Chapter 4

Results

This chapter presents the results obtained from experimentally cutting UG2 reef samples, a comparison between the results obtained from cutting UG2 reef and sandstone samples and finally the results of the final numerical simulations are compared to the experimental results.

4.1 UG2 rock properties

Determining rock properties of UG2 reef rock is difficult due to the large inconsistency of this rock type. Literature was used to obtain an estimations for the rock properties of the UG2 reef rock. The only property that was known, of the sample that was used in the experimental cutting tests, is the density of the UG2 reef sample. The UG2 reef sample has a density of 4.19 g/cm^3.

Figure 4.1 shows the uniaxial compressive strength of UG2 reef samples at different locations. Lonmin Platinum and Impala Platinum have different values when taken from different places in the mine. The values varied from 115.8 MPa to 81 MPa in Lonmin Platinum mine and from 91 MPa to 110 MPa in Impala Platinum mine. This shows the inconsistency of the rock type.

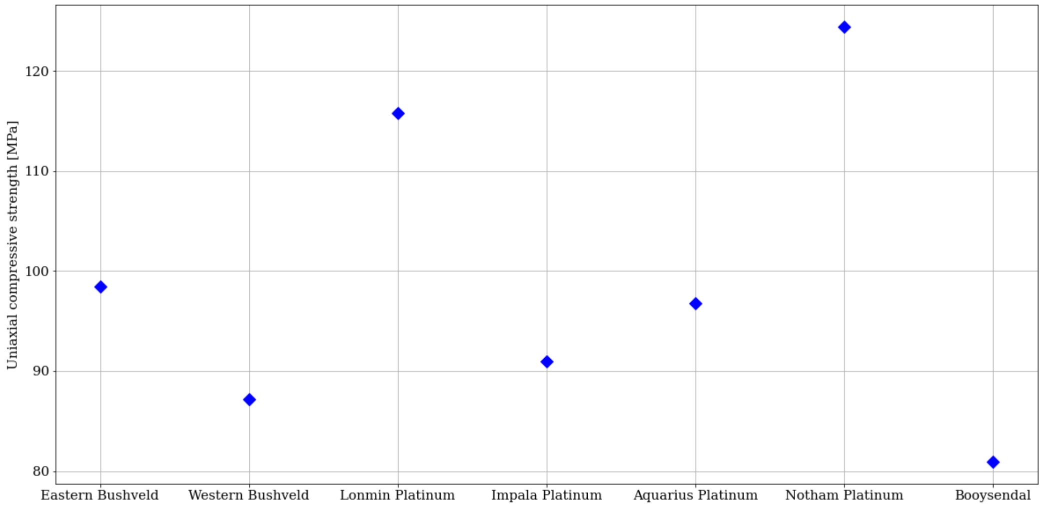

Figure 4.1: Uniaxial compressive strength of UG2 reef samples at different locations.

Literature (Höll, 2009) also gives us data on the density, Young's modulus and Poisson's ratio. Table 4.1 shows the data for three different test results from Everest Platinum Mine.

Table 4.1: Rock properties for UG2 from Everest Platinum.

Uniaxial compressive strength [MPa]	Density [g/cm^3]	Young's Modulus [GPa]	Poisson's ratio
139.3	3.8	115.4	0.499
94.3	3.61	55.2	0.152
138.7	3.84	98.8	0.342

These rock properties was used to determine the initial parameter values for the CSCM in the numerical simulation.

In this study the UG2 reef sample was obtained from the Siyanda Bakgatla Platinum Mine, located in Swartklip, Limpopo. The rock sample was taken out of the underground mine and brought to our laboratory. The sample was not affected by weathering. The sample was cut into manageable size samples that was used in the laboratory scale cutting tests. Figure 4.2 shows the UG2 reef sample before it was cut into smaller sized samples.

Figure 4.2: UG2 reef sample.

4.2 Experimental results

In the experiments, UG2 reef rock samples were cut using different cutting parameters. The parameters that were changed are cutting depth, cut spacing to cutting depth ratio and skew angle. Cutting depths of 2 mm and 4 mm were used, where the skew angle was 0°, and the cut spacing to cutting depth ratio was changed from one to six.

The skew angle was changed from $-10°$ to $0°$ and to $+10°$ while the cutting depth remained 2 mm and the cut spacing to cutting depth ratio was changed from one to six. These changes in parameters will show the influence of the different parameters on the cutting performance when cutting UG2 reef samples with a conical pick.

For each set of parameters, a total of six cuts were made. The sequence of cuts depended on the cutting depth and the available cutting area of the UG2 reef sample. For 2 mm of cutting depth, two sets of cuts were required to get six cuts per set of cutting parameters. For 4 mm of cutting depth, three sets of cuts were required to get six cuts per set of cutting parameters.

Only cutting depths of 2 mm and 4 mm were tested due to forces required when cutting at larger cutting depths. The strength and stability of the machine was a concern at larger cutting depths. Owing to limited time and the concern of machine failure the cutting depth did not pass 4 mm in depth.

Figure 4.3 shows the UG2 reef rock sample pre-cut and after a 2 mm cutting sequence. The same cutting sequence was used as discussed in section 3.3.

(a) Pre-cut.

(b) After 2 mm cutting sequence.

Figure 4.3: UG2 reef rock sample pre-cut and after a 2 mm cutting sequence.

The following results were obtained for cutting the UG2 reef sample at a cutting depth of 2 mm and a skew angle of $-10°$, $0°$ and $+10°$. Figure 4.4 shows the mean normal force at a cutting depth of 2 mm and different s/d values.

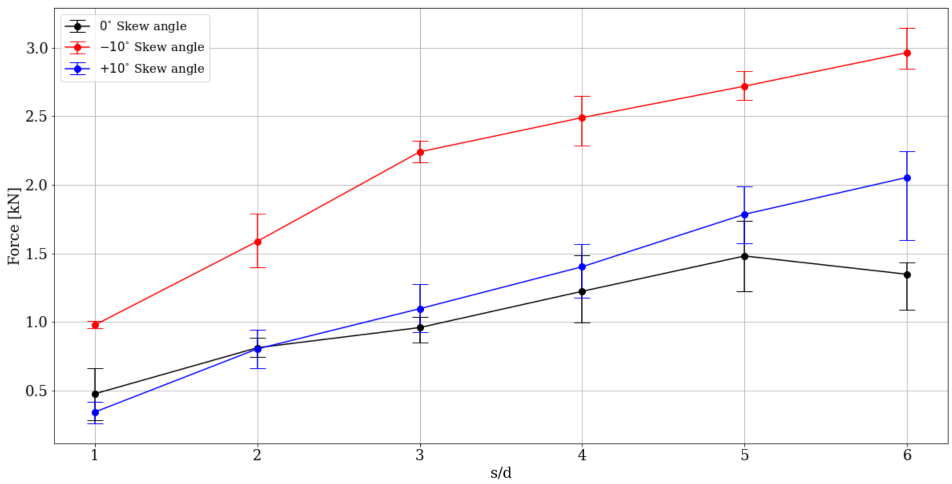

Figure 4.4: Mean normal force at 2 mm cutting depth and different s/d values.

Figure 4.5 shows the mean drag force at a cutting depth of 2 mm and different s/d values.

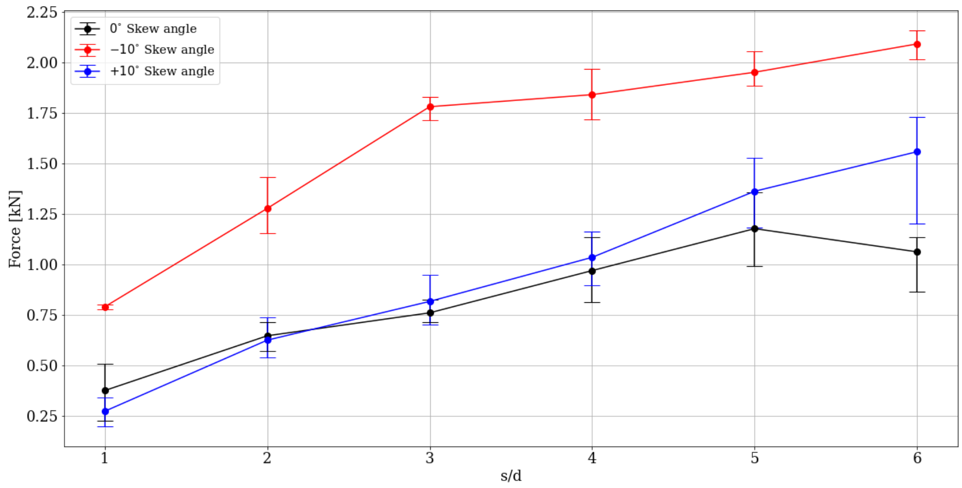

Figure 4.5: Mean drag force at 2 mm cutting depth and different s/d values.

Both the mean normal force and mean drag force follow the same trend as the sandstone from section 3.3, where the mean force increases linearly with the s/d value. Also the mean forces for a negative skew angle are higher than that of zero skew angle and positive skew angle. The mean forces for zero skew angle and positive skew angle are similar to one anther just like the sandstone.

Figure 4.6 shows the mean side force at a cutting depth of 2 mm and different s/d values. The zero skew angle and positive skew angle were cut in the same direction. This is why the mean side force values for the zero skew angle and positive skew angle are mostly positive.

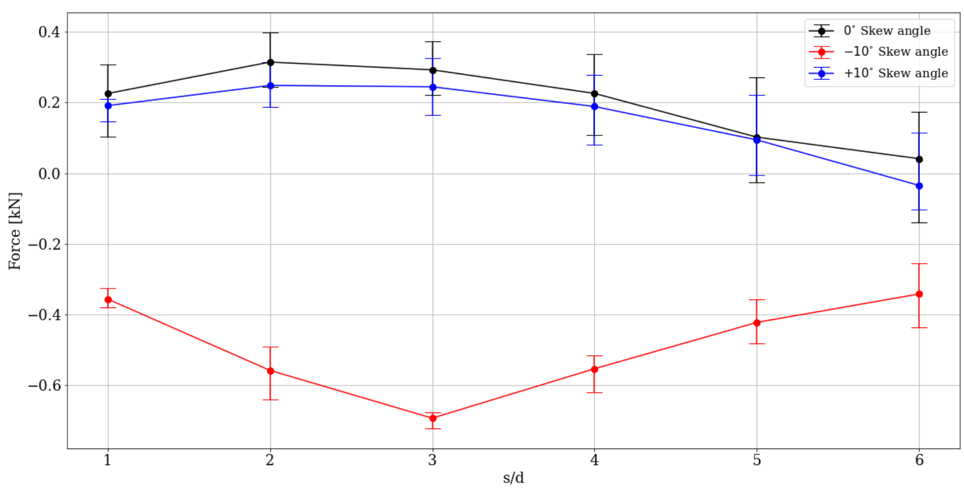

Figure 4.6: Mean side force at 2 mm cutting depth and different s/d values.

The mean side force follows the same trend as the sandstone from section 3.3 where the negative skew angle has the highest magnitude in force values and the positive skew angle has the lowest magnitude in force values, compared at different s/d values. For the positive skew angle the direction of side force changes close to a s/d value of 5 similar to the sandstone. Figure 4.7 shows the peak normal force at a cutting depth of 2 mm and different s/d values.

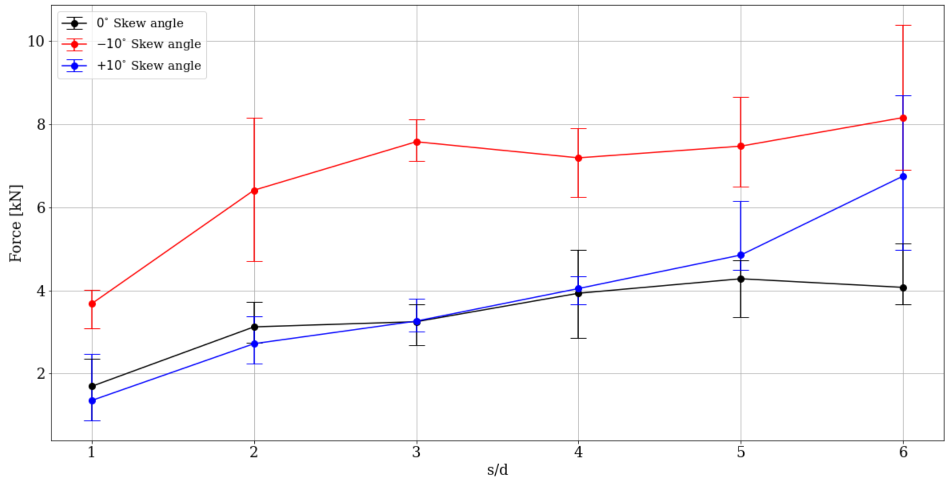

Figure 4.7: Peak normal force at 2 mm cutting depth and different s/d values.

Figure 4.8 shows the peak drag force at a cutting depth of 2 mm and different s/d values.

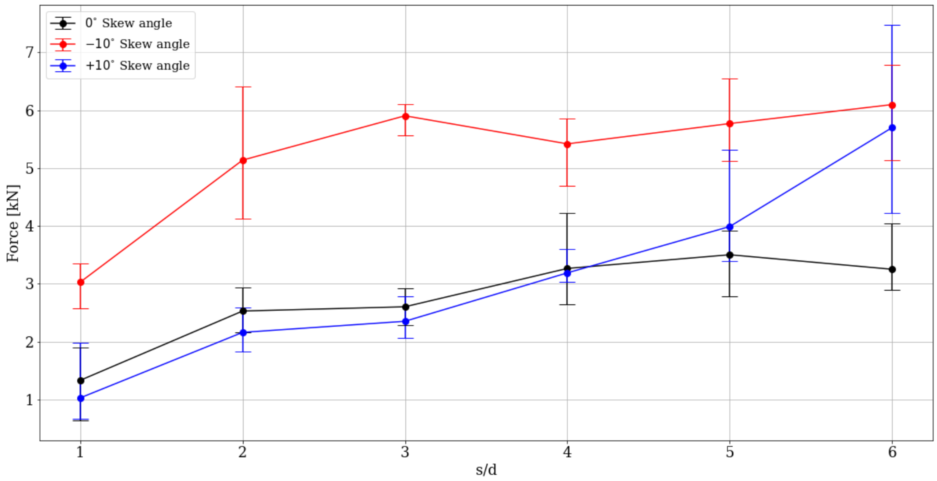

Figure 4.8: Peak drag force at 2 mm cutting depth and different s/d values.

The peak normal force and peak drag force follow a different trend than the sandstone from section 3.3. For the sandstone, at all the skew angles, the peak forces increased linearly. For the UG2 reef sample only at a positive skew angle does this linear relationship occur. For negative skew angle and zero skew angle the peak forces plateaus at a s/d value of 3 and 2 respectively. This is an interesting observation of the UG2 reef sample compared to sandstone. This can be due to inconsistencies in the rock sample, which is discussed in section 4.3, because the direction of the sequence of cutting is different for positive skew angle compared to zero skew angle and negative skew angle as discussed in section 3.3.1.

Figure 4.9 shows the peak side force at a cutting depth of 2 mm and different s/d values.

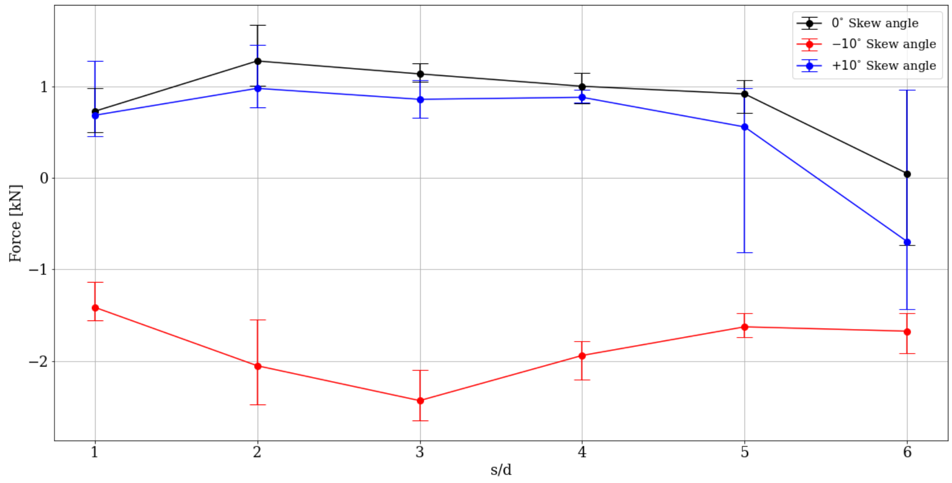

Figure 4.9: Peak side force at 2 mm cutting depth and different s/d values.

The peak side forces follow the same trend as the sandstone.

Figure 4.22 shows the specific energy at a cutting depth of 2 mm and different s/d values.

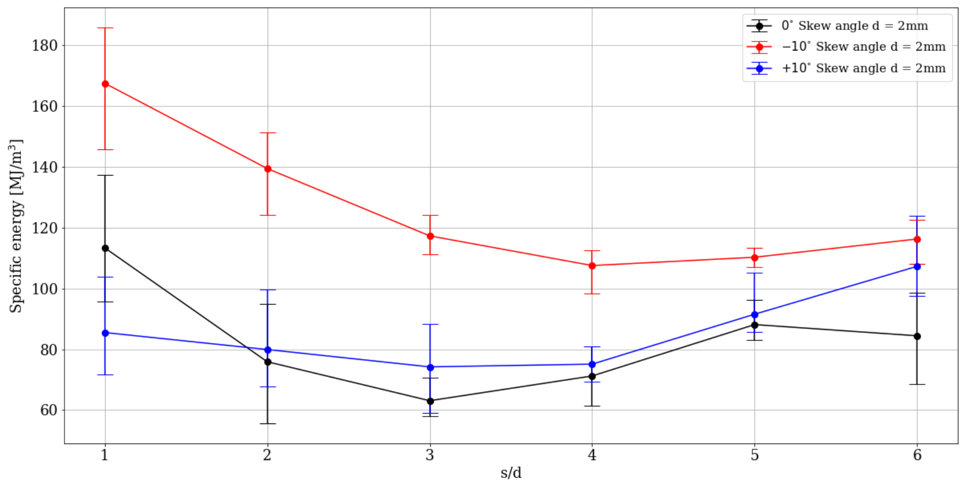

Figure 4.10: Peak side force at 2 mm cutting depth and different s/d values.

The specific energy of the UG2 reef samples, at a cutting depth of 2 mm, follow the same trends as the sandstone from section 3.3. When examining the optimal s/d value for the different skew angles a higher s/d value such as 4 is optimal for a $-10°$. A lower s/d value is optimal for a skew angle of $+10°$. Thus a value of either 2 or 3. For $0°$ skew angle a s/d value of either 3 or 4 will be optimal.

One difference is that for almost all the s/d values the specific energy is lower at a skew angle of $0°$

than a skew angle of $+10°$. Which is not the same for sandstone.

The specific energy plateaus for a skew angle of 0° at a s/d value of 5. This implies that at a s/d value of 5, the previous cut does not have an influence on the current cut.

The following results were obtained for cutting UG2 reef samples at a cutting depth of 4 mm. The skew angle remained the same, at zero for the cutting tests. The s/d value was again changed from one to six. As stated before for the 4 mm cutting depth three cutting sequences had to be performed to get six cuts for each set of cutting parameter. For the three cutting sequences, the data has a larger variance than the data from 2 mm cutting depths.

The larger variance is also due to the inconsistency in the UG2 reef sample. This is discussed in section 4.3. The variance of the forces is also not the best indication of the reliability of the data. A better indication of the reliabilty of the data is the variance of the specific energy. Because the specific energy takes into account both the force and the volume cut.

Figure 4.11 shows the mean normal force at a cutting depth of 4 mm and a skew angle of zero.

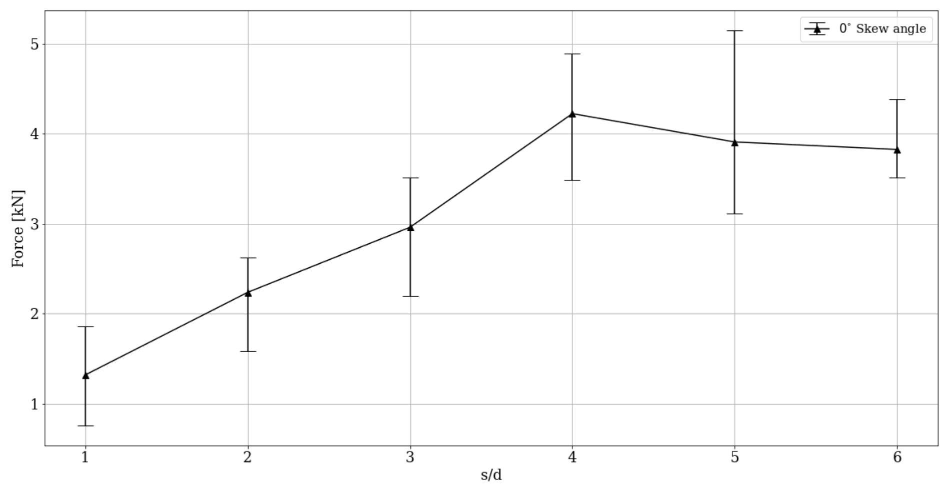

Figure 4.11: Mean normal force at 4 mm cutting depth and different s/d values.

Figure 4.12 shows the mean drag force at a cutting depth of 4 mm and a skew angle of zero.

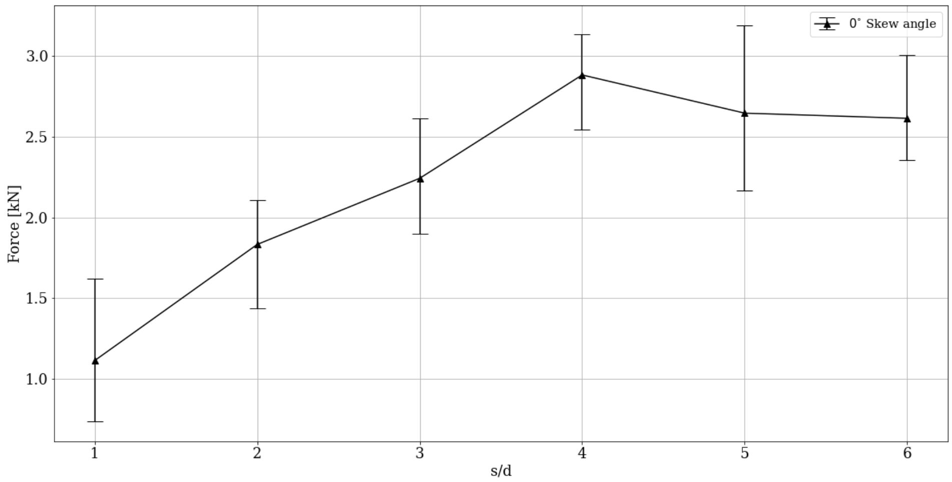

Figure 4.12: Mean drag force at 4 mm cutting depth and different s/d values.

Both the mean normal force and mean drag force plateaus at a s/d of 4. This implies that at a s/d value of 4 and more, the previous cut does not have an influence on the current cut. This does not follow the same trend as the sandstone or the UG2 reef sample at 2 mm cutting depth.

The plateaus show that the depth of cut has a larger influence on the cutting performance and that assuming it follows the same trend as the sandstone would be an incorrect assumption. This behaviour needs to be considered when designing cutting machines and mythologies.

Figure 4.13 shows the mean side force at a cutting depth of 4 mm and a skew angle of zero.

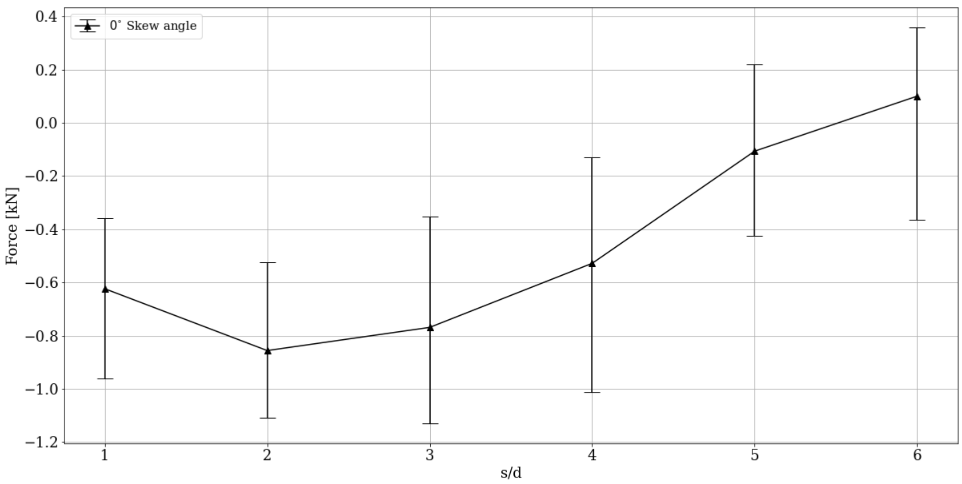

Figure 4.13: Mean side force at 4 mm cutting depth and different s/d values.

The mean side force at a cutting depth of 4 mm follows the same trend for both the sandstone and the UG2 at a cutting depth of 2 mm.

Figure 4.14 shows the peak normal force at a cutting depth of 4 mm and a skew angle of zero.

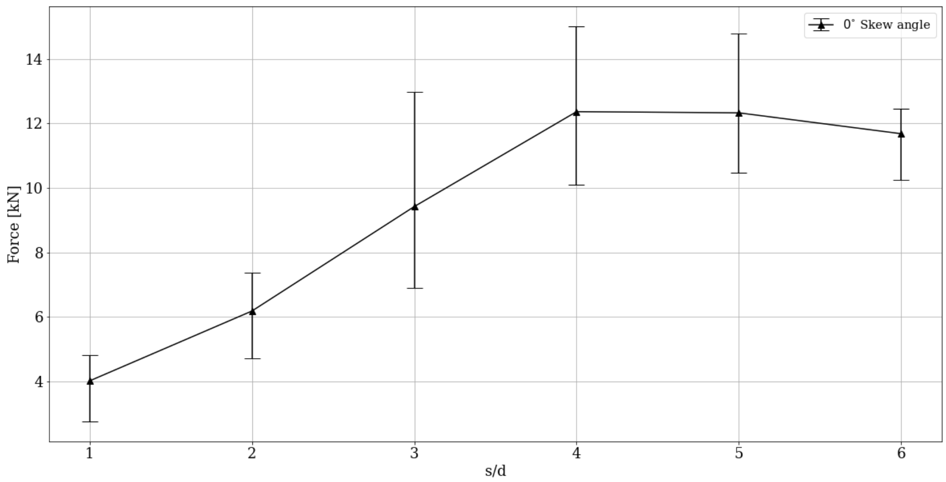

Figure 4.14: Peak normal force at 4 mm cutting depth and different s/d values.

Figure 4.15 shows the peak drag force at a cutting depth of 4 mm and a skew angle of zero.

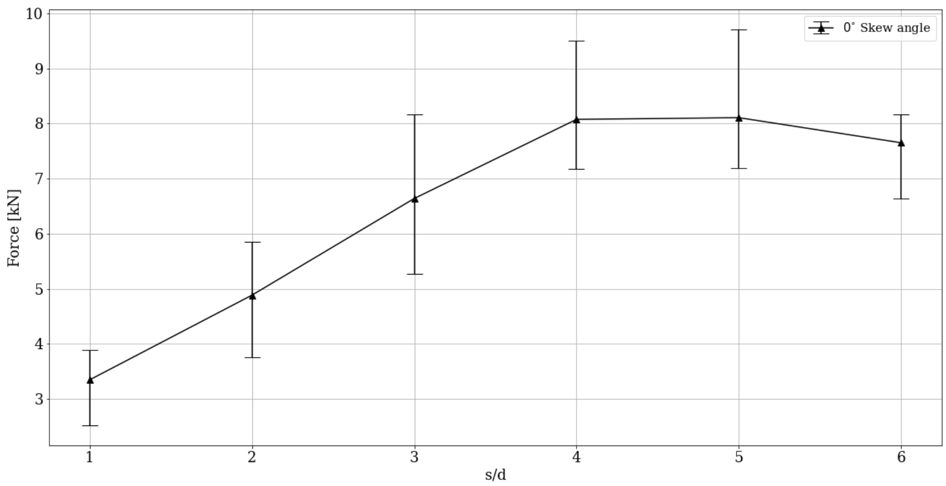

Figure 4.15: Peak drag force at 4 mm cutting depth and different s/d values.

Figure 4.16 shows the peak side force at a cutting depth of 4 mm and a skew angle of zero.

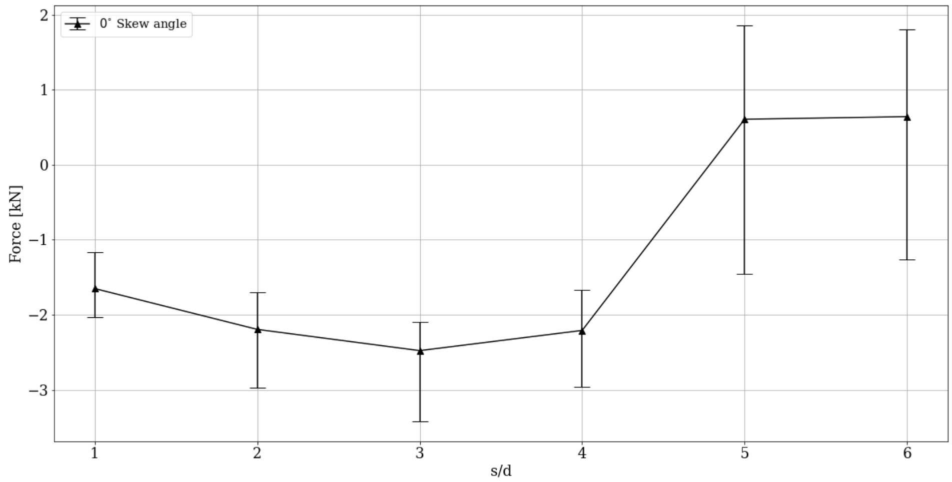

Figure 4.16: Peak side force at 4 mm cutting depth and different s/d values.

All the peak forces show the same trend as the mean forces and as the peak forces at a cutting depth of 2 mm. Both the normal force and drag force plateaus at a s/d of 4. Whereas the side force shows the same tendency as the sandstone.

Information about the cut-ability of the rock can also be seen in the cutting force signals of the different cutting parameters. The following figure shows the force signals at an s/d of 3, cutting depth of 2 mm and 4 mm and for the 2 mm cutting depth the skew angle is 0°, $-10°$ and $+10°$. For the 4 mm cutting depth the skew angle is 0°.

Figure 4.17 shows the cutting force signals for 2 mm cutting depth, s/d = 3 and skew angle = 0°.

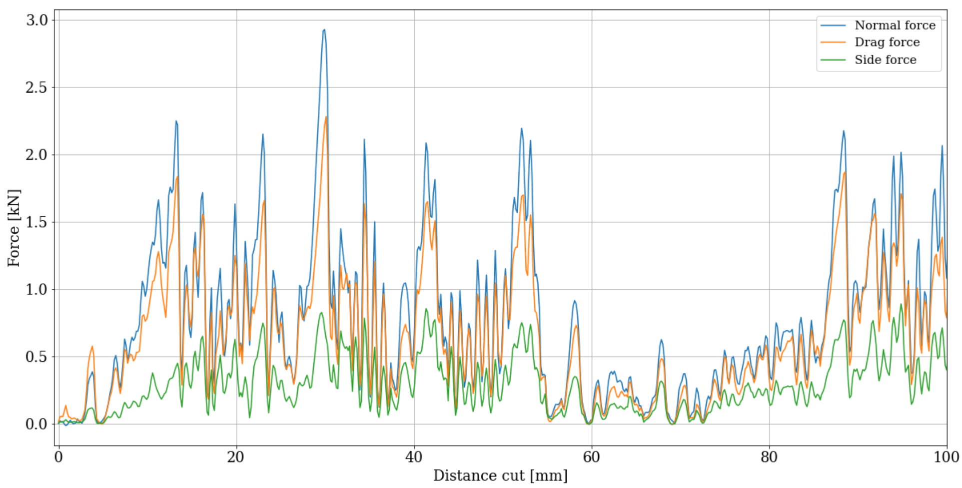

Figure 4.17: Cutting forces for UG2 rock sample at 2 mm cutting depth, s/d = 3 and skew angle = 0°.

Figure 4.17 shows the cutting force signals for 2 mm cutting depth, s/d = 3 and skew angle = $-10°$.

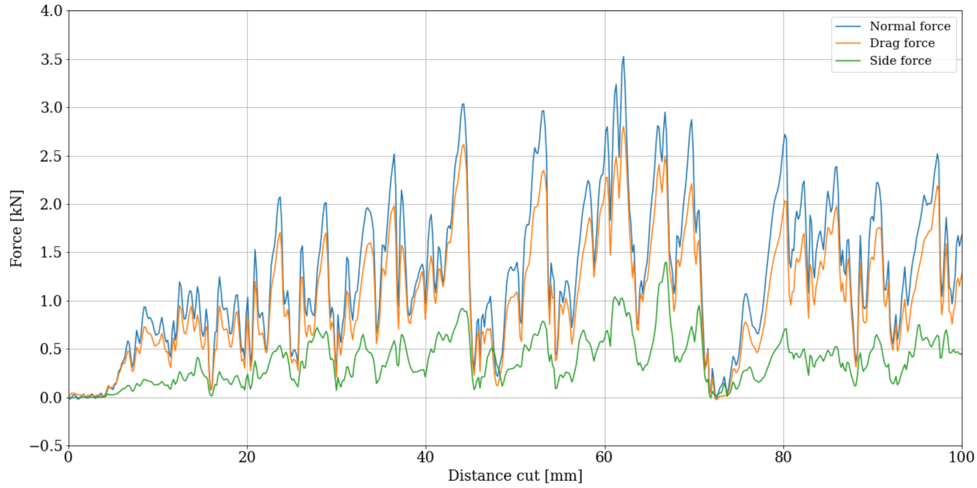

Figure 4.18: Cutting forces for UG2 rock sample at 2 mm cutting depth, s/d = 3 and skew angle = −10°.

Figure 4.17 shows the cutting force signals for 2 mm cutting depth, s/d = 3 and skew angle = +10°.

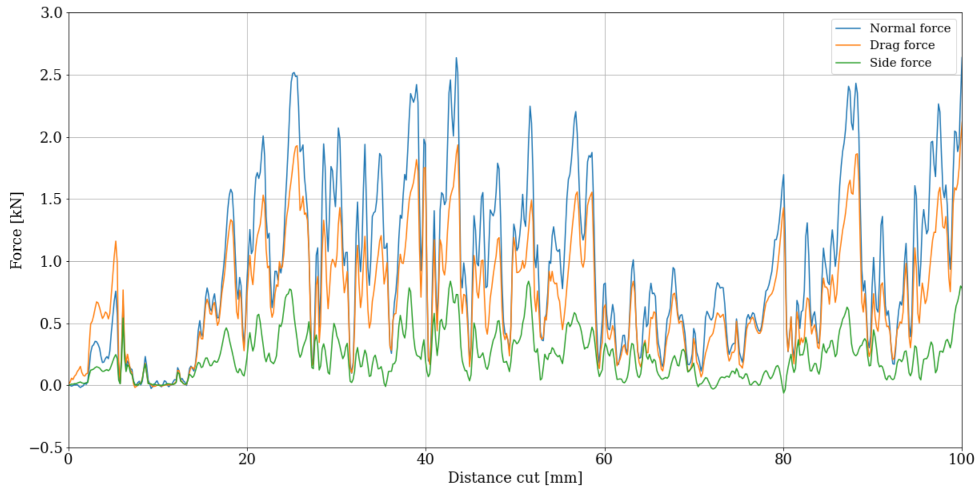

Figure 4.19: Cutting forces for UG2 rock sample at 2 mm cutting depth, s/d = 3 and skew angle = +10°.

Figure 4.17 shows the cutting force signals for 4 mm cutting depth, s/d = 3 and skew angle = 0°.

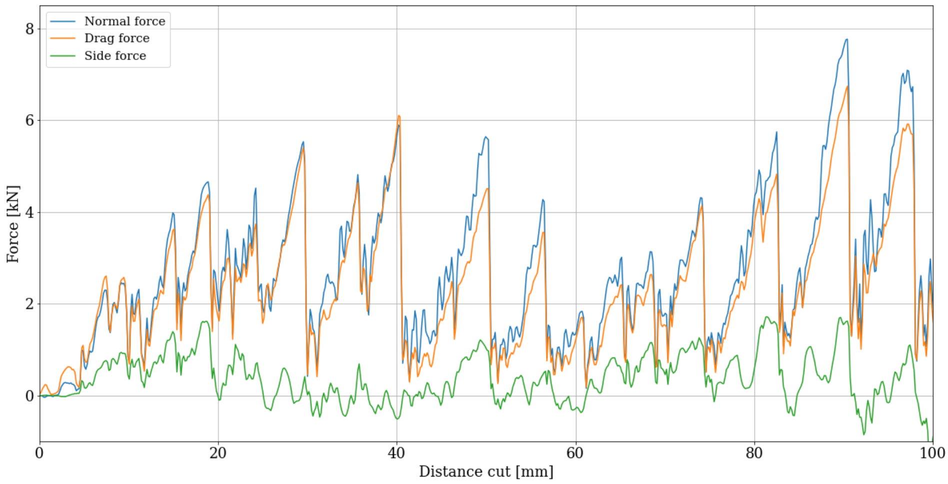

Figure 4.20: Cutting forces for UG2 rock sample at 4 mm cutting depth, s/d = 3 and skew angle = 0°.

The cutting force signals show the same tendencies as the sandstone from section 3.3 where for a cutting depth of 2 mm the force signal is impulsive and for a cutting depth of 4 mm the force signal has a saw tooth shape. A fast Fourier transform (FFT) analysis was performed on the data to show the periodicity of the data. This is discussed in section 4.3.

The force signals of the sandstone are quite regular in shape and amplitude as shown in figure 3.30. This is not the case for the UG2 reef sample. This can be seen in figure 4.18. In figure 4.18 it is clear that the amplitude is lower between a cutting distance of 60 mm to 80 mm. This shows inconsistency in the sample being cut. This is discussed in section 4.3.

Figure 4.21 shows the cut material that was gathered for the 2 mm, figure 4.21a, cutting depth and the 4 mm, figure 4.21b, cutting depth.

(a) 2 mm cutting depth.

(b) 4 mm cutting depth.

Figure 4.21: Cut material of UG2 reef sample.