Dry drilling into weldments from hard-to-machine material

Ing. Lukáš Pelikán, Ing. Tomáš Kellner, Ing. Martin Kyncl

Czech Technical University in Prague, Faculty of Mechanical Engineering, Department of Technology of Machining, Projecting and Metrology, Technická 4, 166 07 Praha 6, Czech Republic

Abstract

This article deals with the application of drilling technology on hard-to-machine material Weldox 960 without cutting fluid. It contains an analysis of a suitable machining tools for this application. It also describes the measures required for implement this technology on a welded frame which is affected by the thermal load. Mainly tool optimization, workpiece clamping and cutting conditions.

Keywords: machining; hard-to-machine metals; Weldox 960; drilling; without cutting fluid

1. Introduction

This article deals with dry drilling into Weldox 960 weldments. The goal is to evaluate the ideal tools for drilling into this material without cutting fluid and to apply previously tested technology for an ideally stiff workpiece on a series of welded frames. From a machining point of view, they represent an issue because there is easy to initiate vibration with high amplitude and they are affected by a significant thermal load.

2. Weldox 960

Weldox 960 is a general structural steel with a minimum yield strength of 960 MPa. Weldox 960 meets the requirements on the corresponding steel grades and qualities according to EN 10 025.

Aplications: Load carrying structures having very high demands on low weight. [1]

Table 1. *Chemical composition of Weldox 960.*

C*	Si*	Mn*	P	S	B*	Nb*
max %	max %	max %	max %	max %	max %	max %
0,20	0,50	1,60	0,020	0,010	0,005	0,04

Cr*	V*	Cu*	Ti*	Al* total	Mo*	Ni*	N
max %	max %	max %	max %	min %	max %	max %	max %
0,70	0,06	0,15	0,04	0,018	0,70	1,5	0,010

Table 2. *Carbon equivalent of weldox 960.*

Plate thickness	CEV	CET
	Typical values	
	%	%
8 mm	0,55	0,37
20 mm	0,55	0,37
40 mm	0,64	0,39

3. Materials suitable for dry machining of hard-to-machine metal

A lot of heat is produced when machining hard–to-machine metals. The heat is not diverted by cutting fluid during dry machining and thus the use of high temperature resistant tools is necessary. Because of this fact the use of high-speed cutting steel can be dismissed (the exception is during threading). It is important to apply the technology also in the case of machining of big weldments where a significant vibration of workpiece is created during the machining. For this reason the cutting ceramics is not suitable.

The best material to use is sintered carbide, type P20 – P30. Sintered carbide offers adequate ratio of toughness and hardness for dry machining applications.

The coating of the tool is very important when applying the dry machining technologies. The absence of cutting fluid causes increased friction between produced chip and the face of the tool. Therefore the right coating can protect the tool from fast tool wear and it can also decrease the friction. To meet these requirements, 2 different coatings can be applied on top of each other.

As the base hard layer, the best coating is the TiAlN coating type. In general, this kind of coating has a high wear resistance during dry machining. It

Kontakt na autora: Lukas.Pelikan@fs.cvut.cz

has the best qualities when the material component ratio of Ti and Al is 1:1.

Mentioned friction above then can be decreased by applying lubrication coating on the base hard coating. WC/C coating types have a high resistance against tool wear. Therefore their functionality is the most visible especially during long machining processes. Hydrogen-free DLC (Diamond Like Carbon) coating shows excellent tribological qualities when their typical friction coefficient is between 0,02 – 0,1. [2][3]

4. Drilling

During drilling without cutting fluid, a major problem is the large amount of heat. Not only it is generated on the cutting edge (lip) of the tool but the warm chip further warm up the body of the drill. Thus the whole tool is warmed up and the wear process is significantly faster. The absence of the cutting fluid makes the outlet of the chip more difficult and further increases the friction between the helix of the drill and the material in the form of chip.

Based on these assumptions and above mentioned experience from previous tests which are published in scientific databases, the optimal solution is to use monolithic drill from sintered carbide with the TiAlN coating which would have the channels for internal cooling. Monolithic drill bits have full coating, which prevents the helix from unnecessary wear and decreases the friction between the failing chips and the tool. Despite the fact that we deal with dry machining the internal cooling possibility of the tool and the usage of the tool on machine which allows air cooling through the center of the tool is very important. The air partly cools off the lip of the drill (even though it has a minimal cooling effect compared to the liquid which is linked to its lower thermal capacity) and helps taking away the chips from the point of the cut.

The choice of cutting conditions derives from two basic requirements. The first one is to minimize the heat produced during the cutting process. The second one is to reduce the time during which the chip leaves the drill and by that not extending the cutting time. Next requirement is the process productivity, which is again linked with the minimization of the cutting time.

Cutting speed has the biggest impact on the heat production. Because of this fact, low cutting speeds are suitable for dry machining. Short time and productivity is assured by relatively high feed per revolution. However, cutting force increases with the lowering of the cutting speed and increasing of the feed per revolution. These values cannot be moved to extremes so that the force effect on the instrument does not cause its rapid destruction.

On the basis of the drilling test into simple plasma cut-off Weldox 960 workpiece, we determined the following cutting conditions as the most suitable by gradual experimental optimization:

Cutting speed:
V_c = 50 m/min
Feed per revolution:
f_{rev} = 0,3 mm/rev
Cooling:
Compressed air through the center of the drill bit.

We have optimized these conditions for the Sandvik CoroDrill 460-XM monolithic carbide drill with a diameter of 17, 5 mm and length of 5D. [5]

4.1 Drilling of smaller weldment

The goal is to transfer dry machining technology to a series of different sized welded frames of a similar character.

First of all we tried to apply technology to a smaller frame from the product portfolio. There is a hole drilling for threads M20 in a 40 mm thick ring with a diameter of 1500 mm.

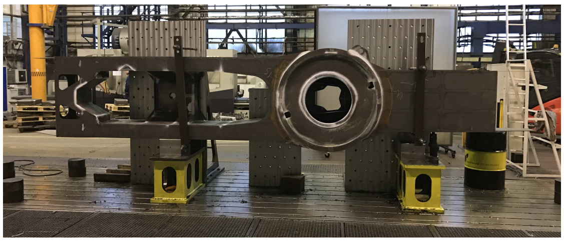

Figure 1. *Frame on the table of the horizontal milling center.*

The problem of this is a difficulty linked with the clamping of the chassis which causes vibrations (due to frame dimensions and material). Then it is big inner tension caused by big number of big welds mainly in the area around the ring where the drilling operations are made.

When we used the tested combination of tool Sandvik CoroDrill 460-XM D17,5 – 5D and cutting conditions V_c = 50 m/min and f_{rev} = 0,3 mm/rev, the technology failed.

The combination of vibrations and large inner tension close to the drilled hole caused a rapid overheating of the tool. Shrinking of the hole during the drilling presses the tool. This fact results in increased friction between rotating facets and the walls of the hole. This effect is further enhanced by vibrations of the workpiece. The generated heat results in very quick destruction of the drill.

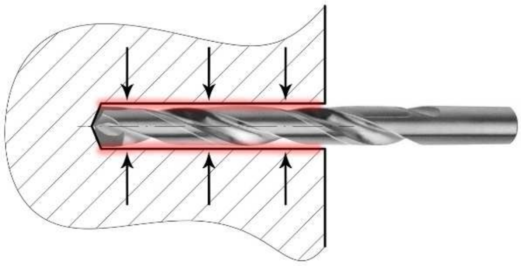

Figure 2. Shrinking of the hole.

4.1.1 The solution for drilling holes D 17,5 mm into smaller weldment

Due to the previous findings, it is necessary to adjust the tool so that it does not friction between rotating facets and the walls of the hole. Due to the vibrations, it is necessary to use a sufficiently tough tool. At the same time, it still must be able to withstand the high cut temperatures and the hot chips leaving by the drill helix.

This was solved by using the exchangeable tip drill from Gühring with non-standard configuration. For the tip Gühring 4115 with diameter 17,5 mm we used narrower body Gühring 4107 (17 mm) instead of the body normally recommended of a diameter 17,5 mm.

This gave a sufficient space of 0.25 mm between the facets and the walls of the freshly drilled hole.

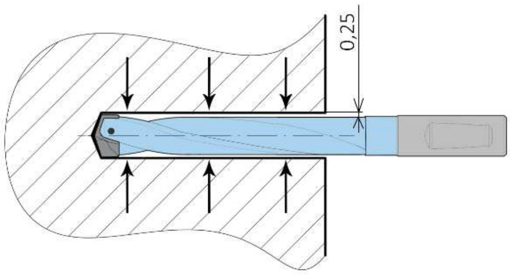

Figure 3. Narrowed body of the drill.

However, there was still a problem with the increased friction of the steel body of the exchangeable tip drill and sticking of the heated soft chip on the drill. This issue was solved by coating the surface of the drill body in coating provided and made by Gühring company. The body was coated with the same coating like the exchangeable tip drill, TiAlN coating, in sales named as "Nano A". It decreased the friction and increased the abrasion resistance of the drill body and this solved the problem with the tool getting overheated and the chip sticking to the body of the drill.

Figure 4. Customized drill bit from Gühring.

We have also adjusted the cutting conditions. We kept the cutting speed V_c = 50 m/min and the feed rate per revolution was reduced to f_{rev} = 0.23 mm/rev. This reduces the forces acting on the workpiece and it reduced vibration.

4.2 Drilling of bigger weldment

We attempted to transfer the technology for holes D 17.5 mm to a larger frame. Holes D 21 mm are drilled here into a 60 mm thick ring with a diameter of 2200 mm.

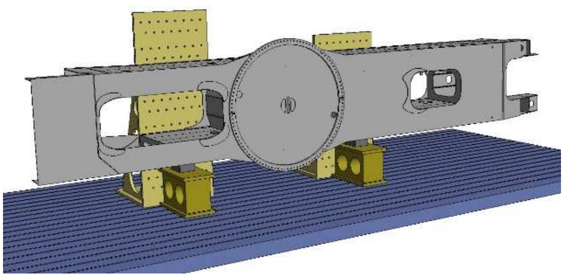

Figure 5. Visualization of the bigger welded frame on the table of the horizontal milling center.

This technology has failed again on this workpiece. There are several reasons why this technology cannot be transferred on similar type frame without modifications.

Larger hole diameter means greater torque on the drill and so that the force transferred to the workpiece is greater. Deeper holes make washout more difficulty and require a longer drill bit. This is logically less stiff. The larger frame is also equipped with larger welds. This means greater internal stress and, above all, a larger heat-affected zone.

All of these effects result in a substantial increase of vibrations and excessive overheating of the tool, resulting in its sudden destruction.

4.2.1 Vibration analysis

To determine the next step, we subjected the drilling process to the vibration spectrum analysis.

The results showed quite clearly where most of the problems originated.

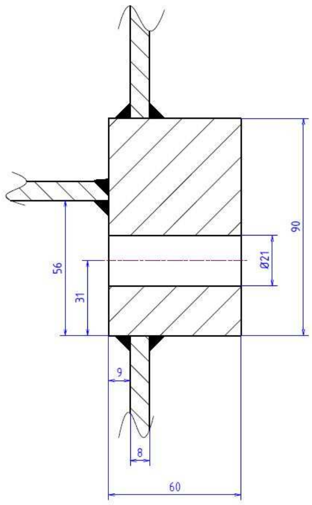

Figure 6. *Cross section of drilled area.*

In the figure is a cross section of a ring profile in which holes are drilled. The heat-affected zone from welds will appear approximately at a depth of about 35 mm. Into this depth, we can drill without bigger problems. The sound of the process is balanced, the chips leave regularly. Vibration analysis shows regular oscillation with the frequency which is twice as big as a drill bit rotations. There is an engage of each of the cutting edges separately.

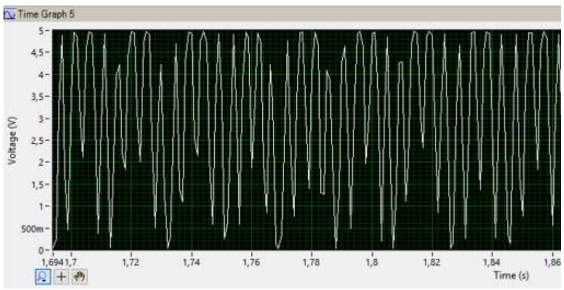

Figure 7. *Vibration analysis to a depth of 35 mm.*

After we exceed this drilling depth, the acoustic performance of the process changes. It is irregular, chips leave hot, and the drill temperature dramatically increases. The course of vibrations reveals an immediate change of character. Irregular long waves are added to the regular short wave, which is initiated by the drill. Low frequencies correspond to oscillations of multi-tone bodies, such as this workpiece. This course is recorded in the depth range from 35 to 50 mm.

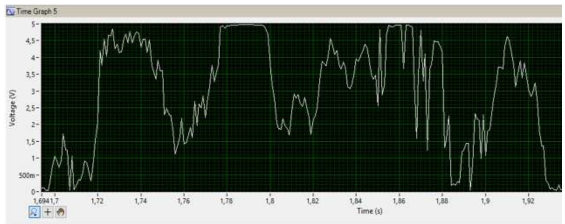

Figure 8. *Vibration analysis from a depth of 35 to 50 mm.*

If the drill gets through this depth, the vibration is suddenly calmed down. Last 10 mm we record a regular short wave with a double frequency of the tool rotation.

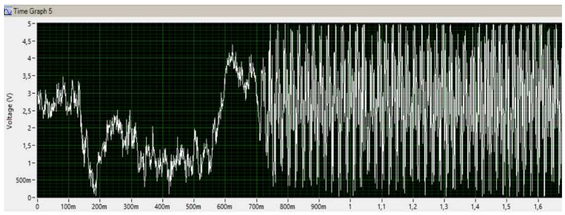

Figure 9. Vibration analysis from a depth of 50 mm.

Due to the area in which the vibration intensity increases, it can be assumed that the cause is the heat-affected zone. The reinforced material has a significantly greater cut resistance. In addition, it is irregular in the range of drill bit edges. This results in the whole frame being oscillate. These shocks dramatically change the working geometry of the drill bit. Therefore, in certain phases there is no cutting but the tool stamps the material. This has a fatal effect on the tool after a longer application.

4.2.2 The Solution for drilling holes D 21 mm into bigger weldment

In order to successfully drill holes with a diameter of 21 mm to a depth of 60 mm into the weldment that is loaded with internal stresses and heat-affected zones, it is necessary to reduce the workpiece vibration while reducing the forces injected to the process, especially in the critical depth between 35 and 50 mm.

The first step was to optimize workpiece clamping. The existing solution used in cutting with the cutting fluid has only counted the support of the workpiece in the axial direction of drilling at only three points. Two of them were on the right supporting tower and one on the left supporting tower. This support was realized using screws that were screwed into towers. This system allows a comfortable alignment of the workpiece with the machine's coordinate system. However, all the support points were quite far from the drilling axis.

We have maintained the existing clamping system which is still possible to easily align the workpiece. After aligning the workpiece, we improved the clamping of another supporting tower that we placed behind the machined area. We inserted a rubber band between the tower and the workpiece with the thickness 20 mm and hardness 70 Sh. We welded the auxiliary ears on the workpiece, whereby we tighted the tower to the workpiece in close contact. Then we fixed the tower to the floor of the machine.

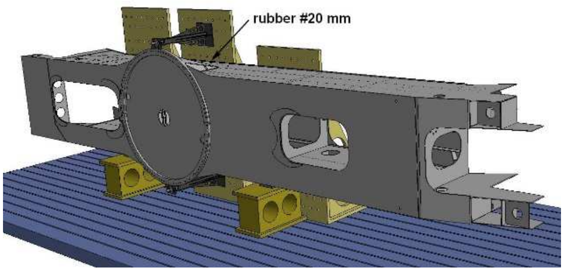

Figure 10. *Clamping of the frame.*

In this way, we supported the workpiece in the drilling axis and added a damping element in the form of a rubber band.

The next step was to optimize the tool. We've used an exchangeable tip with a modified geometry which allows the better chip breaking and better chip removal. It also stabilizes the drill in the radial direction. This is achieved thanks to a different cutting lip angle in the center of the drill bit and at the edges.

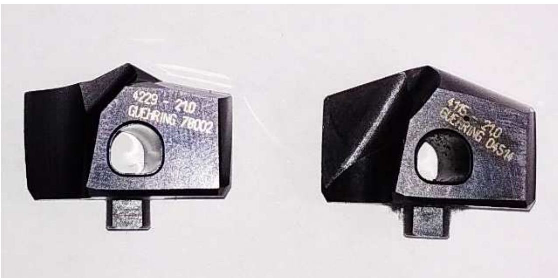

Figure 11. *Exchangeable drilling tips with optimization (left) and standard (right) geometry.*

These are specially developed exchangeable tips by Gühring for drilling into steel beams under unstable conditions. We use their stabilizing capabilities in this application. [4]

As a last step, we reduced the feed rate to f_{rev} = 0.22 mm/rev. To increase productivity, different cutting conditions may be used during drilling of a hole. In the area up to 35 mm, feed rate f_{rev} = 0.3 mm/rev can be applied. At a greater depth where the problematic machining area begins, we reduce the feed rate at the above f_{rev} = 0.22 mm/rev.

5. Conclusion

Just the dry drilling technology for heavy-duty materials raises a number of problems with a large amount of heat and friction. When drilling into an ideally stiff workpiece which is not affected by thermal load, it is still a problem which can be solved.

If the workpiece is an unstable weldment that is subject to high internal stress and heat-affected zones, there may be several other complications. It always depends on the particular case. For the series of weldet frames described in this article, several problems have to be solved by selecting the appropriate tool, clamping and cutting conditions.

From the instrument's point of view, there is a modified exchangeable tip drill with a coated body and modified tip geometry to increase stability.

The clamping was improved in the case of larger weldment by a support in the drilling axis with the vibration damping member.

As suitable cutting conditions for dry drilling in weldox 960 with the drill bit described above, cutting speed V_c = 50 m/min, feed rate f_{rev} = 0.3 mm/rev and air cooling through the center of the drill bit. It is advisable to reduce the feed rate to f_{rev} = 0.22 mm/rev in the heat-affected zones to reduce the injected forces and eliminate undesirable vibrations.

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