Strojnícky časopis – *Journal of* MECHANICAL ENGINEERING,
VOL 73 (2023), NO 2, 117 - 132

MATERIAL RESEARCH FOR THE PRODUCTION OF OUTDOOR AND KITCHEN KNIFE BLADES AT LOW COSTS

BRUÇI Mirlind[1], BAJRAMI Xhevahir[2*], BRUÇI Ari[1], BRUQI Qendrim[1]

[1]Department of Manufacturing and Automation, Faculty of Mechanical Engineering, University of Pristina "Hasan Prishtina", 10000 Pristina, Kosovo.
[2]Department of Mechatronics, Faculty of Mechanical Engineering, University of Pristina "Hasan Prishtina", 10000 Pristina, Kosovo, e – mail: xhevahir.bajrami@uni-pr.edu

Abstract: In today's modern times, consumers have changed the idea of shopping. They want a functional product with performance at a low price. On the other hand, the consumer demands a variety of products in the market in terms of dimensions and usability. As the requirements are different, the engineers are challenged with different tasks related to the design of production systems, process design, organization and marketing. In this research, we will present some of the special materials used for knife blades manufactured worldwide. The proper selection of materials and their thickness significantly affects the production price, processing method, corrosion resistance, mass. Special emphasis in the work is devoted to the design of the knife blade for household requirements, model ARIA22, made of EN 1.4028 stainless steel material. It describes the work of the die block, blanking punch, the necessary energy parameters for the realization of the processing process with piercing and punching, as well as the profitability of the production.

KEYWORDS: Stainless steel, die block, piercing, punching, knife blade

1 Introduction

In order to place a product on the market, financial, human/manpower and technological resources must be provided and then start with design, production, marketing and sales. All above mentioned factors must be in complete accordance and synchronized in terms of functionality among themselves. Failure of one the factors lead towards production failure. The selection of adequate materials, as in our case for the production of the ARIA22 kitchen knife blade requires additional knowledge related to materials, design, tool construction, heat treatment, production. The best steel for making knife blades is produced by giants of world metallurgy such as: "Solingen" in Germany, "Winkison" England, "Wenger" Switzerland. Knife blade products that are also popular in the world come from USA, Sweden, Finland, Japan. Non-corrosive steels (stainless steel, inox or martensitic steels) are mainly used for making knife blades. The stainless steels of the 440 series are consisting of chromium composition that retain their structure and hardness at room temperature even after heat treatment [1]. Their properties are regulated by heat treatment (quenching and tempering) [2]. The chemical composition of the 440-steel series is presented in Table 1.

The values in brackets in Table 1 are allowed and not mandatory.

- **440A steel** has very good quenching and tempering properties, high hardness, higher toughness than 440B and 440C steel. Also used for cutting tools, measuring equipment, bearings [7].

DOI: 10.2478/scjme-2023-0027, Print ISSN 0039-2472, On-line ISSN 2450-5471

- **440 B steel** has higher hardness and toughness than 440A steel and is resistant to wear and corrosion. It is used for cutting tools, measuring equipment, bearings and valves, scalper blades, chisel blades.

In the military industry, it is used for production of bayonets of combat weapons.

Table 1 Chemical composition of 440 series steel

Series	C	Cr	Mn	Str	S	Si	Mo	Cu	Ni
440A	**0,6-0,75**	16,0-18,0	≤1,00	≤0,04	≤0,03	≤1,00	≤0,75	(≤0,5)	(≤0,5)
440B	**0,75-0,95**	16,0-18,0	≤1,00	≤0,04	≤0,03	≤1,00	≤0,75	(≤0,5)	(≤0,5)
440C	**0,95-1,2**	16,0-18,0	≤1,00	≤0,04	≤0,03	≤1,00	≤0,75	(≤0,5)	(≤0,5)
440F	**0,95-1,2**	16,0-18,0	≤1,25	≤0,06	≥0,15	≤1,00	/	(≤0,6)	(≤0,5)

- **440C steel** has the highest hardness after quenching. It is resistant to high temperatures. It has good corrosion and wear resistance. It sharpens easily and has the ability to remain sharpness for a long time, it relatively cheap product. This steel is also used for high-quality cutting tools, nozzles, bearings that work in very corrosive environments, without lubrication and high oxidizing atmosphere [3].
- **440F steel** is used for free cutting and is mainly used in automatic lathes.

In general, the 440 series of martensitic steels are used for the production of centering pins, dental and surgical instruments, very high quality knife blades, valves, dies, oil pumps, bearings.

Table 2 Equivalent standards of steel series 440 [4]

ASTM/AISI	UNS	JIS	DIN/EN	GB
440A	S44002	SUS 440A	1.4109	7Cr17
440B	S44003	SUS 440B	1.4122 **X90CrMoV18**	8Cr17
440C	S44004	SUS 440C	1.4125 X105CrMo17	11Cr17 9Cr18Mo
440F	S44020	SUS 440F	/	Y11Cr17

Table 3 Hardness of 440 series steels and mechanical properties [15]

Steel	Hardness, Annealing (HB)	Heat treatment (HRC)
440A	≤255	≥54
440B	≤255	≥56
440C	≤269	≥58
440F	≤269	≥58
R_m=1750 [MPa]; $R_{p0,2}$=1230 [MPa]; E=200 [GPa]		

Other steels used for the production of knife blades are:

- **AUS-8**-Japanese steel with high chromium content (13-14.5%) and medium carbon value (0.70-0.75%). The high amount of Vanadium in its composition improves the wear resistance and easy sharpening of the blade. The hardness of AUS-8 ranges from 58-59

HRC, if well heat treated, its hardness can reach up to 60 HRC. Produced by Aichi Steel Company. AUS-8 steel is comparable to 440 B steel.

- **8Cr13MoV**- Chinese steel with almost the same characteristics as AUS-8 steel. If it is not heat treated accordingly, then it is difficult to maintain the sharpness of the cutting blade. Its hardness up to 57 HRC.
- **S30V**-One of the best knife blade steels in the world. Hardness of steel as tempered 58-61 HRC. Its hardness can even go above 64HRC. Contains carbon (1.45%), molybdenum (2%), manganese (0.5%), chromium (14%), vanadium (4%), phosphorus (0.030%), nitrogen (0.2%), sulfur (0.03%), tungsten (0.4%).

The disadvantage of this steel is that the cutting blade can quickly lose its edge retention.

- **VG-10**- Special non-corrosive steel with very good characteristics manufactured by Hitachi company. The Japanese company Takefu in Fukui is often mentioned as a seller of such laminated sheets. It is currently one of the best steels in the world for the production of blades for tactical and kitchen knives. The letter G included in the steel type indicates that it is stainless steel of the "gold" standard in the group of non-corrosive steels. The Swedish company Fällkniven is using this steel for production of the F1 knife model since 1995 as mandatory survival equipment for the Swedish air force [5].

Contains carbon (1.05%), molybdenum (1.2%), chromium (15.5%), vanadium (0.30%), phosphorus (0.030%), cobalt (1.5%), magnesium 0, 5%. Combination with chromium, molybdenum and vanadium increases the material's wear resistance. Depending on the heat treatment, its hardness ranges from 56 to 60 HRC. The disadvantage of steel is that the cost of production is very high.

- **1045**- Steel mostly used for sword production. It belongs to the group of low carbon steels with average maximum stress (Rm=565 MPa). Tools for upsetting, forging, axles, crankshafts, gears, bolts, are also made from this steel. Steel hardness 54-60 HRC. Contains carbon (0.42-0.50%), iron (98.51-98.98%), manganese (0.6-0.9%), phosphorus (≤0.04%), sulfur (0.050%).
- **1.4116**- Stainless steel which is used for Swiss knives and tools. It sharpens easily and retains the original sharpening characteristics very well. Victorinox knife blades are made from chrome molybdenum steels. Their chemical composition is: carbon (0.52%), chromium (15%), molybdenum (0.5%), manganese (0.45%) and silicon (0.6%). After complex tempering at 1040 ^{0}**C** the hardness of the cutting blade is 56 HRC. Saws, scissors, have hardness 53 HRC, drink opener 52 HRC, cork spring 49 HRC.
- **Sandvik 12C27**- High quality Swedish stainless steel. The hardness of the steel is from 54-61 HRC. Contains chromium (13.5%), carbon (0.6%), silicon (0.4%), manganese (0.4%), phosphorus (0.003%), sulfur (0.01%).
- **Sandvik 14C28N**-Swedish premium stainless steel. Used for household, hunting and fishing knife blades. The hardness of the steel is from 55-62 HRC. Contains chromium (14%), carbon (0.62%), silicon (0.2%), manganese (0.6%), phosphorus (0.025%), nitrogen (0.11%), sulfur (0.01 %).
- **D2**- carbon steel for tools. It has better properties than steel 1045. The reference standard for D2 steel according to DIN/EN is: 1.2379; X155CrVMo12-1; X160CrMoV121. Chemical composition of D2 steel: carbon (1.4-1.6%), silicon (0.1-0.6%), manganese (0.1-0.6%), phosphorus (max. 0.03%), sulfur (max. 0.03%), chromium (11-13%), molybdenum (0.7-1.2%), vanadium (0.5-1.1%). D2 steel is also used for the production

of forging tools, deep drawing, piercing/punching, scissors, calipers, blades for cutting scrap and tires. Its hardness during good heat treatment is from 60-62 HRC.

- **M390**- Produced by Böhler Edelstahl GmbH&Co KG Kapfenberg, Austria. Chemical composition of steel: carbon (1.9%), chromium (20%), molybdenum (1%), tungsten (0.6%), vanadium (4%), manganese (0.3%), silicon (0 .7%). Its hardness up to 62 HRC.
- **N360**, Böhlers N360 ISOEXTRA® nitrogen stainless tool steel- special non-corrosive steel with low carbon composition. Compared to other steels, it offers high ductility and compressive strength. In addition to knife blades, it is also used in the aviation industry for the processing of various parts, in medicine, pharmacy, food industry. Its hardness up to 58 HRC. Chemical composition: carbon (0.3%), chromium (14.77%), molybdenum (1.02%), nitrogen (0.42%).
- **ATS-34**- Japanese steel with chrome molybdenum composition. It is often compared to 440C steel. Unlike 440 C steel, it has (3-4%) less chromium and the same amount of molybdenum. Therefore, it is less resistant to corrosion but has greater strength. Also used for machining jet engine turbine blades.
- **Elmax**- Steel with high chromium molybdenum and vanadium alloy. Produced by the Bohler-Uddenholm company. Chemical composition: carbon (1.7%), chromium (18%), vanadium (3%), molybdenum (1%), manganese (0.3%), silicon (0.8%). Its hardness up to 61 HRC.
- **San Mai III**- Cold Steel Manufacturer. San Mai is a Japanese term that means "3 layers". It is used for making katana swords and daggers. The laminated construction of the steel material enables perfect material characteristics. The middle layer is of high carbon composition (eg AUS-8 steel) while the outer layer of steel has a lower amount of carbon. In this way the cutting blade is heavier and more resistant to wear and breakage. The sandwich-shaped connection allows for great rigidity so that the cutting blade can withstand lateral stresses. Hardness is related to the "softness" and "flexibility" of the steel in such a way that the cutting blades retain their sharpness well.
- **VG-1**- Steel manufactured by Cold Steel. It is a superior steel compared to other stainless steels.
- **4116**- Steel produced by the German firm ThyssenKrupp with a pronounced balance of carbon and chromium. The chemical composition of steel 4116 is: Carbon (0.55%), Chromium (15%), Molybdenum (0.80%), Vanadium (0.20%), Phosphorus (0.04%), Manganese (1%), Silicon (1%), Sulfur (0.03%). Depending on the heat treatment, its hardness is brought up to 56 HRC. Such strength is attributed to its carbon composition of 0.5%.
- **1055**- Carbon steel manufactured by Cold Steel. The composition of carbon is (0.5-0.6%) and manganese (0.6-0.9%). It is one of the strongest steels, with hardness during quenching of 60-64 HRC. It is used in cases where stability and great durability are required.
- **SK-5**- Japanese steel equivalent to American steel 1055 of Cold Steel. Composition of carbon (0.75-0.85%) and manganese (0.6-0.9%) with hardness up to 65 HRC.
- **0-1-HighCarbon- Steel** ideal for making knife blades with a high carbon composition produced by Cold Steel. The hardness of this oil-cooled steel is 61 HRC.
- **Carpenter® CTS® XHP**-Martensitic steel developed by the Cold Steel company. With high amounts of chromium (16%) and carbon (1.6%) with hardness up to 64 HRC with

air cooling. It has better properties than D2 and 440C steel. Used for tools and special knife blades.

- **Powder steel (ZDP 189)**- Extra Japanese steel from Hitachi company with high carbon composition (e.g., ZDP189 core while ATS-34 side). The chemical composition of steel is: carbon (3%), chromium (20%), molybdenum (1.4%), tungsten (0.6%), manganese (0.5%), silicon (0.4%), vanadium (0.1%), sulfur (0.02%). One of the best steels in its category with hardness up to 65 HRC.
- **3G**- two-layer laminated steel produced by the Swedish company Fällkniven (e.g., VG-2 structure with SGPS- Super Gold Powder steel and VG-2, i.e., SGPS steel core, VG-2 outer layers). Its hardness is 62 HRC. Chemical composition of 3G steel: carbon (1.25-1.45%), chromium (14-16%), molybdenum (2.30-3.30%), vanadium (1.80- 2.20%), manganese (0.40%), silicon (0.50%), phosphorus (0.03%), sulfur (0.03%).
- **Damascus steel**- is the most qualitative but also the most expensive steel for making knife blades. It is processed in the craft forge. In fact, two or more steels with different carbon compositions are mixed, which are sprayed with special substances (borax, ferrochloride.) and then processed by forging and welding in presses or hammers [1, 2].

The Swedish company Fällkniven uses 120-layer steel for the production of knife blades. Their Powders steel (Cowry X) steel in the NL5cxL survival and hunting knife model has a hardness of up to 64 HRC. Chemical characteristics: carbon (3%), chromium (20%), molybdenum (1%), vanadium (0.3%), the rest up to 100% iron. The German manufacturer Böker Solingen produces 67-layer damascus steel blades, the Damascus Gent 1 and Gent 2 models. Their market price for approximately 1cm of blade length is somewhere around 10 Euros. Most manufacturers of Damascus steel do not correctly indicate the characteristics of the material or even present them falsely. Damascus martensitic steels are used for making knife blades. Up to 160-layer, medium-hard Damascus steels with a circular section are used for the production of unique luxury weapons, kitchen utensils, golf props.

Damascus steels up to 100 layers are used for the production of special rifle and revolver barrels as well as hunting axes. Damascus steel and Japanese steel for swords belong to the group of hypereutectoid steels. These high carbon steels at room temperature have yield stress of 900 MPa and ultimate tensile stress of 1100 MPa. The researchers from the technical faculty of Dresden came to the conclusion that these steels themselves contain particles of cementite, so it is a matter of carbide steels. The blacksmiths' association in the USA and in other countries in the world consider Damascus steel, which consists of at least 300 layers.

The Tirpitz knife blade model industrially produced by the German manufacturer Böker Solingen has over 300 layers. The hardness of the blade ranges from 61-63 HRC. The steel used to make the blade of this knife was recycled from the remains of the largest German ship Tirpitz destroyed in the second world war off the coast of Norway [6]. The cost price in the market approximately for 1 cm of length is somewhere around 100 euros.

Some of the functions of the chemical elements used for alloying and processing of these non-corrosive steels are [7]. Manganese improves the properties of the annealing steel and affects the better formation of its structure and increases the hardness and durability. Chromium increases the corrosion resistance of steel. Its high composition makes the steel brittle. Steels that have a value above 10.5% of chromium are stainless steels resistant to corrosion and oxidation [8 -10]. Steels defined as stainless can corrode if their composition contains less than 13% chromium. As a standard in the knife industry, the chromium content of the material is 13%, while according to the ASM standard, a chromium percentage of 10% is sufficient. Nickel increases the corrosion resistance of the steel and makes the blades more durable. Molybdenum has multiple roles. Increases the ability of the material to be tempered, increases the hardness, and makes the metal more flexible and less brittle. Vanadium in the composition of the steel has the task of providing better tempering and maintaining the hardness of the blades. Silicon has multiple properties in steel in terms of improving its characteristics, especially it during the forging. Tungsten increases the scratch resistance, makes the steel stronger and increases the ability against corrosion. This material is used to make the outer reinforcing part of the tank body. In addition to the mentioned chemical elements, steel alloys can also contain nitrogen, sulfur. Besides these analyzed steels, other materials such as titanium, ceramics (Al_2O_3, ZrO_2), single-use plastics are also used for making knife blades.

2 Knife Blade model Aria22 for kitchen needs from stainless steel En 1.4028

For production of the knife blade model ARIA22 for kitchen needs (figure 1), the sheet from stainless steel X30Cr13 (EN 1.4028) with thickness s= 1.5 [mm] and chemical composition: carbon (0.26-0.35%) was chosen. manganese (<1.5%), silicon (<1%), phosphorus (<0.04%), sulfur (<0.03%), chromium (12-14%). The hardness of the steel is from 45-51 HRC. The mechanical characteristics in the heat treated state of the material are: Rm=800÷1000 MPa, Re> 600 MPa [9, 14]. In addition to knife blades, this steel is also used for the production of shafts, bolts, springs, molds for casting under pressure, pistons, dental and surgical instruments.

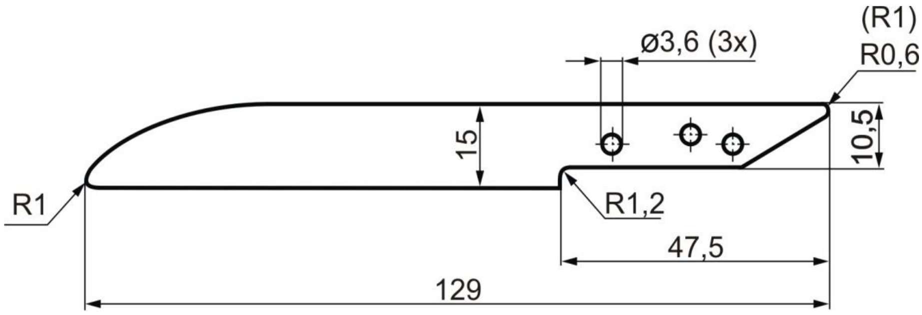


Fig. 1 Aria22 knife blade model.

The knife blade is made with punching and piercing tools.

The choice of the material for the tool working elements as well as their further heat treatment are the main factors that affect the tool lifetime. When choosing the material, the type of production (series or mass) designation, the type of technological operation, dimensions, shape and characteristics of the material from which the part is produced must be taken into account.

The requirements of materials for tools used during processing with metal forming are [7]:

- Very high strength
- Toughness
- Temperature resistance
- Wear resistance
- Dimensional and shape stability during heat treatment

The metals used in the construction are tool steels such: carbon tool steels, alloyed tool steels such as high Cr alloy steels. Carbon steel C 80 W1 is used during the processing of soft metals, whilst for wear resistance are used steels with a high chromium alloy, such as 105 WCr. In mass production during the manufacturing process of small parts, hard metals are used and, in this case, only the working part of the tool is made of hard metal.

When working on large-sized parts, the working elements of the tool are made of iron alloys, which after heat treatment have a hardness of up to 350 HB. In tools for small series of processing, constructive steels can be used for working elements of the tool, which are improved to 45÷50 HRC.

Table 4 presents the materials from high-speed tool steel that are used for the working elements of the tool

Working element of the tool	**Working conditions**	**Designation according to DIN**	**Hardness HRC**
Piercing Punching Piercing die Punching die	For simple contours (For light working conditions s≤4 mm)	C80W1	58÷62
		C105W1	
		C125W	
		90 Cr 3	
		90 MnCr V5	60÷64
	For complex contours (For difficult working conditions s>4 mm)	X 210 Cr 12	56÷64
		210 Cr 46	60÷64
		X 38 CrMo V5	60÷64
		110 WCr V5	60÷64
		60 WCr V7	62÷54

Table 5 presents the materials for making other elements of the tool.

Table 5. Materials for other tool elements

Tool element		Material DIN		Heat treatment	Hardness HRc
		Basic	Replacement		
Handle holder and working elements, base plate		C 35	R-St 44-2	-	-
		C 45	St 50-2	-	-
Leading elements	Guide post	C 15	C 10	cementite, tempering	60±2
		C 80 W1	C 45	tempering	45÷50
	Guide post bushing	C 15	C 10	cementite, tempering	58÷62
		100 Cr 6	C45	tempering	45÷50
	Plate	C45	St 60-2	tempering	50÷54
Runstopper		C 15	C 45	cementite, tempering	50÷55
		C 80 W1		tempering	
Shank		C 35	R-St 44-2		
		C 45	St 50-2		
Backup plate		C 45	C 15	cementite, tempering	45÷50
		C 80 W1	St 50-2	tempering	
Blank holder, ejectors		C 80 W1	St 50-2		
			St 60-2		
Dowel pin		C 80 W1	St 60-2		45÷50
Screws		C 45		tempering	45÷50
Wedge		C 45		Wedge head tempering	-
Spring		Steel for springs			40÷50

The value of the maximum tangential stress depends on many factors such as: the diameter of the puncher, the space between the puncher and the die-block, the thickness of the sheet metal (it decreases with increasing thickness), the rate of deformation, the lubrication of the sheet metal, the tool [11-12]. However, in most cases, the impact of these factors is not so great, and here $R_m \approx 1{,}3 \cdot \tau_m$ and $\tau_m \approx 0{,}8 \cdot R_m$ respectively [12].

- For crank presses with step up to 120 rpm $\tau_m = (0{,}8 \div 0{,}86) \cdot R_m$;

- For hydraulic presses $\tau_m = (0{,}65 \div 0{,}75) \cdot R_m$.

Only in the cases when it comes to small diameters of piercing punch, then the hardness during piercing significantly changes - it increases in relation to the nominal tangential stress. For EN 1.4028 material, the value of the tensile strength obtained by the tensile test has the value: $R_m = 800\ [N/mm^2]$

The calculated shear strength value is: $\tau_m = 650\ [N/mm^2]$.

The relative depth of penetration of the tool into the material depends on the type of material being used, the thickness of the sheet metal, the condition of the tool (in the case when the tool is dull the depth of penetration is greater), the size of the working space and the speed of deformation. The relative depth of penetration of the tool into the material obtained analytically and experimentally for the EN 1.4028 material is: $h_{ot} = 0{,}41$.

Material slip angle (weeping direction): $\beta = 4^0$; $(tg\beta = 0{,}069)$. Clearance calculated according to the analytical method:

$$w = 2 \cdot s(1 - h_{0t}) \cdot tg\beta = 2 \cdot 1{,}5(1 - 0{,}41) \cdot 0{,}069 = 0{,}122\ [mm] \quad (1)$$

$$\left[\frac{w}{s}\right] \cdot 100 = \frac{0{,}122}{1{,}5} \cdot 100 = 8{,}13\ \% \quad (2)$$

Typical clearance in conventional pressworking is expressed as a percentage of the material thickness range between (5%) and (9%) for material thicknesses up to (6,4 mm).

The material is standard sheet metal tray 2000X1000x1.5 [mm] cut off into strips.

Strip Width:

$$B = D + 2b = 129 + 2 \cdot 3 = 140\ [mm] \quad (3)$$

- The strip is acquired with dimensions: 140x1.5 [mm].
- Bridge and strip cutting are acquired: $b_{min} = 2[mm]$.

Step x, number of details per strip and Cutting force are:

$$\left.\begin{aligned} x &= c + b = 15 + 2{,}0 = 17[mm] \\ z &= \frac{L - b}{x} = \frac{2000 - 2}{17} = 117[pieces] \\ F &= L \cdot s \cdot \tau_m = 2(a + b) \cdot s \cdot \tau_m = 2 \cdot (129 + 15) \cdot 1{,}5 \cdot 650 = 280800[N] \end{aligned}\right\} \quad (4)$$

The exact perimeter of the knife blade calculated with AutoCAD: (L=271,583 mm); Perimeter (1555.99 mm^2). The force requirement of the press is: $F_m = 1{,}3 \cdot F = 1{,}3 \cdot 280800 = 365040[N] \approx 42[ton]$

The thickness of the die-block plate (H) for the rectangular shape is calculated according to the expression:

$$H = \left(10 + 5 \cdot s + 0.7\sqrt{a + b}\right) \cdot c\ [mm] \quad (5)$$

Where:

- s [mm]-the thickness of the sheet
- a, b [mm] - the largest dimensions of the hole in the die-block
- c=$f(R_m)$- factor which depends on the tensile stress of the material which is pierced or punched.

This factor is brought to these limits and obtained from table 6.

Table 6. Values of the correction factor c for die-block dimensioning

R_m [N/mm^2]	800	400	250	120
C	1.3	1.0	0.8	0.6
Note: Interpolation is required for between values				

$$H = \left(10 + 5 \cdot s + 0{,}7\sqrt{a+b}\right) \cdot c = \left(10 + 5 \cdot 1{,}5 + 0{,}7\sqrt{129+15}\right) \cdot 1{,}3 = 33{,}67 \text{ [mm]}$$

The obtained result is rounded to the first largest value (order of standard numbers 12, 16, 20, 25, 28, 32, 36, 40, 45, 50, 56, 63, 71 and 80 mm) of the plate thickness from which die-block is worked in the range of 16 to 50 mm.

- The thickness of the die-block is acquired: H=40 [mm]

The width of the edges of the plate (die-block) "e" is calculated with the expression:

$$e = (10 \div 12) + 0.8 \cdot H \text{ [mm]}. \quad (6)$$

The "e" value is rounded to the first larger value, in this case it is not allowed to acquire a value smaller than 25 mm.

If the contour of the detail has sharp internal angles (smaller than 90^0), then the width of the edges of the die-block increases by 15÷20%.

- Additional die-block width: $A = a + 2 \cdot e = 129 + 2 \cdot 52 = 233$[mm]
- Die-block width: $B = b + 2 \cdot e = 150$[mm]

The dimensional die-block is acquired: $AXB = 250X150$[mm].

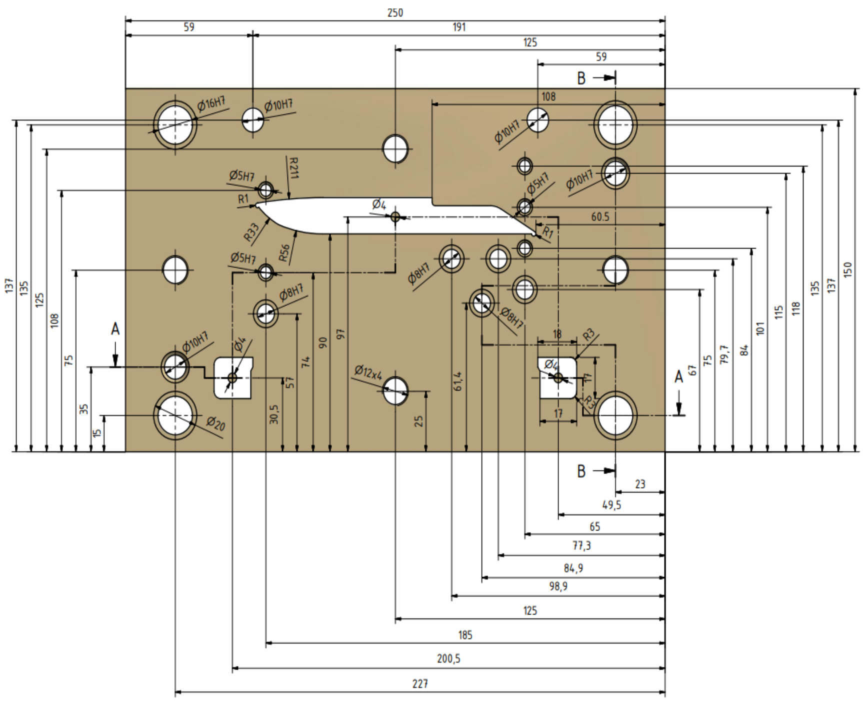


Fig. 2 Knife blade punching die

Verification of die-block bending load:

$$\sigma_p = 0{,}75 \cdot \frac{F \cdot l}{(B-b) \cdot H^2} \leq \sigma_{lej} \text{ [N/mm}^2\text{]} \quad (7)$$

Where:

- σ_{lej}[N/mm^2]- allowable bending stress.
- For hardened and tempered tool steel σ_{lej} =500 [N/mm^2].

$$\sigma_p = 0,75 \cdot \frac{F \cdot l}{(B-b) \cdot H^2} = 0,75 \cdot \frac{280800 \cdot 60}{(150-129) \cdot 40^2} = 376,00[N/mm^2]$$

Since σ_p=376,00 [N/mm^2]<σ_{lej}=500 [N/mm^2] the condition is met.

This method of calculating the die-block is estimated (approximate), but it satisfies the technical requirements (the exact calculations of the plate are based on the theory of resistance of materials where in this case the plate rests on an elastic support).

Verification of the surface pressure on the support surface of the punch:

$$p = \frac{F}{A} = \frac{F}{a \cdot b} = \frac{280800}{129 \cdot 15} = 145,1\ [N/mm^2] \quad (8)$$

Since $p \le p_{lej} \le 250$ [N/mm^2] there is no need for a pressure plate.

The presentation metal sheet strip along with the knives for pitch limitation is shown in figure 3

The die-block is rectified Ra=0.8 [µm].

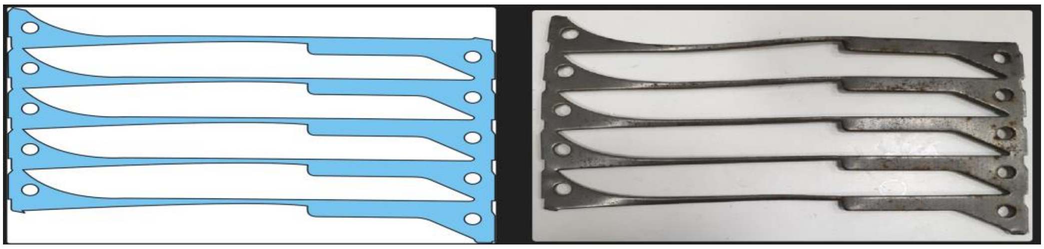


Fig. 3 The sheet metal strip (stripe width after cutting) designed and execution together with the knives for step limitation (side cutter)

Figure 4 shows the dimensions of the punch design for punching the knife blade from EN 1.4028 stainless steel material. Puncher is tempered. Before tempering, the holes for the M6 thread are drilled. The quality of the punch Ra=0.8 [µm]. Punch is made from X210Cr12 with Initial dimensions of 20X135x110 mm.

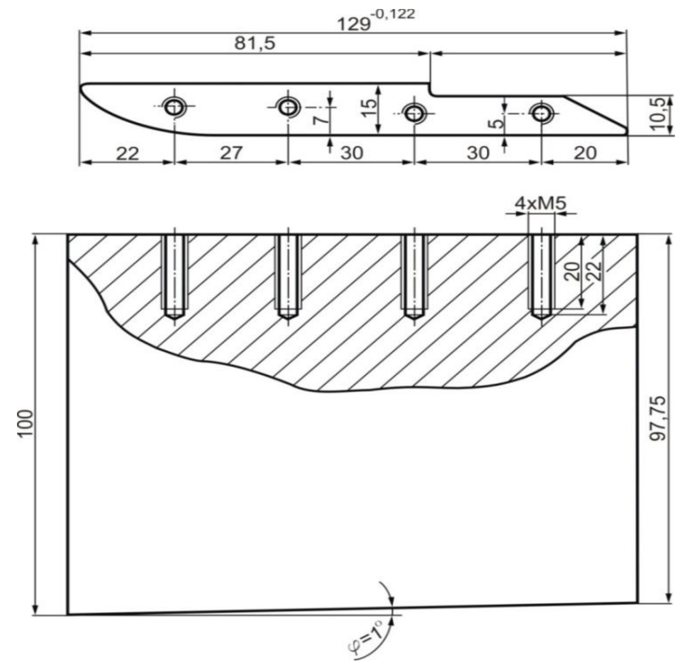


Fig. 4 Dimensions of the punch design of the stainless steel knife blade EN 1.4028.

The dimensions of the hole punches and centerers are given in figure 5.

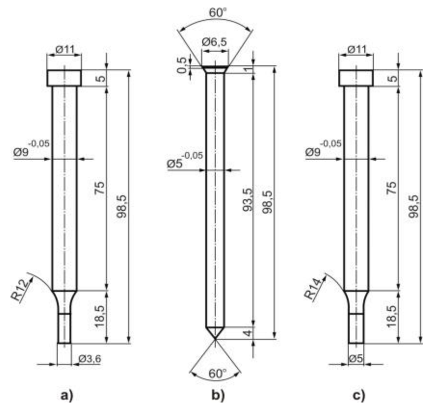


Fig. 5 Dimensions of piercing punches and pilot holes

Piercings and centerers are hardened at 62 HRC:

a) Piercing material X210Cr12 (dimensions of the raw material ø12x100).
b) Centering material EN 60 (DIN 1.0607) (dimensions of the raw material ø7x100).
c) Piercing material X210Cr12 (dimensions of the raw material ø12x100).

The centerer serves to improve the small errors that appear when moving the bar on tools with multiple operations one after the other. These errors occur due to poor tape guidance or poor tape support on the stop. In fact, the centerer represents the special variant of the solution of the positioning of the bar in the tool. The centering element is slightly longer than the punch. So, before the punch meets the sheet metal, the centerer enters the pre-pierced hole and places the strip in the right position.

In our case, it is used since the accuracy of the position of the hole is required in relation to the external shape of the part, that is, when the step is determined by a limiter. The head of the centerer can be of a spherical-conical shape, while in most cases, due to the easier realization, they work with a conical head shape.

The height of the conical part is acquired 5s, the cylindrical surface serves to define the hole and is worked with a height of 1.5s. The diameter of the centering relative to the diameter of the hole is smaller by 0.05 mm. The constructive forms of the centerers can be different depending on the diameter of the hole which serves for centering and the thickness of the sheet metal (for s≤ 2 mm, D=6÷30 mm; s>2 mm, D≤11 mm; s>2 mm, D>11 mm).

The acquisition of bolts for fastening the tool is based on the condition that the maximum overall length of the bolt must be shorter than the thickness of all plates:

$$l_{max} = S_1 + S_2 + S_2 - 2 \text{ (mm)} \tag{9}$$

The overall length of the centering pin is several millimeters shorter than the overall thickness of all the plates. The hole for the pin is drilled in the tolerance area (H7), simultaneously along all the plates, so that they form the whole (H7/m6). Pin holes are reamed along all plates and full length/thickness, leaving no blind holes due to pin removal. The minimum length of the pin on the bottom plate includes (1.5÷2) of the diameter of the pin. The limiter for the gap is selected in the form of a knife figure 6. The pitch limit knife is hardened to 62 HRC.

Before tempering, the M8 thread is opened (dimensions of the raw material 20x20x110). The material from which the pitch limiter is made is X210Cr12. The shank figure 7 is made with dimensions from the row material ø45x 95 [mm].

The other tools are dimensioned based on the general functional scheme of the tool given in figure 7. In the work, the dimensioning of each plate of the tool will be given only in general form [6, 17].

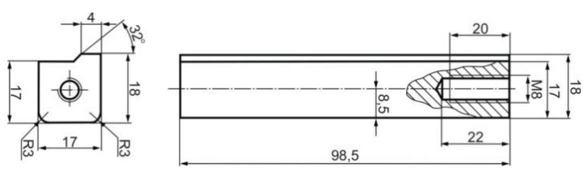


Fig. 6 Dimensions of the pitch limiting knife

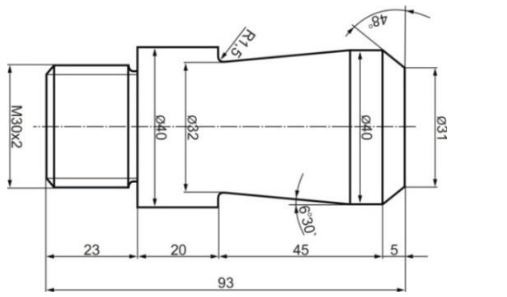


Fig. 7 Shank for fixing the tool in the press

The construction of the dies, their quality, and die life are highly significant aspects of total manufacturing operations, including the quality of the parts produced [16, 17, 21].

The quality of the surface of the knife blade before the final processing operation is Ra=0.78, which is within the range of preliminary predictions Figure 9. After the final processing of the blade, the quality of the obtained surface is Ra=0.38.

3 PROFITABILITY OF ARIA2022 KNIFE BLADE PRODUCTION IN LARGE SERIES

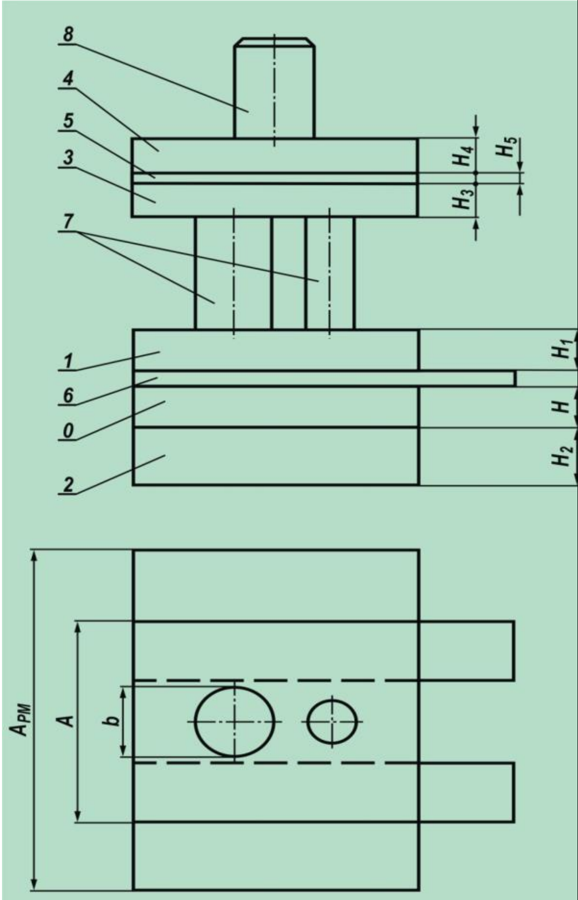
Calculations for electricity costs are calculated with the expression [15]:

$$P_{en} = P_L \cdot P_{kw} \cdot n_h [€] \tag{10}$$

Where:

- $P_L[kW]$ –the energy expenses of the device per hour (taken from the characteristics of the machine);
- $P_{kw}\left[\frac{€}{\text{kwh}}\right]$- price of electricity

- $n_h[hour]$ - the necessary working hours for the entire series.



H= min. 15 mm
H1= H_{PU} = (0,8÷1) H

H2= H_{PM} = (1÷1,5) H

H3= HMV= (0,6 ÷ 0,8) H
H4= HPS = (0,8 ÷ 1,2) H

H5=2 ÷8 mm in this case H5=0. There is no need for a backup plate.

H6=2·s

b [mm]	H[mm]
up to 50	(0,35÷0,5) ·b
50 ÷200	(0,18÷0,3) ·b
over 200	(0,12÷18) ·b

A=b+(2,5÷4) ·H
A_{PM}=A+(40÷70)

Space between metal sheet and guides:
-0,5 up to1 mm (up to 100 mm of the strip width)
-1 up to 1,5 mm (over 100 mm of the strip width)

0-Die-block, 1-Stripper, 2- die holder lower shoe), 3-Punch holder plate, 4-Top Plate, 5-Pressure plate, 6-Sheet Strip Guides, 7-blank punch / piercing punch, 8-Shank.
Note: for sheets with a thickness of less than 0.8 mm, the height of the die can be reduced from H= min 15 mm by 20%, while for sheets with a thickness of more than 3 mm, the value of the height of the die H= min 15 mm can be increased by 20%

Fig. 8 Functional elements of the tool

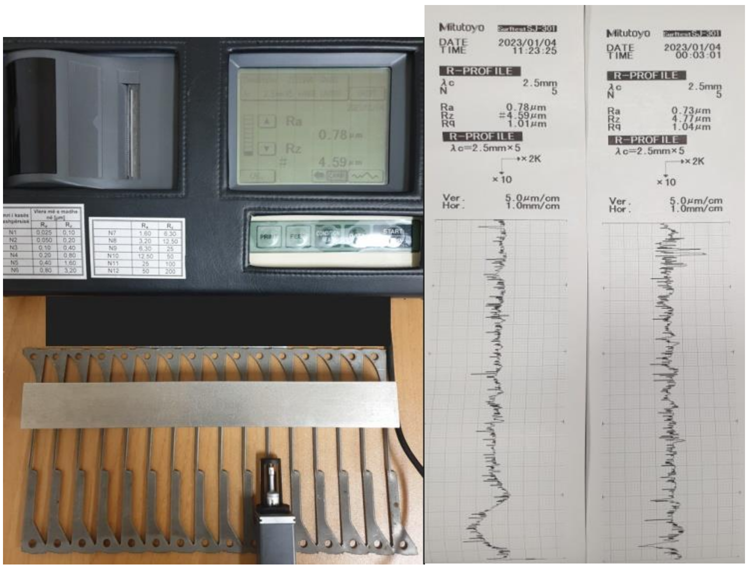


Fig. 9 Material hardness testing before and after knife blade machining

The profitability of production (the number of parts that must be produced so that the series is produced without loss) is calculated with the expression:

$$R_s = \frac{P_{shs}}{P_{f1} - P_v} \text{ [piece]} \tag{11}$$

Where:

- P_{shs} − selling price for the series
- P_{f1} − the increased price for margin profit
- P_v − variable expenses: material expenses, electric power expenses for the wages.

The profitability of the production series should include workers' expenses, workers' health insurance, sales from punching and piercing waste, packaging, marketing. The total amount of material waste is calculated by changing the mass of the tray or drum and the required mass of the parts.

Direct or indirect expenses are fuel expenses, administration, management salaries, car depreciation (varies and is calculated as a percentage as direct payment expenses):

330% - for production

120% - for administrative expenses.

The annual profit is calculated with the expression:

$$F_v = P_{shs} - (P_{tr} + P_v \cdot N) \tag{12}$$

Where are:

- $P_{shs}[Euro]$ − selling price of the series
- $P_{tr}[Euro]$ −total indirect costs (variable expenses)
- $N[piece]$ −the number of parts produced during the year.

As a result of the work of this production system, the production of the Aria22 knife blade is intended to meet the needs of the market and the household consumer. The basic characteristic and validity of this product is its quality and is defined based on the expression:

$$Q = \frac{1}{\sum_{i=1}^{n} k_i}(Q_k + Q_p + Q_e) \tag{13}$$

Where:

- $\sum_{i=1}^{n} k_i$ − the sum of all the coefficients of the construction, production and exploitation quality characteristics.
- Q_k − quality of new construction.
- Q_p − production quality.
- Q_e − exploitation of quality.

The quality values for this production should and are within these limits :

$$0 \leq Q \leq 1$$

All the examined parameters are within the target function and the assumptions made at the beginning of manufacturing of a product in terms of quality, hardness, toughness and the price 20% cheaper compared to the same products on the market figure 10.

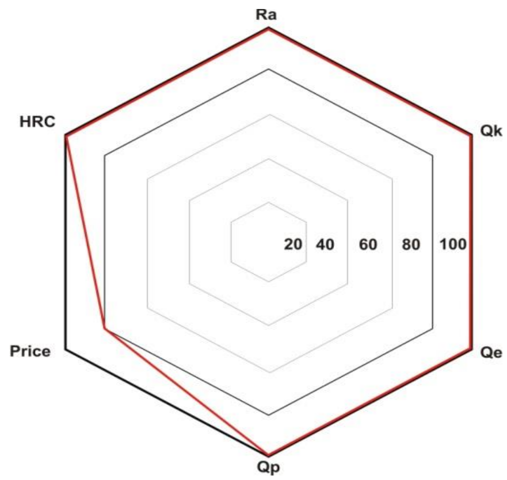


Fig. 10 Target function parameters

Conclusion

The developed and manufactured blade of the Aria22 knife model meets all the rigorous requirements for large series production and responds to the target function set at the beginning of the work. The designed tool and the quality of the blade of the acquired knife is in line with the predictions and in accordance with the characteristics of other global competing manufacturers, Ra=0.38 after final processing. The selected material meets the conditions for mass production in the category of non-corrosive steels with a chromium value (12-14%), which means that it is a material resistant to corrosion and oxidation as well as resistant to organic acids, nitrates and substances others found in food. The blade of the household knife selected for processing from steel EN 1.4028 is flexible, elastic, retains the initial sharpness for a long time, beautiful in terms of appearance, aesthetic and practical. Improving the hardness of the knife blade and adapting it to the specific market requirements will be a priority in the future because different world manufacturers in order to increase the hardness, rigidity of the cutting blade and to protect it from corrosion today apply the coating of the knife blade with a thin titanium layer up to 3 microns. Such a coating increases the hardness of the cutting blade up to 90 HRC. Significant importance should be given to the production certification and the warning that the product material contains the chemical element chromium, which in the state of California is known as a cause of cancer and birth defect or other reproductive harm.

The information, drawings, data, and calculations provided in the work represent typical data or average values and should not be interpreted as definitive guarantees of maximum or minimum values achieved.

LITERATURE

[1] Verhoeven, J. D. “Fundamentals of physical metallurgy”, John Wiley & Sons Incorporated, **1975**.

[2] Verhoeven, J. D. “Metallurgy of steel for bladesmiths & others who heat treat and forge steel”, Iowa State University, pp. 66 – 68, **2005**.

[3] George E. D., Kuhn, A. K., Lee Semiatin, S. “Handbook of workability and process design”, ASM international, **2003**.

[4] “Thomasnet” Available online: https://www.thomasnet.com/ (accessed on 6 March 2023).

[5] “The Swedish company Fällkniven”, Available online: https://fallkniven.se/en/product-information/steel/ (accessed on 1 March 2023).

[6] “Die Böker Messer-Manufaktur”, Available online: https://www.boker.de/ (accessed on 6 March 2023).

[7] “Technical Data”, Available online: https://www.worldironsteel.com/ (accessed on 2 March 2023).

[8] Berrahou, M., Kaoula. A. “Experimental and numerical study on the efficiency of the repair of composite structures cracked and v-notched by different types and shapes of composite material patch”, Strojnícky časopis – Journal of Mechanical Engineering 72 (1), pp. 1 – 14, **2022**. DOI: 10.2478/scjme-2022-0001

[9] Keerthana, B., Kumar, G. V., Babu, K. A. “Effect of minimum quantity lubrication on surface roughness and temperature in milling of EN31 steel for die making”, Strojnícky časopis – Journal of Mechanical Engineering 69(1), pp. 61 – 68, **2019**. DOI: 10.2478/scjme-2019-0005

[10] “Cold Steel San Mai Tanto Series Fixed Blade Knife”, Available online: https://www.amazon.com/Steel-Tanto-Fixed-Blade-Knife/dp/B07CCWDP4K?th=1 (accessed on 2 March 2023).

[11] Bruçi, M. “Theory of Metal Forming”, University of Prishtina “Hasan Prishtina”, Faculty of Mechanical Engineering, Pristina, **2020**.

[12] “Martensitic stainless steel”, Available online: http://www.steelnumber.com. (accessed on 2 March 2023).

[13] Pöhlandt, K. “Materials Testing for the Metal Forming Industry”, Springer- Verlag Berlin Heidelberg, **1989**.

[14] Pöhlandt, K. “Materials testing for the metal forming industry”, Springer Science & Business Media, **2012**. DOI: 10.1007/978-3-642-50241-5

[15] Kurt, L. “Handbook of metal forming”, McGraw-Hill Book Company, **1985**. ISBN 0-07-036285-8

[16] Nielsen, Ch., Martins, P. “Metal Forming Formability, Simulation, and Tool Design”, ISBN: 9780323852562, 1st Edition - February 12, **2021**.

[17] Landgraf, P., Birnbaum, P., Meza-García, E., Grund, T., Kräusel, V., Lampke, T. “Jominy End Quench Test of Martensitic Stainless Steel X30Cr13”, Metals 2021 11(7), 1071, **2021**. DOI: 10.3390/met11071071

[18] Günter, S., Kühn, K.-D., Hoffmeister H.-W. “Fertigungstechnik”, Springer-Verlag, **2007**.

[19] Ambrogio, G., Filice, L., Gagliardi, F. “Formability of lightweight alloys by hot incremental sheet forming”, Materials & Design 34, pp. 501 – 508, **2012**.

[20] Zhang, R., Shao, Z., Lin, J. “A review on modelling techniques for formability prediction of sheet metal forming”, International Journal of Lightweight Materials and Manufacture 1(3), pp. 115 – 125, **2018**.

[21] Jančo, R. “Stress Analysis of Pressing Joint of Two Conical Pipes”, Strojnícky časopis – Journal of Mechanical Engineering 73(1), pp. 117 – 124, **2023**. DOI: 10.2478/scjme-2023-0009