TECHNICALUNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 65, Issue Special IV, December, 2022

IDENTIFICATION OF A TECHNOLOGY TO OBTAIN DAMASCUS STEEL WORKPIECES

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Abstract: *Damascus steel is a composite metallic material made using different welding processes by forging some steel components with different chemical compositions at high temperatures. These steels can have high hardness, ensuring good wear behavior and toughness, which contributes to a decrease in the brittleness typical of ordinary hard steels. The imposed decision technique was used to select a manufacturing technology for Damascus steel workpieces. For the conditions considered, it was found that it is more convenient to manufacture Damascus steel workpieces starting from steel strips with different carbon contents. The application of this technology allowed the manufacture of Damascus steel workpieces.*
Key words: *Damascus steel, manufacturing technology, technology selection, imposed decision technique, strip use.*

1. INTRODUCTION

Damascus steels are layered composite metallic materials manufactured by various high-temperature forging welding processes from steels of different chemical compositions. These steels were and still are used to make cutting objects, armor, interior design objects, etc.

Since ancient times, from the middle of the 1st millennium BC, those who first manufactured Damascus steel used the so-called Wootz steel in southern India. They aimed to create a material with special mechanical properties.

The main characteristic of Damascus steel was hardness, given by the steel component with a high carbon content (1.2-1.6 % C).

At the same time, Damascus steel had good toughness, thanks to the low-carbon steel component [1-5].

Another important characteristic that differentiates it from steels with an approximately homogeneous structure is related to the appearance of the surface. This surface included fine undulating lines in the form of water waves. The wavy lines were dark in color due to the presence of the high-carbon steel component, and they alternated with light-colored lines generated by the presence of the low-carbon steel [1].

Damascus steel workpieces are basically manufactured by several known processes [1-12], such as:

a) hot forging of Wootz steel obtained by melting iron ore in a crucible;

b) hot forging of a package of sheet metal strips from steels with different carbon contents, followed by multiple folding and forging until the strips are welded by hot pressing;

c) hot rolling of a package of sheet metal strips made of steels with different carbon contents, followed by twisting along the longitudinal axis of the package, for better welding and combination of components made of different steels;

d) hot pressing of a prismatic metal box, hermetically sealed and filled with various metal granules, small pieces, shavings, and metal powder, all made of steels with different carbon contents. After removing the box through various processes, the cores made of solidarized granules by hot pressing are forged until the proposed shape is achieved.

In recent decades, the properties of Damascus steels have been of interest to researchers in the field of machine manufacturing.

Thus, in a technical report drawn up in 2003, Taleff highlighted aspects related to the microstructure of a knife with Damask patterning [2].

Strobl et al. [3] confirmed that when making Damascus steel, the high-temperature forging of sheet metal strips from steels with different carbon contents leads to the formation of composite metallic materials that combine, to a certain extent, the mechanical properties of initial steels.

In work published later [4], the authors describe how a Sax sword made of Damascus steel was replicated.

Knowing the chemical components that led to the making of this sword in the 8th century in Europe, a similar Damascus steel was produced by hot forging 9 plates from two different sheets of steel. One of the steels was low-alloy steel with less than 0.1% carbon produced in 1550, and the second was high-carbon steel with a carbon content between 0.42 and 0.5 % C.

After several forgings, a prismatic workpiece was obtained. The workpiece was twisted several times along the longitudinal axis. It was thus possible to generate the two cutting edges of the sword.

Fabricated Damascus steel test samples were subjected to metallographic investigations. The obtained images highlighted the presence of martensite, acicular ferrite, and pearlite, as well as some defects specific to hot welding (decarburized areas and areas with oxide formation between the package plates at high temperatures).

Grazzi et al. investigated the microstructure of several fragments of genuine Wootz steel test samples resulting from cutting objects and protective armor from museum artifacts. The investigations were carried out by non-destructive methods, namely neutron imaging and neutron diffraction [5].

The spatial arrangement of cementite, pearlite, and ferrite in the mass of the studied steel, the carbon content of each fragment, other alloying elements, and some impurities were observed.

Compared to the classic methods of metallographic microscopy, some advantages of the research method were highlighted, such as making an image of the entire section of the studied object without the need to destroy the samples and some possibilities of verifying the authenticity of the materials.

Results of extensive research on the different properties of some Damascus steels were published in the last decade by Sukhanov [6, 7].

Some preliminary research results on obtaining workpieces from Damascus steel were published in [12].

Following our research, this paper will highlight the use of selecting a technology for obtaining Damascus steel workpieces. It will also present the main technological stages that concretely led to the realization of Damascus steel workpieces from sheet metal strips of steel with different carbon contents, using forging and hot twisting.

2. MAIN ASPECTS OF OBTAINING DAMASCUS STEELS WORKPIECES

The first stage of the production of Damascus steel, regardless of the production method, from sheet metal strips or by agglomeration of granules, aims to determine the materials that will be included in the composition of Damascus steel by taking into account certain of their mechanical properties, such as hardness, elasticity, tenacity, wear resistance.

It is also necessary to take into account some technological properties of the component steels, such as the weldability by hot forging, the heat treatment required to be applied later, the tendency to oxidize at high temperatures, etc.

The method of forging the package of sheet metal strips from steels with different carbon contents involves the following technological operations:

a) separation of sheet metal strips to a previously established size;

b) finishing the edges of the strips and removing the oxides;

c) the alternative arrangement of the strips in a package, taking into account the carbon content and the degree of weldability by hot forging of the steels in the composition of the strips;

d) the consolidation of the package using the assembly by electric arc welding;

e) heating the package to the forging temperature;

f) to avoid hot oxidation of the components made of different steels, covering the surfaces of the package with borax; forging or multiple hot pressing until the strips are solidified;

g) polishing and grinding of the workpiece surfaces;

h) passivation of the surfaces of the workpiece using an acid solution to highlight the characteristic pattern of Damascus steel [1, 12].

The method of manufacturing parts from Damascus steels by forging the package from strips provides the following *advantages*:

- obtaining layered materials with special mechanical properties (high hardness, better tenacity, wear resistance, elasticity);
- the possibility of determining the steel components according to the mechanical properties of each steel category;
- reuse of materials with higher economic value;
- obtaining composite materials that give a special appearance to the part surface as a result of the application of multiple forgings and twists.

Some of *the disadvantages* of making Damascus steels by forging are as follows:

- the technological manufacturing process of relatively long duration, which can lead to a high manufacturing cost;
- the possibility of oxidation at high temperatures of the contact surfaces, which can lead to the appearance of hot welding defects of the component strips;
- the need to comply with specific requirements for hot forging welding methods of highly alloyed steels;
- the need to have tools and equipment for hot forging and to carry out appropriate heat treatments.

The manufacture of Damascus steel workpieces by *the particle agglomeration method* [3] involves the following technological operations:

a) making a prismatic sheet metal box without a cover, using an electric arc welding assembly along all the edges of the box;

b) to avoid welding the composite material with the box walls, paint the interior walls with a cellulose-based solution;

c) placing the component materials in successive layers inside the box. In this way, the larger granules will be placed first and then the metal powder, with intermediate pressings until a maximum filling;

d) electric arc welding of the closing cover of the box along all the edges;

e) attaching by welding a steel bar to one of the ends of the box for subsequent handling of the box during forging;

f) pressing and forging the box in several cycles until it is considered that a proper joining of the granular components has taken place;

g) removal of all the walls of the box; forging the workpiece obtained in several cycles until the desired shape of the workpiece is obtained;

h) polishing and grinding of the surfaces of the workpiece;

i) passivation in acid solution to highlight the characteristic pattern of Damascus steel.

Using forging the package from strips, the manufacture of Damascus steels by the particle agglomeration method presents some advantages.

Such *advantages* are the following:

- the possibility of obtaining composite materials with a finer structure, determined by the components in powder form;
- the possibility of reusing some metal powders, some small parts, and some technological scraps resulting from the use of other technological processing procedures;
- high hardness due to the use of a pressing process, which is also used in the case of the technology of sintering parts from metal powders at high temperatures;
- reducing the risk of oxidation of the component materials due to their compaction in the protective metal box.

For the justifiable selection of a technology that can be applied in manufacturing Damascus steel workpieces, the imposed decision technique will be used, as described in the specialized literature [13, 14].

3. WEIGHTING OF THE EVALUATION CRITERIA OF SOME TECHNOLOGIES FOR THE MANUFACTURE OF DAMASCUS STEEL WORKPIECES

Since it is necessary to weigh the evaluation criteria of some technologies for manufacturing Damascus steel workpieces, some of the stages specific to the imposed decision technique [13, 14] will be used.

In principle, this technique uses some coefficients of importance determined by comparing two-by-two alternatives to solve the problem using previously weighted selection criteria.

As criteria for evaluating the technologies that can be used for the manufacture of Damascus steel workpieces [1-12], the following could be taken into account:

- manufacturing costs (criterion *A*);
- the probability of obtaining the desired hardness for the hard component of the steel (criterion *B*);
- the probability of obtaining the desired toughness for the tough component of the steel (criterion *C*);
- available or accessible equipment for the manufacture of Damascus steel workpieces (criterion *D*);
- available or accessible equipment for checking some properties of Damascus steels (criterion *E*);
- the possibilities of changing the values of some input factors in the manufacturing process of Damascus steel workpieces to develop some experimental research regarding the weights of the influences of these input factors on specific properties of Damascus steel (criterion *F*).

The weighting of the evaluation criteria of some technologies for the manufacture of Damascus steel workpieces will be carried out by comparing the identified criteria two by two and giving grades of the type 1 - 0, when the first criterion is valued as more important, 0 - 1, when the second criterion is considered more important, 0.5 - 0.5 when the two compared criteria are judged to be of equal importance.

The number N_c of comparisons can be determined using a relation of the form:

$$N_c = \frac{n(n-1)}{2}, \qquad (1)$$

where n is the number of evaluation criteria considered, in the case under the present analysis, which involves the use of six comparison criteria (n=6 criteria).

In the situation under consideration, the number of comparisons will be:

$$N_c = \frac{6 \cdot (6-1)}{2} = 15. \qquad (2)$$

Table 1. The weighting of the evaluation criteria of some manufacturing technologies of Damascus steel workpieces.

Criterion *j*	**Number of the comparisons**															**Sum N_{dj}**	**Coefficient of importance K_j**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**		
A	0	0	0.5	0.5	0											1	0.066
B	1					0.5	0	0.5	0							2	0.133
C		1				0.5				0	0.5	0				2	0.133
D			0.5				1			1			1	0		3.5	0.233
E				0.5				0.5			0.5		0		0	1,5	0.1
F					1				1			1		1	1	5	0.333

The results of the comparisons are mentioned in Table 1.

In the penultimate column of Table 1, the N_{di} sums of the marks obtained by each of the six criteria considered (*A*, *B*, *C*, *D*, *E,* and *F*) were entered.

The last column in table 1 was intended to include the value of a so-called coefficient of importance K_i, determined as a ratio between the sum N_{di} of the marks given to each criterion and the total number of comparisons.

4. THE SELECTION OF A TECHNOLOGY FOR THE MANUFACTURE OF DAMASCUS STEEL WORKPIECES

Starting from the evaluation criteria proposed for selecting a technology for manufacturing Damascus steel workpieces, the comparison of the two technologies identified (*a* – the technology of forging a package of steel sheet strips with distinct carbon contents and *b* – the particle agglomeration method) using each evaluation criterion was conducted. The results of these comparisons are included in Table 2.

In order to select one of the two technologies *a* and *b* by using all six technology evaluation criteria, we will use the determination of coefficients of importance corresponding to the two technologies *a* and *b*:

$$N_{vi} = \sum_{j=1}^{N} K_{ij} K_j \ , \quad (3)$$

where N_{vi} is the coefficient of importance for variant *i*, K_{ij} are the coefficients of importance corresponding to each of the two variants *a* and *b* when using each of the six evaluation criteria (*A*, *B*, *C*, *D*, *E,* and *F*), and K_j are the values of the coefficients of the importance of criteria *j*.

Using the relation (3) leads to the following:

$$N_{va}=0.5 \cdot 0.066+0.5 \cdot 0.133+0.5 \cdot 0.133+1 \cdot 0.233+0.5 \cdot 0.1+1 \cdot 0.333 = 0.781, \quad (4)$$

$$N_{vb}=0.5 \cdot 0.066+0.5 \cdot 0.133+0.5 \cdot 0.133+0 \cdot 0.233+0.5 \cdot 0.1+0 \cdot 0.333 =0.215. \quad (5)$$

Table 2. Determining the values of the coefficients of importance K_{ij} for each variant *i*, by considering each of the criteria *j*, in the case of the two technologies for making some Damascus steel workpiece.

Version of technology	Criterion A			Criterion B		
	Comparison	Sum N_{di}	Coefficient of importance, K_{ij}	Comparison	Sum N_{di}	Coefficient of importance, K_{ij}
a	0.5	0.5	0.5	0.5	0.5	0.5
b	0.5	0.5	0.5	0.5	0.5	0.5
Version of technology	Criterion C			Criterion D		
	Comparison	Sum N_{di}	Coefficient of importance, K_{ij}	Comparison	Sum N_{di}	Coefficient of importance, K_{ij}
a	0.5	0.5	0.5	1	1	1
b	0.5	0.5	0.5	0	0	0
	Criterion E			Criterion F		
Version of technology	Comparison	Sum N_{di}	Coefficient of importance, K_{ij}	Comparison	Sum N_{di}	Coefficient of importance, K_{ij}
a	0.5	0.5	0.5	1	1	1
b	0.5	0.5	0.5	0	0	0

According to the aforementioned calculations, due to a higher value of the coefficient of importance in the case of variant *a*, the development of a technology for manufacturing Damascus steels according to this variant will be preferred.

Fig. 1. Bundle of sheet metal strips of different steels assembled by welding (bundle dimensions: 150x20x30 mm^3).

To date, attempts have been made to manufacture Damascus steel workpieces, and some of the results obtained will be briefly described below.

Thus, it resorted to using sheet metal strips of steels that have distinct chemical compositions.

Figure 1 shows the package made of sheet metal strips of different steels.

To ensure a certain tenacity of the material of the workpiece, unalloyed carbon steel strips with a breaking strength of 50 daN/mm^2 were used.

The chemical composition of unalloyed carbon steel contains 0.4% carbon, 0.6% manganese, 0.055% potassium, 0.055% sulfur. Higher hardness of some areas of the workpiece was achievable by using tool steel strips (1.04% carbon, 0.3% manganese, 0.25% silicon, 0.2%

Fig. 2. Bundle of sheet metal strips of different steels during forging.

Fig. 3. The bundle of sheet metal strips of different steels before applying the twisting operation (bundle dimensions: 200x22x18.5 mm^3).

chromium, 0.25% nickel, 0.02% potassium, 0.025% sulfur) and spring steel (0.50% carbon, 0.8% manganese, 1.5% silicon, 0.10% vanadium).

For the material of the workpiece to have higher wear resistance, manganese steel strips were included in the package.

Sheet metal strips of different steels were assembled by applying thin weld beads in directions perpendicular to the plane of the strips.

The image in figure 2 highlights how the forging of the strip pack was carried out on a

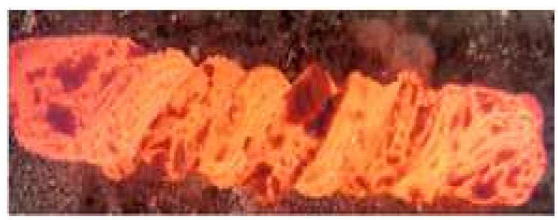

Fig. 4. Image of the strip pack after applying a first twist operation.

pressing equipment. The result of preparing a surface of the forged package to highlight the new positions of the sheet metal strips can be seen in figure 3.

The application of a twisting operation of the package led to its aspect highlighted in figure 4.

The difficulties of performing the twisting, generated by the relatively large torsion moments required, revealed the need to design and develop a device to facilitate the performance of the twisting operation, and this aspect will be approached in the next period.

5. CONCLUSIONS

The consultation of the specialized literature led to the conclusion that the problem of manufacturing workpieces from Damascus steel continues to be of interest. It was found that there are two principal technologies for manufacturing Damascus steel workpieces, namely the one that takes into account the use of sheet metal strips of different steels and, respectively, a technology that involves the use of granules of different steels.

Evaluation criteria of the two principal technologies for manufacturing Damascus steel workpieces have been established.

Using principles specific to the imposed decision technique, the values of some coefficients of importance were determined.

The values of the coefficients of importance highlighted the possibilities of using the technology based on sheet metal strips.

Some attempts to use this technology were developed, some results of the application of that technology being illustrated in the paper. In the next period, it is planned to design and make a device for twisting the package of sheet metal strips and also to make some samples that will be used in tests to evaluate the material's mechanical properties of the previously prepared workpiece.

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IDENTIFICAREA UNEI TEHNOLOGII PENTRU OBȚINEREA DE SEMIFABRICATE DIN OȚEL DE DAMASC

Abstract. Oțelul de Damasc este un material metalic compozit, realizat prin utilizarea unor procedee diferite de sudare prin forjarea la temperaturi înalte a unor componente din oțeluri cu compoziții chimice diferite. Aceste oțeluri pot avea durități mari, asigurând o bună comportare la solicitări de uzare, dar și o tenacitate bună, ceea ce contribuie la o diminuare a fragilității specifice oțelurilor dure obișnuite. A fost utilizată tehnica deciziei impuse pentru a selecta o tehnologie de fabricare a unor semifabricate din oțel de Damasc. Pentru condițiile luate în considerare, s-a constatat că este mai convenabilă fabricarea semifabricatelor din oțel de Damasc plecând de la fâșii din oțeluri cu conținuturi diferite de carbon. Aplicarea acestei tehnologii a permis fabricarea unor semifabricate din oțel de Damasc.

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