Izbor burgije za bušenje sa SHP pod visokim pritiskom

Jelena Stanojković^{1*}, Miroslav Radovanović¹

¹Mašinski fakultet, Univerzitet u Nišu, Srbija

Izbor burgije za bušenje u konkretnom materijalu je složen zadatak. U ovom radu je predstavljen izbor burgije za bušenje sa sredstvom za hlađenje i podmazivanje (SHP) pod visokim pritiskom legure aluminijuma primenom metodologije višekriterijumskog odlučivanja. Za višekriterijumski izbor korišćen je softverski paket Smart Picker Pro. Na osnovu četiri kriterijuma (brzina razanja, korak, pritisak SHP i vreme obrade) izvršeno je rangiranje četiri alternative (burgija proizvođača: Iscar, Sandvik, Seco i Kennametal).

Ključne reči: bušenje, burgije od tvrdog metala, aluminijum, višekriterijumsko odlučivanje.

1. UVOD

Bušenje je postupak izrade otvora i rupa. Glavno kretanje je obrtno i izvodi ga alat (burgija). Pomoćno kretanje je pravolinijsko i izvodi ga alata ili odradak. Glavno kretanje definisano je brzinom rezanja, odnosno brojem obrtaja na alatnoj mašini, a pomoćno kretanje korakom (aksijalnim pomeranjem alata) ili brzinom pomoćnog kretanja. Pri prodiranju u materijal obratka sečiva burgije se kreću po zavojnoj površini. Tokom bušenja najvažniji faktor koji utiče na performanse alata je temperatura koja se javlja u zoni rezanja. Povišena temperatura dovodi do ubrzanog habanja i smanjenja životnog veka alata. Habanje reznog alata utiče na kvalitet obrade i formiranje strugotine. U procesu bušenja strugotina se odvodi duž zavojnih žlebova burgije. Problem odvođenja strugotine se javlja kod bušenja jer trenje između burgije i strugotine uzrokuje sporije odvođenje strugotine, njeno gomilanje, a samim tim do povećanja obrtnog momenta [1].

Razlikujemo četiri vrste bušenja:

- bušenje bez SHP,
- bušenje sa minimalnom količinom SHP,
- bušenje sa SHP i
- bušenje sa SHP pod visokim pritiskom.

Obrada bez upotrebe SHP se u poslednje vreme dosta izučava u tehnologiji obrade rezanjem. Ovakva vrsta obrade sigurno može imati svoju ekonomsku opravdanost. Značajna je takođe njena prednost sa ekološke tačke gledišta. Kod ove vrste bušenja preporučuje se primena manjih brzina rezanja. U bliskoj vezi sa bušenjem bez upotrebe SHP je bušenje sa minimalnom količinom SHP.

Za efikasnije bušenje koristi se SHP. Benefiti primene SHP kod bušenja su:

- smanjuje temperaturu rezanja,
- olakšava odvođenje strugotine,
- poboljšava kvalitet obrade,
- smanjuje habanje alata i
- povećava životni vek alata.

Dovođenje SHP može biti:

- pomoću mlaznice (spoljašnje) i
- kroz telo alata (unutrašnje).

Kod spoljašnjeg dovođenja SHP, mlaznica usmerava SHP na alat. Obično se koriste jedna ili dve mlaznice. Spoljašnje dovođenje SHP koristi se kod

bušenja rupa, čija je dubina, manja od $3xd$ (d je prečnik burgije), gde se ne javlja problem odvođenja strugotine. Kod dubina bušenja većih od $3xd$ koristi se unutrašnje dovođenje SHP.

Unutrašnje dovođenje SHP se vrši pomoću otvora u telu alata koji se prostiru duž cele dužine burgije. Prečnik otvora je 0.7-1.5 mm [2].

2. BUŠENJE SA SHP POD VISOKIM PRITISKOM

Metoda bušenja sa SHP pod visokim pritiskom poznata je već duže vreme. Prvi koraci načinjeni su pedesetih godina dvadesetog veka. Prvim inovatorom smatra se Pigott [3] koji je za obradu čelika koristio burgiju od brzoreznog čelika i SHP pod pritiskom od 27 bara. Utvrdio je da se temperatura smanjila za 24° , a da se životni vek alata povećao osam puta.

Na osnovu pritiska SHP postoji podela bušenja na:

- bušenje pod niskim pritiskom (5-20 bara),
- bušenje pod visokim pritiskom (20-150 bara) i
- bušenje pod ultra visokim pritiskom (>150 bara).

Bušenje sa SHP pod visokim pritiskom se najčešće koristi kod bušenja gde je dubina rupa veća od $3xd$. Preporuka za korišćenje bušenja sa SHP pod visokim pritiskom je da pritisak treba biti veći od 20 bara i protok veći od 30 l/min.

Protok kod bušenja sa SHP pod visokim pritiskom se povećava sa povećavanjem prečnika burgije, dok pritisak opada. Kod burgija sa manjim prečnikom pritisak je veći zbog efikasnijeg odvođenja strugotine (strugotina se gomila na malom prostoru).

Prednosti bušenja sa SHP pod visokim pritiskom su [2,4,]:

- smanjeno glavno vreme obrade,
- bolji kvalitet obrađene površine,
- poboljšano odvođenje strugotine,
- smanjeno habanje alata i
- duži životni vek alata.

Bušenje sa SHP pod visokim pritiskom je istraživalo veliki broj istraživača. Lopez je u radu [4] istraživao kako upotreba SHP pod visokim pritiskom utiče na proces bušenja, glodanja i struganja. Birmingham je u radu [5] istraživao prednosti SHP pod visokim pritiskom pri bušenju i glodanju. Dosao je do zaključka da upotreba SHP po visokim pritiskom smanjuje vreme za 17-43% i troškove obrade za 15-64%. Arai i Ogawa su u radu [6]

istarživali uticaj temperature i brzine rezanja na habanje alata pri bušenju sa SHP pod visokim pritiskom legure titanijuma.

3. VIŠEKTERIJUMSKO ODLUČIVANJE

Metodologija višekriterijumskog odlučivanja je jedna od najpoznatijih oblasti u teoriji odlučivanja. Višekriterijumsko odlučivanje koristi skup matematičkih metoda i alata. Metodologija višekriterijumskog odlučivanja zasnovana je na strukturisanju problema i donošenju odluke. Tipično ne postoji jedinstveno optimalno rešenje za takve probleme i potrebno je koristiti preferencije donosioca odluke. Donosioc odluke traži najbolje rešenje iz niza dopustivih rešenja saglasno usvojenim kriterijumima. Rešavanje problema višekriterijumskog odlučivanja može se realizovati na različite načine. Prvi način je odabir odgovarajuće, najbolje alternative iz skupa raspoloživih alternativa.

Drugi način je odabir skupa dobrih alternativa ili grupisanje alternativa [7].

Roy B. je definisao glavne faze prilikom višekriterijumskog odlučivanja:

- definisanje problema,
- izbor cilja određivanja,
- određivanje kriterijuma,
- određivanje alternativa,
- rangiranje alternativa i
- donošenje odluke.

Pored ovoga može se javiti i problem eliminacije. Problem eliminacije je posebna oblast višekriterijumskog odlučivanja.

Danas postoji veliki broj metoda i softvera za višekriterijumsko odlučivanje. U zavisnosti od rešavanog problema u tabeli 1 date su višekriterijumske metode sa pratećim softverima [8].

Tabela 1. Metode višekriterijumskog odlučivanja i softveri

Metod višekriterijumskog odlučivanja	Softver
Promethee-Gaia	Decision Lab, D-Sight, Smart Picker Pro, Visual Promethee
Promethee	DECERNS
Electre	Electre IS, Electre III-IV
UTA	Right Choice, UTA+, DECERNS
AHP	MakeItRational, Expert Choice, Decision Lens, HIPRE 3+, ChoiceResults, DECERNS
ANP	Super Decisions, Decision Lens
MACBETH	M-MACBETH
TOPSIS	DECERNS
DEA	Win4DEAP, Efficiency Measurement System, DEA Solver Online, DEA Frontier, DEA-Solver PRO, Frontier Analyst
FlowSort	Smart Picker Pro
ELECTRE	Electre Tri, IRIS

Za izbor bugrije za bušenje sa SHP pod visokim pritiskom legure aluminijuma korišćen je softver Smart Picker Pro.

Softver je razvijen od strane Smart Picker 2011. godine. Dizajniran je tako da na osnovu datih kriterijuma pomaže u izboru najbolje alternative. Softver Smart Picker Pro sprovodi dve metode višekriterijumskog odlučivanja [8]:

- metod rangiranja Promethee i
- metod sortiranja FlowSort.

Metod rangiranja Promethee (Preference Ranking Organisation Method For Enrichment Evaluations) je jedna od novijih metoda višekriterijumskog odlučivanja. Pripada grupi metoda višeg reda. Prednost ove metode je u načinu strukturisanja problema, kao i dobroj softverskoj podršci i vizuelnom prikazu dobijenih rezultata. Promethee metoda se razvijala tako da danas postoje četiri verzije ove metode. Promethee I je metoda delimičnog, odnosno parcijalnog rangiranja alternativa. Promethee II je metoda kojom se postiže kombinovano rangiranje alternativa. Obe metode je razvio Jean-Pierre Bran 1982 godine. Kada se vrši rangiranje svih alternativa po svim kriterijumima preporučuje se korišćenje obe metode višekriterijumskog odlučivanja, tj. korišćenje metode Promethee I i metode Promethee II. Nekoliko godina kasnije Jean-Pierre Brans i Bertrand Mareschal su razvili metodu Promethee III, gde se rangiranje alternativa vrši na osnovu intervala, i metodu Promethee IV, gde se

rangiranje alternativa vrši na osnovu kontinuiranih kriterijuma [9].

FlowSort je metoda sortiranja kod višekriterijumskog odlučivanja. Kod ove metode višekriterijumskog odlučivanja u proces sortiranja uključeno je više donosioca odluke. FlowSort metoda je razvijena od strane Nemery and Lamboray 2008 godine [10].

4. IZBOR BURGJE ZA BUŠENJE RUPE U ALUMINIJUMU SA SHP PO VISOKIM PRITISKOM

Za bušenje rupe prečnika 15 mm i dubine 60 mm u aluminijumu iz kataloga proizvođača reznog alata Iscar, Sandvik, Seco i Kennametal izdvojili smo spiralne burgije od tvrdog metala nominalnog prečnika 15 mm, dužine 5xd, ugla vrha 140° sa otvorima u telu za dovod SHP pod visokim pritiskom.

Glavno vreme obrade t_m se izračunava pomoću formule:

$$t_m = \frac{L}{V_f} = \frac{L}{f \cdot n} \quad (1)$$

gde je: t_m [min]-glavno vreme obrade, L [mm]-dubina bušenja, V_f [mm/min]-brzina pomoćnog kretanja, f [mm/o]-korak i n [o/min]-broj obrtaja. Na osnovu slike 1 dubina bušenja se računa pomoću formule:

$$L = l_i + l + l_t \quad (2)$$

gde je: L [mm]-dubina bušenja, $l_i=1$ mm-dodatak za ulaz burgije, l -dubina rupe, dok se l_t računa pomoću formule:

$$l_t = \frac{\frac{d}{2}}{\tan \frac{\sigma}{2}} \quad (3)$$

Izračunavanjem pomoću formula (2) i (3) dobijamo dubinu bušenja koja u ovom slučaju iznosi 63.747 mm.

Slika 1. Šema za određivanje dubine bušenja

Radi lakšeg odvođenja strugotine, proizvođač alata Sandvik preporučuje da se aksijalno kretanje alata zaustavi 2-3 sekunde na 1/3 dubine bušenja pri čemu alat i dalje rotira, kako bi se lakše odvodila strugotina. Postupak se ponavlja na 2/3 dubine bušenja. Kod ovog postupka burgija se ne izvlači van rupe [11]. Tada se glavno vreme obrade računa pomoću formule:

$$\begin{aligned} t_m &= t_m' + t_m'' + t_m''' \\ &= \frac{l_i + \frac{l}{3}}{f \cdot n} + t_d + \frac{\frac{l}{3}}{f \cdot n} + t_d + \frac{\frac{l}{3} + l_t}{f \cdot n} \\ &= \frac{L}{f \cdot n} + 2t_d \end{aligned} \quad (4)$$

Kriterijumi na osnovu kojih će se vršiti izbor burgije su: brzina rezanja, korak, pritisak SHP i glavno vreme obrade, tabela 2.

Tabela 2. Kriterijumi i alternative za izbor burgije

Alternative	Kriterijumi			
Burgije od tvrdog metala	Brzina rezanja	Korak	Pritisak SHP	Glavno vreme obrade
	(m/min)	(mm/o)	(bar)	(s)
SCD-ACG5 (Iscar)	140	0.45	45	6.9
R840 (Sandvik)	122	0.406	40	7.7
SD205A (Seco)	140	0.48	40	6.7
B285 (Kennametal)	120	0.38	40	8

Tabela odlučivanja u vidu alternativa i kriterijuma u softverskom paketu Smart Picker Pro je prikazana na slici 2.

	Name	C1	C2	C3	C4
		Brzina rezanja	Korak	Pritisak SHP	Glavno vreme obrade
A1	SCD-ACG5 (Iscar)	140.0	0.45	45.0	6.9
A2	R840 (Sandvik)	122.0	0.406	40.0	7.7
A3	SD205A (Seco)	140.0	0.48	40.0	6.7
A4	B285 (Kennametal)	120.0	0.38	40.0	8.0

Slika 2. Tabela sa kriterijumima i alternativama u softverskom paketu Smart Picker Pro

Kriterijumi za izbor burgije su: maksimalni brzina rezanja, korak i pritisak SHP, a minimalno glavno vreme obrade. Na slici 3 je prikazan dijagram alternativa sa zadatim kriterijumima. Izlomljenim linijama i različitim bojama su prikazane alternative, tj. burgije različitih proizvođača, dok su uspravnim linijama prikazani kriterijumi (brzina rezanja, korak, pritisak SHP i glavno vreme obrade).

Slika 3. Dijagram alternativa sa kriterijumima

Prikaz rangiranja alternativa na osnovu zadatih kriterijuma u softverskom paketu Smart Picker Pro može biti pomoću [12]:

- tabele,
- dijagrama i
- Gaia karte.

Rangiranje pomoću tabele prikazano je na slici 4. Na prvom mestu je burgija proizvođača Iscar, zatim Seco, Sandvik i na kraju Kennametal.

	Actions	Net Flows	Position
	A1 - SCD-ACG5 (Iscar)	0.557	1.0
	A2 - R840 (Sandvik)	-0.37341	3.0
	A3 - SD205A (Seco)	0.28367	2.0
	A4 - B285 (Kennametal)	-0.46726	4.0

Slika 4. Rangiranje pomoću tabele

Rangiranje alternativa na osnovu zadatih kriterijuma se može predstaviti i pomoću dijagrama, slika 5. Dijagram rangiranja pokazuje rezultate rangiranja svih alternativa. Alternative sa globalnim pozitivnim rezultatima prikazane su plavom bojom, dok su alternative sa negativnim rezultatima prikazane crvenom bojom.

Slika 5. Rangiranje pomoću dijagrama

Gaia karta predstavlja problem odluka, slika 6. Karta dozvoljava da se brzo otkriju slabosti i prednosti alternativa. Alternative su prikazane u jednoj ravni i na taj način ih je lako uporediti. Pored toga karta omogućava da se brzo otkriju i sličnosti između alternativa.

Tačke predstavljaju alternative, dok obojene linije predstavljaju zadate kriterijume. Crna strelica D, poznata kao linija odluke, predstavlja pravac kompromisa donošenja odluke. Njen položaj zavisi od težina kriterijuma.

Slika 6. Rangiranje pomoću Gaia karte

5. ZAKLJUČAK

Bušenje sa SHP pod visokim pritiskom spada u novije tehnologije obrade i koristi se kod bušenja gde je dubina rupa veća od 3xd. Izbor burgije za bušenje sa SHP pod visokim pritiskom rupa u aluminijumu zasnovan je na korišćenju višekriterijumskog odlučivanja primenom softverskog paketa Smart Picker Pro. Alternative za izbor su burgije proizvođača Iscar, Sandvik, Seco i Kennametal, dok su kriterijumi: brzina rezanja, korak, pritisak SHP i glavno vreme obrade. Softverski paket Smart-Picker Pro je na osnovu zadatih kriterijuma izdvojio burgiju proizvođača Iscar, kao najbolju alternativu za bušenje sa SHP pod visokim pritiskom legure aluminijuma.

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Selection of Drill for Drilling with High Pressure Coolant

Jelena Stanojković^{1*}, Miroslav Radovanović¹

¹Faculty of Mechanical Engineering, University of Niš, Serbia

The selection of drill for drilling in a concrete material is a very important task. This paper presents the selection of solid carbide drill for drilling holes in aluminum alloys with high pressure coolant using the multi-criteria decision methodology. The multi-criteria decision method is implemented in the Smart Picker Pro software package. On the basis of four criteria (cutting speed, feed per revolution, pressure coolant and cutting time) four alternatives were ranked (drills from manufacturers: Iscar, Sandvik, Seco and Kennametal).

Keywords: Drilling, Solid carbide drill, Aluminum alloy, Multiple-criteria decision method

1. INTRODUCTION

Drilling is a machining process for creating holes in a solid material. The main rotary motion in drilling is the running of a tool (drill). Secondary translational movement is carried out by a tool or workpiece. The main movement is defined by cutting speed or number of revolutions at the machine tool, and supported by the movement of feed rate (axial displacement tools for one revolution). The trajectory of the drill is a helical surface formed during the penetration of the drill into the material of the workpiece. During the drilling process, the most important factor affecting the performance of the tool is the temperature that occurs in the cutting zone. Increased temperatures may lead to rapid tool wear and the formation of chips. In the process of drilling chips are evacuated along the helical groove of the drills. The problem of chip evacuation occurs in drilling because of the wear between the drill and chips, which cause lower chip evacuation, and its accumulation, leading to an increased moment of cutting force [1].

Based on the quantity of the coolant the drilling process can be:

- Dry drilling,
- Minimum quantity lubrication drilling,
- Drilling with coolant and
- High pressure coolant drilling.

Dry drilling, or drilling without a coolant, has been the most studied in the machining technology. This kind of drilling technology certainly has its economic viability. Also important it is advantage from an environmental point of view. With this type of drilling technology it is recommended to use lower cutting speeds. Closely related to this drilling technology is the drilling with minimum quantity lubrication.

The benefits using drilling with coolant are:

- Chip evacuation,
- Reduced cutting temperature,
- Reduced tool wear,
- Better surface quality and
- Increased tool life.

The coolant supply can be:

- External and
- Internal.

The external coolant supply uses one or two coolant nozzles, which are directed toward the tool axis. The external coolant is used for drilling holes whose depth is less than $3xd$ (d is the drill diameter), where there is no problem of chip evacuation. The internal coolant is used for drilling holes whose depth is larger than $3xd$.

The internal coolant supply is performed through the hole in the tool body, which extends along the length of the drill. The diameter of coolant holes is 0.7-1.5 mm [2].

2. DRILLING WITH HIGH PRESSURE COOLANT

Drilling with high pressure coolant has been known for a long time. The first steps were made in the 1950s. The first author to report on this type of drilling was Pigott [3]. He used a high speed steel twist drill for machining steel with high pressure coolant. The pressure coolant in this case was 27 bars. He found that the temperature dropped for 24° and the tool life increased eight times.

Based on the pressure coolant, drilling is divided into processes which use:

- Low pressure coolant (5-20 bars)
- High pressure coolant (20-150 bars) and
- Ultra high pressure coolant (>150 bars).

Drilling with high pressure coolant is commonly used when the depths of holes are larger than $3xd$. Recommendations for drilling with high pressure coolant are that the pressure should be greater than 20 bars with a flow rate more than 30 l/min.

The flow rate in the drilling process increases with an increasing diameter of the drill, while the pressure decreases at the same time. Smaller diameter drills need higher coolant pressure than large drills, because less coolant passes through. The coolant pressure will be critical for smooth chip evacuation.

The benefits of drilling with high pressure coolant are [2,4]:

- Reduced machining time,
- Better surface quality,
- Improved chip evacuation,
- Reduced tool wear and
- Longer tool life.

Drilling with high pressure coolant has been investigated by many of researchers. Lopez in [4] investigated how the high pressure coolant affects the process of drilling,

* Corresponding author: Aleksandra Medvedeva 14, Niš, stanojkovic.jelena89@gmail.com

milling and turning. Bermingham in [5] investigated the benefits of high pressure coolant in drilling and milling. He came to the conclusion that the high pressure coolant reduces the time for 17-43% and processing costs for 15-64%. Arai in [6] investigated effect of temperature and cutting speed on tool wear when drilling with high pressure coolant titanium alloy.

3. MULTIPLE-CRITERIA DECISION

Multi-criteria decision methodology is one of the most popular areas in decision theory. Multi-criteria decision (MCD) uses a set of mathematical methods and tools. Methodology of multiple criteria decision is based on the structuring of problems and making decisions. Typically, there is no single optimal solution for such problems and it is necessary to use the preferences of decision makers. Decision makers seek the best solution from a range of permissible solutions in accordance with the approved criteria. Solving the problem of a multi-criteria decision can be implemented in different ways.

The first way is to select the appropriate best alternatives from a set of available alternatives. Another way is to select a set of good alternatives or alternative grouping [7].

Roy B. (1981) defined the four main problems when making a decision:

- Define problem,
- Determination of goal,
- Determination of criteria,
- Determination of alternatives,
- Rank alternatives and
- Decision making.

Apart from this, the problem of elimination can also occur. The problem of elimination is a separate branch of sorting problems. Today there are a great number of methods and developed software programs for implementation of multi-criteria decision. Depending on the type of problem multi-criteria decision can be performed using the following methods and software, Table 1 [8].

Table 1. Different multi-criteria decision methods and software programs

Multi-criteria decision method	Software
Promethee-Gaia	Decision Lab, D-Sight, Smart Picker Pro, Visual Promethee
Promethee	DECERNS
Electre	Electre IS, Electre III-IV
UTA	Right Choice, UTA+, DECERNS
AHP	MakeItRational, Expert Choice, Decision Lens, HIPRE 3+, ChoiceResults, DECERNS
ANP	Super Decisions, Decision Lens
MACBETH	M-MACBETH
TOPSIS	DECERNS
DEA	Win4DEAP, Efficiency Measurement System, DEA Solver Online, DEA Frontier, DEA-Solver PRO, Frontier Analyst
FlowSort	Smart Picker Pro
ELECTRE	Electre Tri, IRIS

To select a drill for drilling aluminum alloys with high pressure coolant the Smart Picker Pro software package was used. The software was developed by Smart Picker in 2011. It is designed to improve the decision making process. Based on the given criteria it facilitates the choice of the best alternative. Smart Picker Pro includes two MCD methods [8]:

- The ranking method Promethee and
- The sorting method FlowSort

The ranking method Promethee (Preference Ranking Organization Method For Enrichment Evaluations) is one of the newer method of criteria decision. It belongs to the group of higher order method and the advantage of this method is the method of structuring the problem, as well as good software support and visual presentation of the results.

Today there are four versions of the ranking method Promethee. Promethee I is the method of partial, or partial ranking of alternatives. Promethee II is a method to achieve a combined ranking of alternatives. Both methods developed by Jean-Pierre Bran in 1982. When the ranking of alternatives by all criteria recommended to use both methods for decision. A few years later, Jean-Pierre Bertrand Brans and Mareschal developed a method Promethee III, where the ranking of alternatives is done on the basis of the interval, and the method Promethee IV,

where the ranking of alternatives is done on the basis of continuous criteria [9].

FlowSort is the sorting method for decision making. In this method for decision making in the process of sorting included few decision maker. FlowSort method was developed by Nemery and Lamboray 2008 [10]

4. DRILL SELECTION FOR DRILLING WITH HIGH PRESSURE COOLANT

For drilling holes diameter of 15 mm and depth of 60 mm in aluminium alloy we selected form catalogues of manufacturers of cutting tools Iscar, Sandvik, Seco and Kennametal. Length of all twist drills made of tungsten carbide is 5xd and angle of 140° with internal coolant.

Machining time t_m is calculated using equation:

$$t_m = \frac{L}{V_f} = \frac{L}{f \cdot n} \quad (1)$$

where: t_m [min]-machining time, L [mm]-drilling depth, V_f [mm/min]-feed rate, f [mm/r]-feed per revolution, n [r/min]-spindle speed. Drilling depth, Fig. 1., is calculated using equation:

$$L = l_i + l + l_t \quad (2)$$

where: L [mm]-drilling depth, l_i =1 mm-addition for the input drill, l -depth of the hole and l_t based on the equation:

$$l_t = \frac{\frac{d}{2}}{\tan \frac{\sigma}{2}} \quad (3)$$

Calculating by using equations (2) and (3) obtains the value of drilling depth, which in this case amounts to 63.747 mm.

Figure 1. The scheme for determination of drilling depth

To help chip evacuation, the tool manufacturer Sandvik recommends the pecking cycle where the feed should be stopped for 2-3 seconds at 1/3 drill depth while the drill is still rotating. The pecking cycle is repeated at 2/3 drill depth. Here the drill need not be taken completely out of the hole, as this could create recutting of chips and cause edge damage [11]. Machining time is calculated using equation:

$$\begin{aligned} t_m &= t_m' + t_m'' + t_m''' \\ &= \frac{l_i + \frac{l}{3}}{f \cdot n} + t_d + \frac{\frac{l}{3}}{f \cdot n} + t_d + \frac{\frac{l}{3} + l_t}{f \cdot n} \\ &= \frac{L}{f \cdot n} + 2t_d \end{aligned} \quad (4)$$

The criteria for selecting the drill are cutting speed, feed per revolution, pressure coolant and machining time, Table 2.

Table 2. Criterias and alternatives for drills selection

Alternative	Criteria			
	Cutting speed	Feed per revolution	Pressure coolant	Machining time
	(m/min)	(mm/r)	(bar)	(s)
SCD-ACG5 (Iscar)	140	0.45	45	6.9
R840 (Sandvik)	122	0.406	40	7.7
SD205A (Seco)	140	0.48	40	6.7
B285 (Kennametal)	120	0.38	40	8

A decision table with criteria and alternatives for drill selection in Smart Picker Pro is shown in Fig. 2.

	Name	C1	C2	C3	C4
		Cutting speed	Feed per rev.	Coolant pressure	Machining time
A1	SCD-ACG5 (Iscar)	140.0	0.45	45.0	6.9
A2	R840 (Sandvik)	122.0	0.406	40.0	7.7
A3	SD205A (Seco)	140.0	0.48	40.0	6.7
A4	B285 (Kennametal)	120.0	0.38	40.0	8.0

Figure 2. Table with criterias and alternatives in Smart Picker Pro

Cutting speed, feed per revolution and coolant pressure are maximization criteria and machining time is a minimization criterion where higher assessment value alternatives are preferred. A diagram with the criteria and alternatives is shown in Fig. 3. Alternatives (drills of four manufacturers) are marked in different colors, while the vertical lines indicate the criteria (cutting speed, feed per revolution, coolant pressure and machining time).

Figure 3. Overview of criteria and alternatives

Analysis of results can be shown in different ways in Smart Picker Pro [12]:

- Ranking scores in a table,
- Ranking charts (graphical representation of ranking) and
- Gaia map (graphical representation of a decision problem)

Ranking scores in a table is shown in Fig. 4. This figure displays the scores and the ranks for all drills for drilling aluminum alloys with high pressure coolant according to the preference parameters. In the first place is the drill from the manufacturer Iscar, followed by Seco, Sandvik and finally Kennametal.

	Actions	Net Flows	Position
A1	SCD-ACG5 (Iscar)	0.557	1.0
A2	R840 (Sandvik)	-0.37341	3.0
A3	SD205A (Seco)	0.28367	2.0
A4	B285 (Kennametal)	-0.46726	4.0

Figure 4. Ranking scores in a table

Graphical representation of ranking scores can be represented by ranking charts, Fig. 5. Charts displays the scores of all the alternatives. The alternatives with a global positive score are displayed in blue whereas the alternatives with negative scores are displayed in red.

Figure 5. Ranking charts

The Gaia map represents the decision problem, Fig. 6. The map allows a quick discovery of the strengths and weaknesses of alternatives in one plane and thus compare them. In addition, it allows to quickly detect any similarities between alternatives. Moreover, the map enables the user to quickly and easily discover similarities between actions.

Points are alternatives, and colored lines are criteria. The black arrow D, also called the decision stick, represents the direction of the compromise of the decision maker. The position depends on the weight given to the criteria. If an action lies in the direction of a criterion (arrow), it means that it behaves very well on that criterion. In this case the best choice is the drill manufacturer Iscar.

Figure 6. Gaia map

5. CONCLUSION

Drilling with high pressure coolant is a new approach in machining technology and is used for drilling holes where the depth is greater than 3xd. The selection of drills for drilling aluminum alloys with high pressure coolant was carried out using the Smart Picker Pro

software package, based on multi-criteria decision methodology. Drill manufacturers (Iscar, Sandvik, Seco and Kennametal) were used as selection alternatives, while the selection criteria were: cutting speed, feed per revolution, pressure coolant and machining time. The Smart Picker Pro solver suggested the use of solid carbide drill (SCD-ACG5) by the manufacturer Iscar as the best solution.

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