 mm/rev (Rq=0,8 μm)

To prove the latter case there are the profiles and 3D maps about the surface quality. At all temperatures higher than the room temperature it is noticed the presence of the chip attached to the drilling surface, already quietly identified by maps (Fig.25-26).

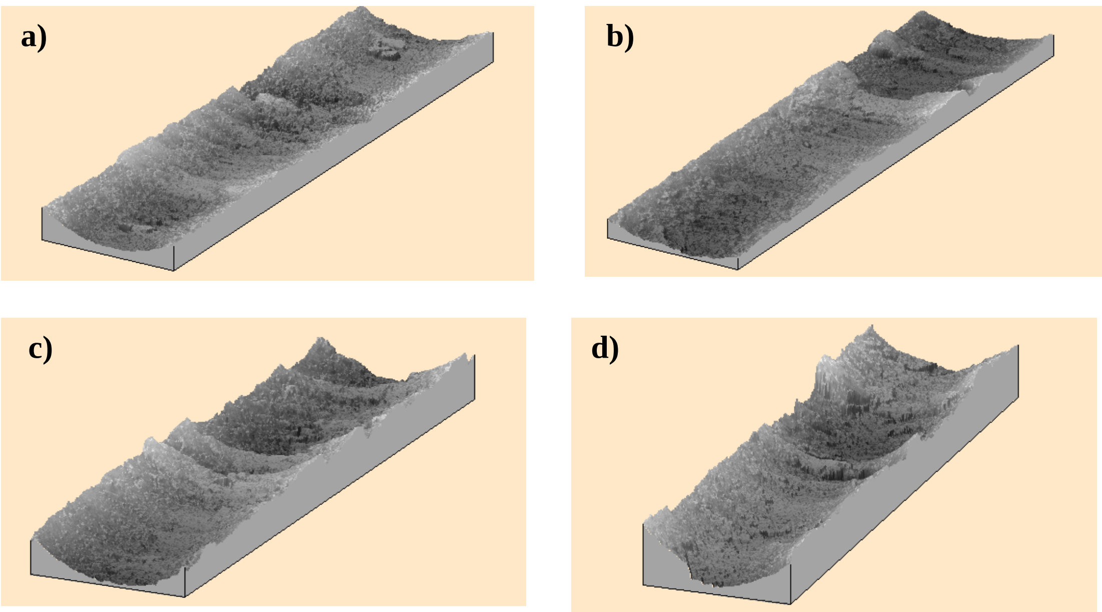


Fig.26 3D maps for the drilling considering to a) 60°C (Rq = 1,5 μm), b) 80°C (Rq = 1,3μm), c) 100°C (Rq = 1,2 μm) and d) 120°C (Rq = 1 μm), at a_z = 0,04 mm/rev

Therefore about what we said until now about the hot drilling hot in Al6061/SiC_w, the heating causes no noticeable effect on the stress state, that raises during processing. The surface quality of holes is slightly worse, but in exchange for a significant reduction of the material hardness around the hole.

8.3 Al6061/Al_2O_3

To verify the influence of the reinforcement on the drilling operations of composite, experimental tests have been carried out about the Al6061/Al_20_3.

About the FIMEC tests, carried out by the methodologies described in the Par.7.5, Fig.27 show them for the difference tests speed adopted.

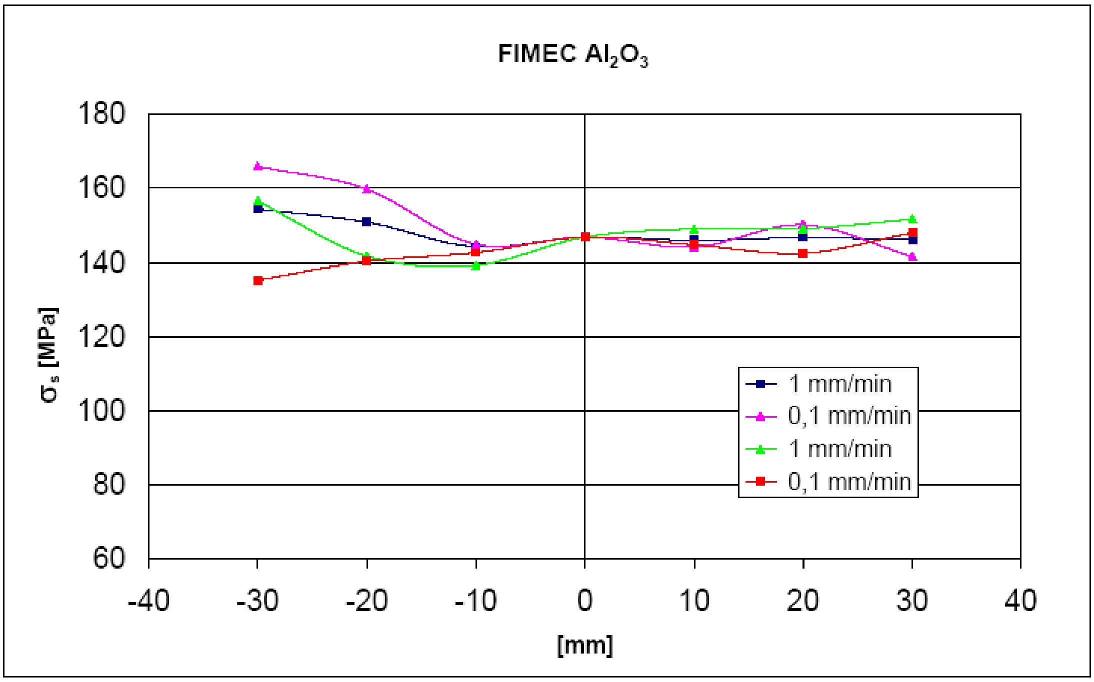
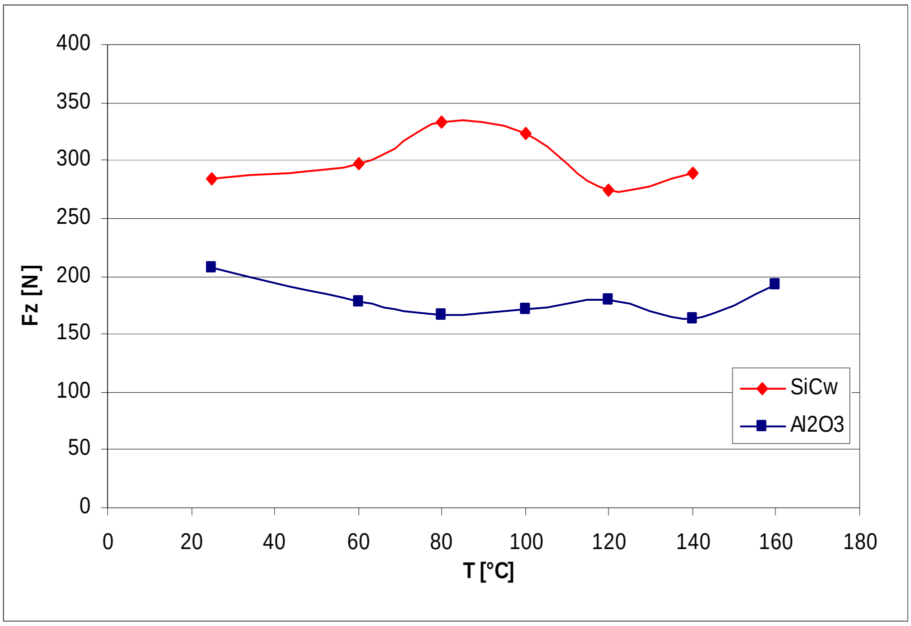


Fig.27 Yield stress calculated about the indicated composite as function of radial distance from the centre of the circular section

The results indicate as in this case the probe speed is not influent for the value of yield stress. Differences are notable about an external part of the analyzed section, cause probably the not uniform reinforcement radial distribution on the bar. This fact will be important during the evaluating of cutting forces and it makes think about the importance of the technologic process on the following operations.

About the cutting forces values for the drilling of this material, the obtained results have been at once compared with that for the aforesaid composite with reinforcement of SiC and obviously with the same matrix.

The comparison is showed in Fig.28. In this case the drilling operation have been carried out at v_{feed}=*77,5 mm/min* and *n =500 rpm*.



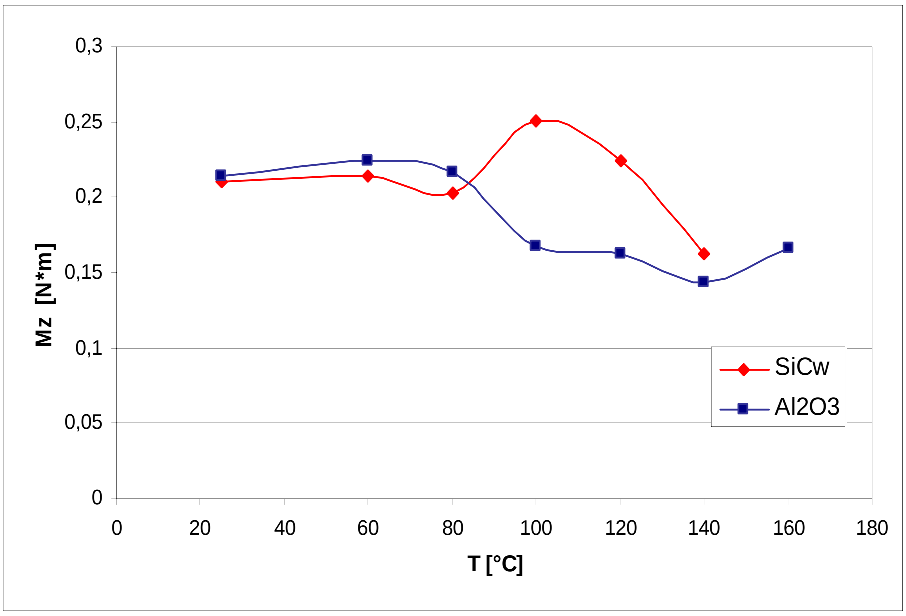
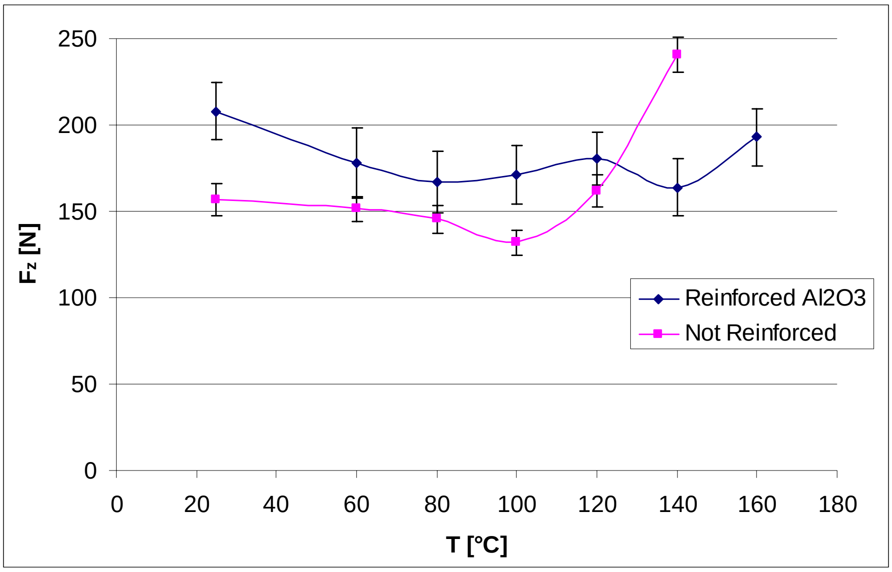


Fig.28 Comparison F_z and M_z for the composite Al6061/SiC_w and Al6061/Al_2O_{3p}

Logically it is necessary to recall that the reinforcement percentage is minor in the actual composite (10%). Nevertheless the analysis of the eventual advantage that the hot drilling can involve results interesting, especially if the new reinforcement changes the not great results about that in SiC.

By that an higher effect on the drill by the harder reinforcement as the SiC_w, especially in thrust F_z. Instead about torque M_z for the first temperature the behaviour is the same, then it change drastically from 100°C. For the composite reinforced with particle M_z decreases up to 140°C, for a reduction of about 30%, that also happens to F_z but with less incisiveness. This is not bad, especially recalling that the by torque stress directly agent on the cutting edge comes causing their wear. Therefore in this case it is clear as the Al6061/Al_2O_3 lends in a better way to an hot drilling system, probably associated to an inhibitor effect of the reinforcement about the formation of filling chip that the SiC_w didn't have..

At this point we wanted to develop a comparison (with the same cutting parameters v_{feed} and *n*) between the considered material and that gave the best results in terms of F_z and M_z minimization, i.e. with an widespread aluminium alloy, the Al6082, in order to verify the validity of the results in terms of its effective application and the real effects of the reinforcement (Fig.29).



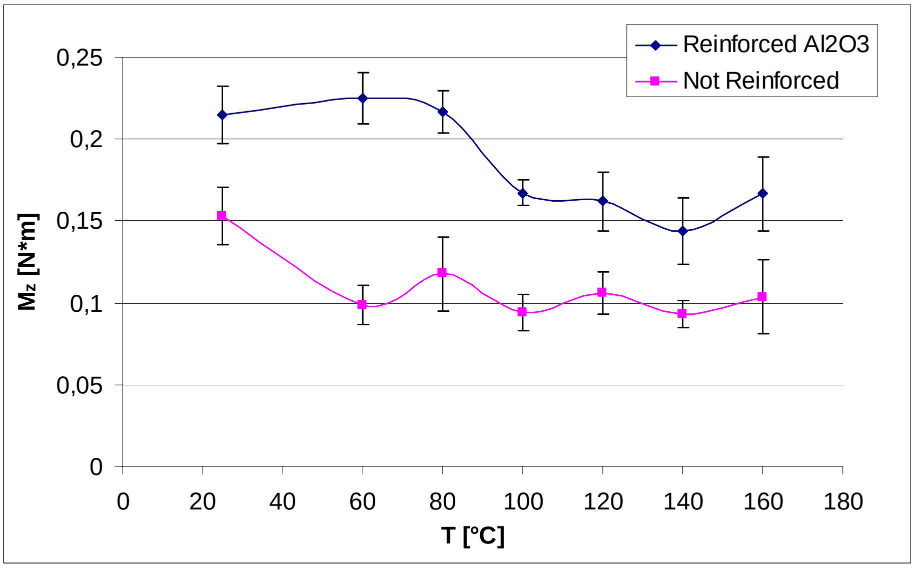


Fig.29 Comparison of F_z and M_z for the composite Al6061/SiC_w and the Al6082 alloy

If the not reinforced alloy it is possible to see the presence of a minimum temperature at 100°C, the reasons for which are given in [45], this situation is not true in the composite, although there is an effective decrease in the values. This observation may be explained however with the resistance decrease, due to the sample heating, of the aluminium alloy constituting the matrix. It must be noted that the values of the analysis at the different temperatures, except at 140°C, are all higher than those about the tests on the alloy Al6082, cause in this case the particle reinforcement is fundamental. Nevertheless the role of the the matrix, that is not irrelevant compared to all that what has been analyzed.

About the comparison with the not reinforced alloy, you can see that they have a similar trend. The difference is that the composite values are higher than in Al6082, again because of the presence of ceramic particle reinforcement. In addition at the 160°C temperature a slight increase in the torque value is observed, and as for the thrust, the reason is found in the condition changing about the chip formation mechanism.

The complexity of the cutting condition for this situation is demonstrated by the wear tests carried out on this latter composite, verifying the trends of thrust F_z and torque M_z as function of the number of worked drilling.

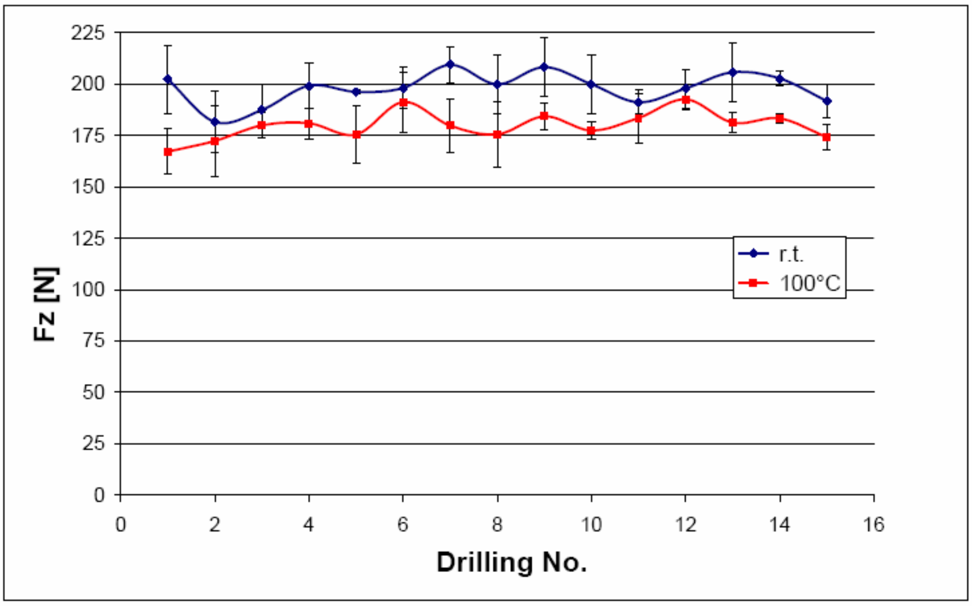


Fig.30 Thrust force F_z vs. number of drilling by the same drill

The results about the temperature for the minimum thrust F_z are just confirmed, despite of the irregular trend (Fig.30). It is not possible to say the same concept for the torque M_z, that moreover results more important for the wear condition. In fact by Fig.31 it is noticeable the not respect of the reduction of the force with the temperature, in fact Mz becomes higher in the subsequent realized drilling.

The situation is due to the not suitability of the adopted HSS drill, that over time feel too much the abrasive action of the particle reinforcement.

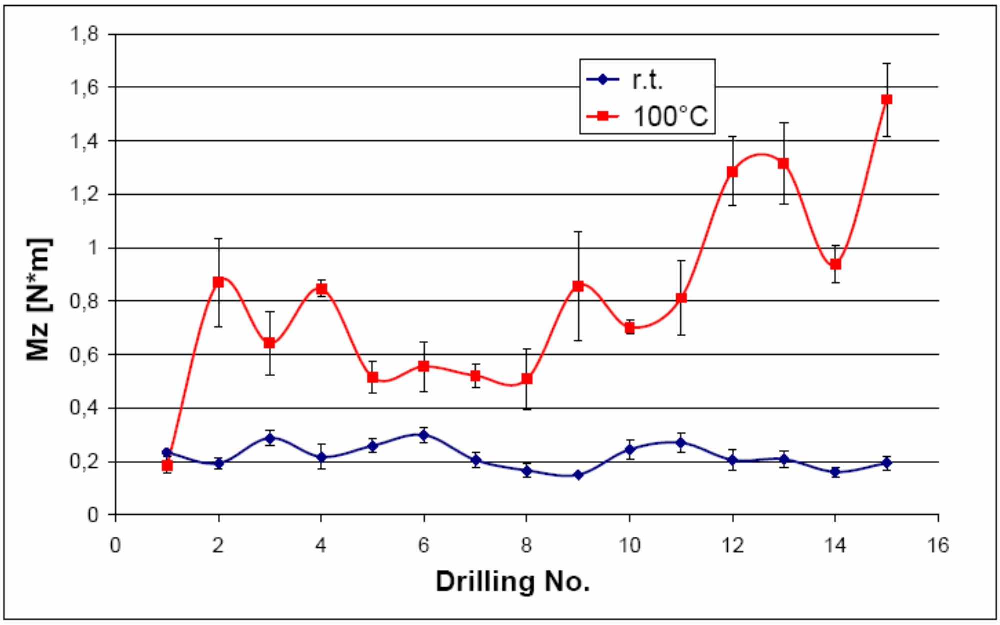


Fig.31 Thrust force F_z vs. number of drilling by the same drill