Cutting Performance and Obtainable Quality Applying 6,000 bar Abrasive Waterjets

H. Werth[1], W. Hiller[1], C. Luetge[1], J.-P. Koerner[1], F. Pude[1], I. Lefevre[2], R. Lefevre[2]

[1] UHDE High Pressure Technologies GmbH, Germany
[2] L & D Jet Techniek, Belgium

Abstract

UHDE HPT has been developing, designing and building high pressure intensifiers for more than 40 years in the widest range of applications. The operating pressure may reach incredible 14,000 bar (203,280 psi).
For the waterjet technologies UHDE HPT has developed two concepts for the 6,000 bar (87,000 psi) pressure range. Both concepts have proven themselves in practical application. The incremental increase of the working pressure far more improves the working efficiencies and economical benefits:

- higher cutting speed,
- improved cutting quality at same cutting speed,
- deeper cuts without adding abrasives,
- low operating costs.

In this paper results of comparisons between 3,500 and 6,000 bar abrasive waterjet cutting operations will be presented.

Keywords: 6,000 bar, jet cutting, abrasive, AWIJ, cutting performance, surface roughness,

1 High Pressure Intensifier

For industrial applications typical intensifiers are designed for 3,500-3,800 bar design pressure and operate at pressures of 2,500 to 3,800 bar depending on the required cutting application. Since water jet cutting is competing with a lot of other cutting processes like laser-cutting or plasma-cutting it has to prove to be a superior technology to expand its market share. Therefore a further development in the direction of higher cutting speeds and better accuracy has to be enforced.
To achieve this goal higher operating pressures for the intensifiers and the nozzle system have to be obtained. Therefore the development of intensifiers for higher pressures is an important factor to increase the productivity of the process.

The above described tendency to increase the pressure has been already taken into account by all intensifier manufacturers and that is why they are offering lately pumps for service pressures up to 4,200 bar.

Certainly this is a step in the right direction to increase cutting speeds but the result is limited and has to be paid with shorter life of the HP-components.

A real step to revolutionise the process is to have a system operating at 6,000 bar.
Only by having such pressures available at the cutting nozzle would allow cutting metals or other hard materials without abrasives at an acceptable speed.

Therefore a development of the Uhde intensifiers to pressures of up to 6,000 bar has been undertaken.

Such development was based on Uhde’s long standing experience in building autofrettage pumps for 14,000 bar and the experience related to pumps for food pasteurisation systems up to 6,000 bar.

Thus all basic data about fatigue life of high pressure components under such pressures are available with Uhde and can be used for further development of reliable intensifiers.

1.1 The flexible two-stage HP intensifier concept

In order to overcome the fatigue problems, a flexible 6 kbar 2-stage pump concept has been chosen to get practical experiences with such a system in a job shop during day to day operation. Furthermore, the investment costs of such a pumping system have to be affordable and the investment risk has to be limited by using standard - only slightly modified - catalogue HP intensifiers as a developmental basis. One standard water-jet cutting pump (Type HP19/37-S) operates at 3.5 kbar and delivers into a buffer vessel. The pump is pressure controlled and operates such that the buffer vessel is held at a constant pressure. Second-stage pump (Type HP19/45-S) is connected with its suction piping to that buffer vessel and compresses the water to the final discharge pressure of up to 6 kbar.

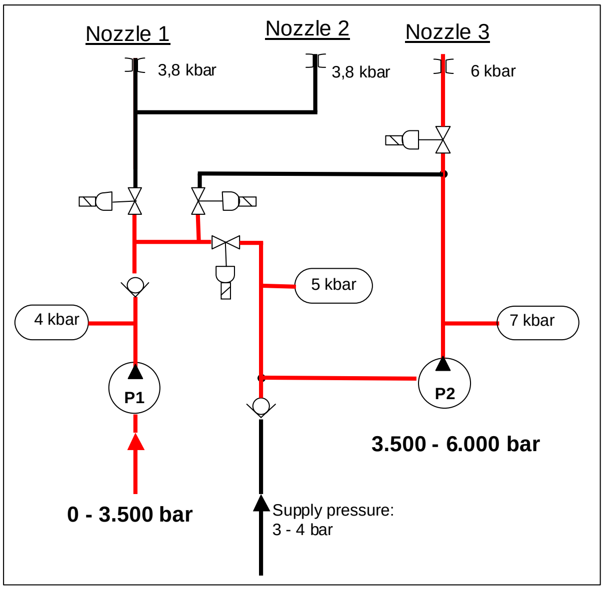

Figure 1 Flexible 2-stage pump concept

The flexible system arrangement shown in figure 1 permits the either independent or joint operation of both HP intensifier according to the specified basic characteristics of the installed pressure intensifiers for the single-mode.

The use of various electrically/pneumatically actuated high-pressure valves permits the easy selection of the relevant modes (single-stage or two-stage) on the control panel of the cutting installation [1].

The advantage of this concept is that the pulsations from 0 to 6,000 bar are distributed to two stages (figure 2). The dynamic load on the second stage pumps is reduced to an acceptable level of 2.5 kbar. All critical components (check-valves, packing, hp cylinder) benefit from that reduction in load.

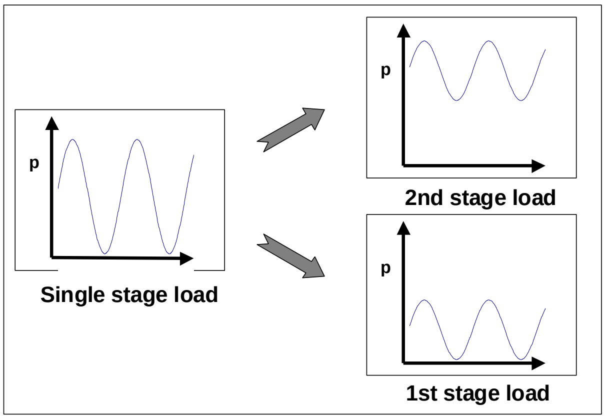

Figure 2 The 2-stage operation for pressure load

The cylinder can be designed without problems for infinite life [2], this applies also for the check valve body. The load on the check valve seat is also greatly reduced, since the closing element is supported by the first stage pressure and does not experience the full pressure loading from the high pressure.

Another advantage of this flexible 2-stage system is that the user can decide to cut e.g. with three of four abrasive cutting heads at normal pressures or one abrasive cutting head at 6 kbar.

Figure 3 shows the HP pumping system in front of a 5-axis portal handling system.

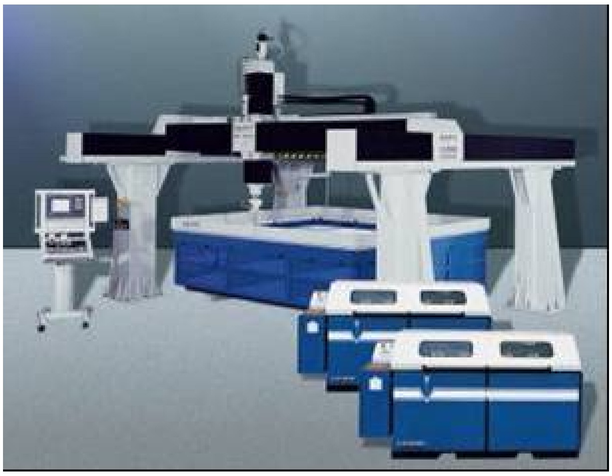

Figure 3 Numeric controlled 6 kbar AWIJ portal system

1.2 HP piping

The HP piping used is made of the material HP160, which was subjected to an autofrettage treatment:

Two dimensions have been chosen:

- Fixed piping: outer diameter 9.53 / inner diameter 3.21 mm
- Flexible piping: outer diameter 6.35 / inner diameter 2.39 mm

The average water discharge rate (real) through the orifice is presented by following equation:

$$V_{eff} = c_D * A_{nozzle} * \sqrt{\frac{2 \text{ x } (p_1 - p_2)}{\rho}}$$

The resulting flow rate is V_{eff} = 1.4 l/min by using an orifice of d_W = 0.20 mm at an operating pressure of 6,000 bar.

The velocity in the HP pipe, having a nominal width of 2.39 mm and taking into account turbulent flow, is calculated as follows:

$$v = \frac{V_{eff}}{A_{ti}}$$

The resulting velocity for the smallest tube within the HP unit is v = 5.4 m/s.

2 Cutting performance

The cutting performance of the ultra high pressure abrasive waterjet at 6,000 bar was tested in comparison with a "state-of-the-art" 3,500 bar AWIJ. Cutting tests were performed at L&D JobShop applying a 3-axis CNC handling system. Cutting samples were wedge shaped aluminium blocks (see figure 4). Aim of this geometric selection is the utilisation of the complete jet power by transferring the cutting process to a kerfing process. This also simplifies the evaluation of the test results due to the possibility of using one sample block for various cutting/kerfing trials. The aluminium block is not cut into pieces and the cutting performance for the chosen parameters can easily be read off by measuring the length of the "cutting track" on the bottom side of the sample block and divide it by two. This works if the angle of the wedge is chosen to 30° because of the known angle relation sin30° equals 0,5.

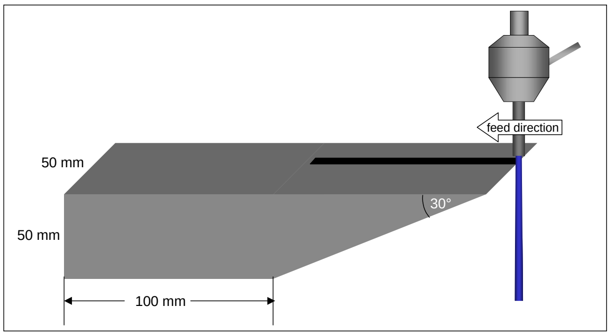

Figure 4 Experimental setup (schematic)

On every specimen up to 10 tracks were placed and afterwards measured by reading off the distance between the tip of the wedge and the first boundary on the bottom side of the block (see figure 5, right side). That means that a restarted cutting behind a "metal bridge" will not be taken into account for evaluation.

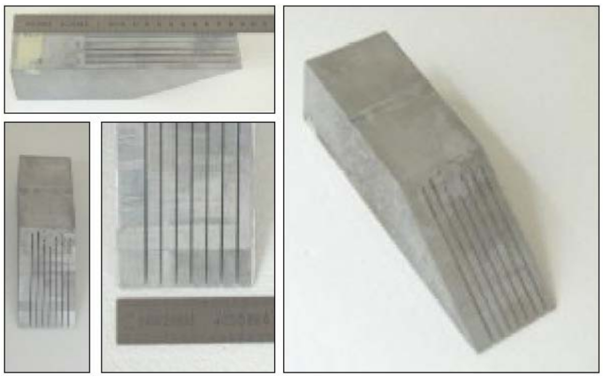

Figure 5 Specimen after cutting/kerfing

2.1 Test results

Cutting tests were performed with cutting head Allfi-Centerline® and hp-valve Allfi-Typ-VI-Slimline®. The dimensions of the water orifice and the focussing tube were fixed as follows:

Table 1 Dimensions of abrasive cutting head

	water orifice	focussing tube
inner diameter	$d_W = 0.20$ mm	$d_F = 0.76$ mm

The abrasive material used for the tests was Garnet Mesh 80.

In a first step the optimal mass flow rate of the abrasive material was investigated. Due to different volume rates of the water flow through the orifice based on the different pressure levels (3,500 and 6,000 bar) the capacity of the pure jet to be mixed with abrasive grains is not identical.

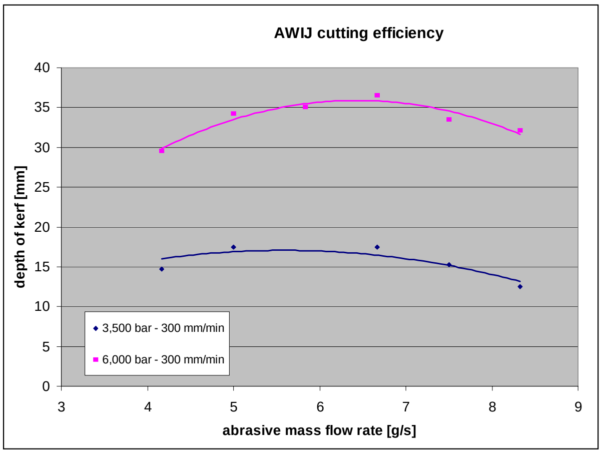

Figure 6 Variation of abrasive mass flow rate for finding an optimum

Therefore cutting tests with a variation of the abrasive mass flow rate (figure 6) were performed with the goal to find an optimum for each pressure level.
Figure 6 shows idealized graphs for finding:

Table 2 Optimal abrasive mass flow rate for selected parameters

	3,500 bar	6,000 bar
opt. mass flow rate [g/s]	$m_{opt,\,3,500} = 5.33$	$m_{opt,\,6,000} = 6.67$

In the second step the evaluated optimal mass flow was applied for further tests. Now a comparison of the cutting efficiencies of both the 3,500 and the 6,000 bar abrasive water jet could be undertaken under fair conditions.

Figure 7 shows the results of a cross-over comparison using the optimal mass flow rate for the own and the test partner's parameters (figure 7). This is for demonstrating that the cutting performance with reduced abrasive consumption is also highly efficient.

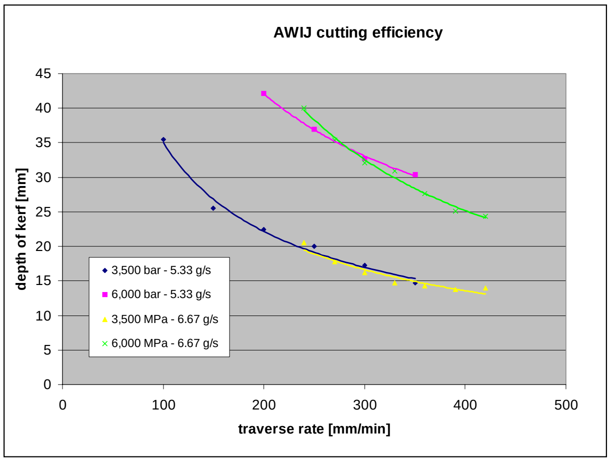

Figure 7 Comparison of 3,500 and 6,000 bar AWIJs with cross-over used abrasive mass flow rates

The cutting performance, represented by the obtained depth of kerf, is shown in table 3 for different traverse rates:

Table 3 Obtained depths of kerfs varying the traverse rate

	3,500 bar 5.33 g/s	6,000 bar 5.33 g/s
200 mm/min	22.5 mm	42.1 mm
250 mm/min	20.0 mm	37.0 mm
300 mm/min	17.3 mm	32.8 mm
350 mm/min	14.8 mm	30.4 mm

(5.33 g/s ≅ 320 g/min)

3 Surface roughness

One critical point when machining materials with abrasive waterjets is the obtainable surface roughness on the cutting edge. Due to the energy loss of the jet on its way through the workpiece the surface roughness becomes worse if the energy level falls below a boundary value.

If the jet parameters are stable the quality of the cut can be influenced by the traverse rate. That means that a disproportional increase of cutting speed will lead to a loss of quality.

3.1 Test results

Tests were performed with different materials (aluminium, stainless steel) with different thickness for each particular sample group (20mm, 50 mm, 100 mm).

After cutting the surface roughness of each sample was measured in different positions (see table 4) with fixed distances to the point of jet entrance (top side of the sample). The measurement results were generated by a sensing device working with a small diamond on the tip.

Table 4 Positions for measurement of surface roughness

material thickness [mm]	measurement positions [mm]
20	7 /15
50	9 / 25 / 41
100	10 / 40 / 60 / 90*

* due to selected parameters roughness could not be measured (see figure 8)

Figure 8 shows a photograph of an 100 mm sample after measuring and marking.

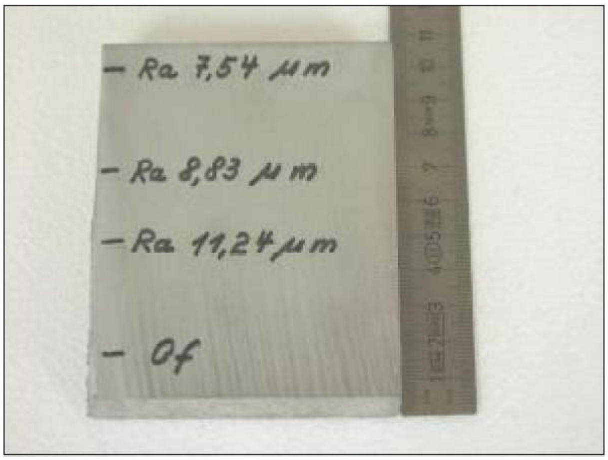

Figure 8 100 mm aluminium sample marked with results of roughness measurement

In the bottom position the surface profile is presented by striation marks; the surface is rough *and* wavy. The used sensing device is not able to generate data on such a profile ("Of" means "no function").

For visualization the results from the samples can be transferred in a bar diagram (figure 9).

This shows the general trend of increasing roughness values with both an increasing traverse rate and an increasing distance from the point of jet entrance.

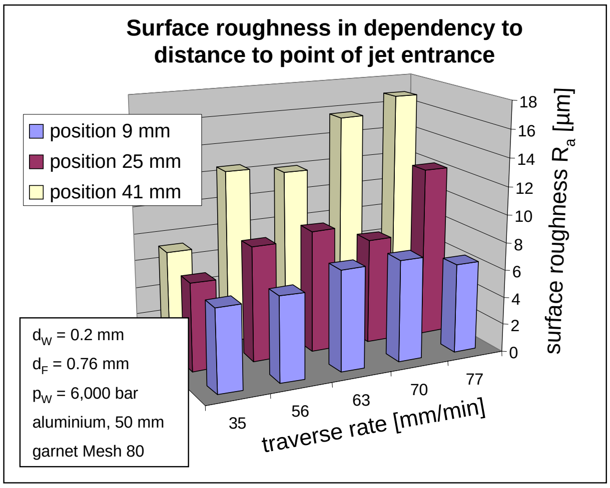

Figure 9 Allocation of roughness values on the cutting edge depending on the cutting speed

In figures 10 and 11 results coming from stainless steel samples are compared. In these graphs the points represent one combination of pressure level and measuring position (e.g. position 25 mm and 3,500 bar) are aligned with an idealized straight line.

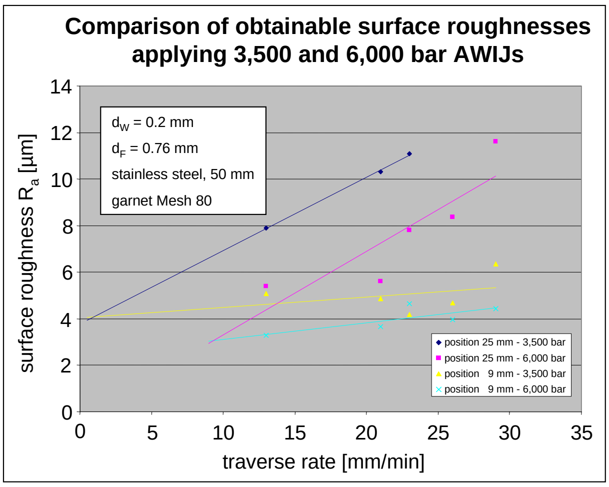

Figure 10 Prediction of max. tarverse rates for quality cuts (50 mm stainless steel)

For each pressure level these lines intersect in that point, where that traverse rate is reached which leads to similar surface qualities on both the top and the bottom of the cutting edge. This means a quality cut with a constant roughness over the whole surface.

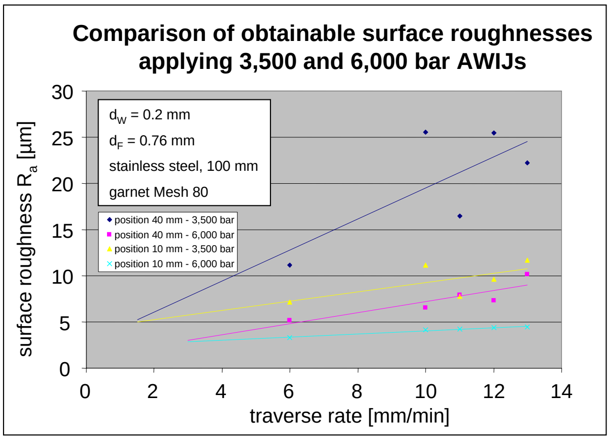

Figure 11 Prediction of max. tarverse rates for quality cuts (100 mm stainless steel)

As expected the cutting speed for quality cuts with a 6,000 bar AWIJ is much higher than that of the compared 3,500 bar AWIJ.

Exemplary for the obtained results table 5 shows results of trials with 50 mm samples.

Table 5 Obtained surfaces qualities on 50 mm samples

traverse rate [mm/min]		surface roughness R_a [µm]		
		measurement position		
aluminium	st. steel	9 mm	25 mm	41 mm
	13	3.27	5.38	7.86
	21	3.64	5.62	11.90
	23	4.65	7.81	--
	26	3.96	8.35	--
	29	4.42	11.63	--
35		5.97	6.33	7.28
56		6.10	8.27	12.58
63		7.28	8.81	12.08
70		7.36	7.62	15.73
77		6.43	12.28	16.95

4 Conclusions and outlook

The tests made at L & D jobshop show an increase of machinable material thickness at an proportion of about 87%. This result is reached by an increase of pressure of 71%. To find reliable data for the particular top cutting speed of each selectable parameter field the number of trials must be increased enormously.

The increase of cutting performance with a constant abrasive mass flow rate gives an extra economic benefit for the applicants of this ultra high pressure technology. Doubling the cutting speed compared to 3,500 bar systems a 6,000 bar AWIJ consummates only half of the abrasive material for the same cutting application. Being aware of the big proportion of cutting cost that is caused by the consumption of abrasive material the increase of pressure leads to an effective opportunity to save money.

The cutting efficiency of 6,000 bar abrasive water injection jets brings a further progress for this technology being in continuous competition with other non conventional cutting technologies like laser beam -, flame – or plasma arc cutting. The increase of cutting speed at stable qualities of the cutting edge in comparison with 3,500 bar systems allows to offer jobshop activities where in the past no economic success was achievable.

Also the enhancement of possible material thickness to machine opens new application fields for this innovative technology.

The ongoing development with the goal to increase the lifetime of wear parts in e.g. the pump units will lead to further acceptance for this presently called non conventional tool.

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