

This invention relates to a process for direct shaping and optimisation of the mechanical characteristics of penetrating projectiles of high-density tungsten alloy, in particular for military ammunition.

5 Penetrating projectiles which are used in military weapons have undergone considerable development in recent years. The use of alloys of increasing density, in respect of which efforts have been directed at optimising the mechanical characteristics thereof, in combination with an increase in the rate of fire, has made it possible to produce
10 increasingly effective projectiles.

Among the alloys used, mention may be made of the following:

- alloys based on depleted uranium, with which it is possible to achieve a density of close to $19,000 \text{ kg/m}^2$ and good ductility and the use of which is rendered attractive by the need to find outlets for
15 the stocks of depleted uranium which are generated by the nuclear industry;

- tungsten carbide with an addition of about 13% to 15% of cobalt which however suffers from the disadvantage of being of a density of $14,000 \text{ kg/cm}^3$, which is insufficient for certain uses. Moreover its
20 low level of ductility can represent a handicap in regard to piercing multiple targets;

- tungsten-base alloys which are produced by powder metallurgy, that is to say tungsten with its usual impurities, the low ductility of which and the machining of which, always being a high delicate
25 operation, constitute a handicap in regard to using it, but also tungsten with voluntary additions, for example of nickel, copper and iron, resulting in alloys of W-Ni-Cu and W-Ni-Fe type, the properties of which can be relatively well controlled in dependence on the use

thereof. That is the case in regard to W-Ni-Cu alloys of a density of between approximately 17,500 and 18,500 kg/m³, which are of a mean ductility that is an attractive aspect when fragmentation of the projectile is desired, but also and in particular in relation to W-Ni-
5 Fe alloys whose density can also be adjusted to between 17,500 and 18,500 kg/m³ by varying the tungsten content (93% to 97% by weight) while its ductility can be modified in dependence on the Fe/Ni ratio.

The production of W-Ni-Cu and W-Ni-Fe alloys which are also referred to as 'heavy metals' involves using powder metallurgy. The
10 raw materials used are formed by powders of each of the metals of a granulometry of between about 2 and 10 μ m. They are mixed in rotary apparatuses, in particular, so as to produce a homogeneous product, the analysis of which corresponds to the desired composition.

That mixture is then put into the form of blanks of a profile
15 which is suitable for the required use, either by a compression operation in a steel shaping die or by isostatic compression, in the course of which the powder which is placed in a rubber mould is subjected to the action of a compression fluid in an enclosure at high pressure.

Those blanks are porous, of low density and fragile and they have
20 to be subjected to a densification operation which is effected by sintering at between 1400 and 1600°C approximately in furnaces in a hydrogen atmosphere. In the course of that operation a ternary phase formed by the three metals involved is formed by diffusion and becomes
25 liquid. That liquid encases the grains of tungsten and permits complete densification of the alloy by a substantial dimensional contraction of the blank.

The alloys based on tungsten metal, the process for the production of which has just been described above, may exhibit good
30 ductility: by virtue of that property, it is possible to improve their elastic limit and their breaking stress, by a working operation.

Thus for example a blank made from an alloy containing by weight 93% W, 4.5% Ni and 2.5% Fe, which after sintering at 1450°C has the following characteristics:

- density: 17,500 kg/m³
- 5 - resistance to 0.2% elongation Rp 0.2: 750 MPa
- breaking strength Rm: 950 MPa
- elongation in percent: 25

after homogeneous working with a rate of reduction in section of about 18%, has the following strength values:

- 10 Rp 0.2: 1100 MPa
- Rm : 1250 MPa

A work-hardened material of that kind is used to produce subcalibre projectiles intended for piercing armour plating, as it has a high elastic limit capable of withstanding the stresses due to
15 acceleration in the gun in which the muzzle velocities can attain 1400 to 1600 m/sec.

In that type of use the blank is generally of a cylindrical shape and the working operation is produced by hammering in a moving mode. In order to impart the definitive profile of the projectile to the
20 blank, it is then subjected to a suitable machining operation.

A process of that kind was described in US No 3 979 234. It is stated therein that projectiles of W-Ni-Fe of the composition by weight: 85-90% W and such that Ni/Fe is between 5.5 and 8.2, are produced by powder compression, sintering, working with a rate of
25 reduction of 20% and then final machining of the worked blank. The invention indicates that it is thus possible to achieve a Rockwell C hardness of 42, which is uniform to within plus or minus one unit.

It should be noted however that such a process suffers from two major disadvantages:

- 30 - on the one hand the operations of machining the blank after sintering and after working result in a relatively substantial loss of

expensive material, which has a serious adverse effect on the cost price of the projectiles, not to mention the labour costs that it involves;

- on the other hand, homogeneity of the properties of the projectiles is not always desirable. In fact, projectiles are subjected
5 to different forces acting thereon, in the course of use thereof, as follows:

- . mechanical shock stresses when the projectiles are loaded at a high rate into the barrel of the gun;

- . very high elastic stresses during the phase of acceleration in
10 the gun; and

- . various stresses upon impact against the target which may be composed of layers of different materials, causing phenomena of compression, working and increase in temperatures.

Moreover it is desirable that, in the final phase of penetration,
15 the projectiles can fragment in order to increase their destructive capacity.

For all those reasons, it is an attractive proposition to provide projectiles which have zones with different metallurgical characteristics which are optimised in such a way as best to comply with the specific
20 forces to which they will be locally subjected.

EP-A-143 775 provides a satisfactory solution to the latter problem by the production by cold forging of a blank of tungsten alloy in appropriate form of a projectile whose mechanical characteristics vary locally according to the degree of reduction in section which can vary
25 between 0 and 30% in a direction which is parallel to the axis of the blank. However that document does not provide a solution to the problem of direct shaping of the projectile in its definitive shape in the forging operation in order to avoid the need for any subsequent machining operation and indeed even any machining of the shaping blank prior to
30 forging.

It is for that reason that the applicants sought and developed a process which makes it possible to solve the two problems referred to above at the same time.

The aim of the process is therefore to shape penetrating
5 projectiles, in particular for military ammunition, by work-hardening at a temperature between ambient temperature and 500°C of a compressed and sintered blank of an alloy of tungsten comprising additions of metallic elements such as Fe, Ni and Cu, having an axis of revolution, of a density of at least 17,000 kg/m³, the work-hardening operation being
10 effected in accordance with a variable degree of reduction in section in a direction parallel to the axis of the blank of suitable shape, characterised in that in order simultaneously to produce the projectile in its definitive shape and characteristics which are variable and adapted locally to the stresses involved in use, said blank of suitable
15 shape is subjected to a work-hardening treatment with a degree of reduction in section which can vary from 5% to 60%, by a shaping tool means comprising hammers whose profile is determined by the shape of the finished projectile.

For that purpose the travel of the hammers can be regulated with a
20 tolerance of ± 0.05 mm with respect to the diameter of the projectile.

Thus the invention provides for using a tungsten alloy preferably selected from alloys such as W-Ni-Cu and W-Ni-Fe.

Those metals are put into the form of blanks having an axis of revolution, that is to say in most cases they are cylindrical or
25 cylindrical-conical.

The blanks are of a density which is at least 17,000 kg/m³ and are produced by powder metallurgy from powders of tungsten, nickel, iron and copper which have been mixed, compacted in the form of blanks and sintered in a hydrogen atmosphere at between 1400 and 1600°C, that is to
30 say under conditions which, combined with the nature of the alloy, make

it possible to provide ductile products which do not run the risk of being degraded in the work-hardening operation.

Another object of the invention is that the rough-produced blanks of suitable shape, which are produced after sintering without any preliminary machining operation intended for imparting thereto the definitive profile of the projectile, are subjected to work-hardening treatment.

That treatment is carried out on blanks either in the cold condition or after preliminary moderate heating which does not exceed 500°C. The heating operation depends on the nature of the alloy and makes it possible, in regard to some thereof, to reduce the force to be applied to achieve the desired degree of work-hardening.

Under those conditions the material which constitutes them being relatively ductile, it lends itself well to deformation and the definitive profile can thus be imparted to the projectile without having recourse initially to a machining operation while at the same time imparting thereto a much higher level of mechanical strength.

However unlike the prior art, in the different sections of the blank which are perpendicular to its axis of revolution, the work-hardening operation is controlled to provide a particular level thereof dependent on the shape of the blank so as to produce, throughout the length of the projectile, mechanical characteristics which are adapted, that is to say optimised, to the heterogeneous stresses to which the projectile is subjected in the course of its active phases. Thus, the degree of reduction from the initial section S to the final section s of the blank as defined by the ratio $(S-s)/S \times 100$ may vary from 5% to 60%.

If an object of the invention is for the rough-produced blank of suitable shape to be directly subjected to a work-hardening treatment in order to produce the definitive profile of the projectile, the process according to the invention is applied in the same way to a blank of

suitable shape which is produced by machining a rough-produced blank, generally of simple geometrical shape, cylindrical, parallelepipedic, etc, in accordance with the prior art. In that case a part of the economic attraction of the process which involves eliminating the operation of machining the sintered blank before working same is lost but without thereby calling into question again the essential object of the process and the advantages, in particular technological advantages, which derive therefrom.

As regards not machining after work-hardening, besides the attraction that that involves in regard to avoiding labour and equipment maintenance costs and wastage of relatively expensive material, it makes it possible to keep surface layers in a compression state at the surface of the projectile, which greatly enhances its resistance to the different elastic forces to which it is subjected.

The work-hardening operation is performed by means of any suitable process, preferably with rotary hammering of the blank so as to develop mechanical characteristics of an axially symmetrical nature. The hammering operation can be carried out by means of different apparatuses such as for example a rotary or alternating hammering machine provided with a shaping tool arrangement comprising at least two hammers.

Thus it is possible for example to use a tool arrangement having four hammers, the profile of which is defined by the shape of the desired projectile. The striking rate of the hammers is about 2000 to 2500 blows per minute.

The hammers are made of high-speed steel but for substantial production series, it is found to be more appropriate for them to be made of tungsten carbide in order to deal with the problems of wear and the dimensional tolerances to be achieved on the projectile. In order to limit the force to be exerted by the machine, the blanks are preheated before hammering to a temperature of between 250°C and 500°C depending on the materials involved and the degrees of work-hardening employed. The

blank is introduced into the tool arrangement by a push mechanism which permits it to be held between centres and which, by means of a jack, provides for translatory movement of the projectile along the axis of the tool arrangement at a variable speed compatible with the hammering stresses involved.

The travel of the hammers may be precisely controlled in order to provide for the desired degrees of work-hardening and the dimensional tolerances required on the different parts of the projectile. The dimensions in regard to diameter can be easily controlled to give a tolerance of ± 0.05 mm.

In order to appreciate the variations attained in the mechanical characteristics in dependence on the degree of work-hardening, set out below in Table I are the results which were obtained on testpieces measuring 15 mm in diameter, corresponding to three types of tungsten alloys, in respect of measurements of Vickers hardness HV30 in dependence on the measurement points with respect to the axis of the bar.

TABLE I

	Alloy W-Ni-Fe(93% W)			Alloy W-Ni-Fe (95% W)			Alloy W-Ni-Fe(97% W)		
	Degree of working 6% 10% 15%			Degree of working 6% 10% 15%			Degree of working 6% 10% 15%		
Distance from the axis in mm	HV30	HV30	HV30	HV30	HV30	HV30	HV30	HV30	HV30
0	400	435	476	422	457	487	436	476	527
2	412	442	481	429	464	492	441	482	532
5	422	454	486	438	471	498	467	494	538
7	438	476	499	459	484	519	489	508	550

It is noted that:

- the variation in hardness is a direct function of the concentration of tungsten in the alloy on the one hand and the degree of work-hardening produced, on the other hand;

- within the material, the hardness follows a rising function going from the centre of the testpiece to the outside surface layers;

- that variation from the centre towards the edge is not linear but becomes faster at the periphery, the rate of increase increasing in proportion to an increasing level of working. For the three types of alloys in question, it is noted that:

. for a degree of working of 6%, the mean difference in HV30 from 0 to 5 mm is greater than that from 5 to 7 mm,

. whereas it is equivalent thereto for a degree of working of 10%, and

. it is lower than same for a degree of working of 15%,

which confirms the attraction of not removing or damaging by machining the surface layers of the material which are produced after work-hardening.

The invention can be illustrated by means of the following three embodiments which will be better understood by referring to the nine Figures of accompanying drawings.

The Figures of the accompanying drawings show views in axial section of the blanks before and after hammering, on which are indicated the hardness values as measured at different points as well as the profile of the tooling arrangement used for the hammering operation.

Figures 1 to 3 correspond to Example 1, Figures 4 to 6 correspond to Example 2 and Figures 7 to 9 correspond to Example 3.

EXAMPLE 1: Alloy of tungsten-nickel-iron with 93% tungsten

A mixture of powders with the following contents by weight is produced:

- 93% of pure tungsten
- 4.5% of pure nickel
- 2.5% of pure iron.

The blanks are produced by isostatic compression at 2000 bars of the mixture of powder in moulds of a shape which is homothetic with that shown in Figure 2. They are then placed on plates of alumina and sintered in a tunnel furnace in a hydrogen atmosphere at 1460°C.

After treatment of the blanks under vacuum at 1100°C, the following characteristics are found on testpieces:

- $R_p 0.2 = 750 \text{ MPa}$ approximately
- $R_m = 950 \text{ MPa}$ approximately
- $E\% = 25$ approximately
- density = 17600 kg/m^3 approximately.

The shaping operation is then carried out in a hammering machine having four hammers, the profile of which is shown in Figure 1.

In this Example, the aim is to achieve a high level of hardness at the front of the projectile (tip), good ductility in the central part of the projectile and a capacity for fragmentation in the rear part of the projectile.

The striking hammers were made of high-speed steel. The blanks were preheated to about 350°C prior to hammering. To limit the work-hardening stresses, the operation was carried out in two successive passes between the hammers. The tool arrangements were set in the first pass to a degree of reduction of approximately 25% at the sections which were most highly work-hardened. After the second pass, a heat treatment was effected in argon at about 550°C.

The variation in the shapes of the projectile and hardness HV30 before and after hammering is shown in Figures 2 and 3.

10 EXAMPLE 2: Alloy of tungsten-nickel-iron with 95% of W

A mixture of powders containing the following components by weight is produced:

- 95% of pure tungsten
- 3.2% of pure nickel
- 15 - 1.8% of pure iron.

The blanks are compressed in an isostatic chamber at 2000 bars in rubber moulds of a form which is homothetic with the shape of the blank shown in Figure 4. They are then sintered in a tunnel furnace in hydrogen at 1510°C. After treatment of the blanks under vacuum at 20 1100°C, the following characteristics are obtained on testpieces:

- $R_p 0.2 = 720 \text{ MPa}$ approximately
- $R_m = 940 \text{ MPa}$ approximately
- $E \% = 25\%$ approximately
- density = 18000 kg/m^3 approximately.

25 The hammering operation is then effected, using the machine referred to in Example 1. The profile of the hammers, which is adapted to this type of projectile, is shown in Figure 4.

In this Example, the aim was to achieve a high level of hardness in the tip of the projectile, a high level of elasticity in its central part and a high level of ductility at the rear. The striking 30 hammers were made of high-speed steel and the blanks were preheated to about 400°C before hammering. The hammering operation was carried out

in a single pass.

A heat treatment was then effected, in argon, at about 860°C.

The variation in the shapes of the profile and the hardness HV30, before and after hammering, is shown in Figures 5 and 6.

5 EXAMPLE 3: Alloy of tungsten-nickel-iron with 98% of W

A mixture of powders with the following contents by weight is produced:

- 96.85% of pure tungsten
- 2.15% of pure nickel
- 10 - 1.00% of pure iron

The blanks are compressed in an isostatic chamber at 2000 bars in rubber moulds, the shape of which is homothetic with that of the blank shown in Figure 7. They are sintered in a tunnel furnace in hydrogen at 1600°C. After a treatment under vacuum at 1100°C, the following

15 characteristics are obtained on testpieces:

- $R_p 0.2 = 740$ MPa approximately
- $R_m = 960$ MPa approximately
- $E \% = 17$ approximately
- density = 18500 kg/m^3 approximately.

20 The hammering operation is then effected, using the machine referred to in Example 1. The profile of the hammers, which is adapted to that type of core, is defined in Figure 7.

In this Example, the attempt was to achieve maximum hardness in the tip of the projectile, a high level of hardness combined with

25 substantial ductility in its central part and maximum ductility at the rear. The striking hammers were made of tungsten carbide and the blanks were preheated to about 450°C. The hammering operation was performed in two successive passes.

A heat treatment was then effected, in argon, at about 450°C.

30 The variation in the shapes of the projectile and hardness HV30, before and after hammering, is shown in Figures 8 and 9.

It can be seen that the hammering operation made it possible to increase the hardness values and to make them heterogeneous, in particular along the length of the projectile.

CLAIMS

1. A process for shaping penetrating projectiles, in particular for military ammunition, by work-hardening at a temperature between ambient temperature and 500°C of a compressed and sintered blank of an alloy of tungsten comprising additions of metallic elements such as Fe, Ni and Cu, having an axis of revolution, of a density which is at least equal to 17,000 kg/m³, the work-hardening operation being effected in accordance with a variable degree of reduction in section in a direction parallel to the axis of the blank of suitable shape, characterised in that in order simultaneously to produce the projectile in its definitive shape and characteristics which are variable and adapted locally to the stresses involved in use, said blank of suitable shape is subjected to a work-hardening treatment with a degree of reduction in section which can vary from 5% to 60%, with a shaping tool means comprising hammers whose profile is determined by the shape of the finished projectile.

2. A process according to claim 1 characterised in that the travel of the hammers whose profile is determined by the shape of the finished projectile can be regulated with a tolerance of ± 0.05 mm with respect to the diameter of said projectile.

3. A process according to claim 1 or claim 2 characterised in that the blank of suitable shape is a rough-produced blank obtained from a mixture of powders belonging to the group formed by powders of W-Ni-Fe and W-Ni-Cu, which was compressed in a shaping mould and then sintered in hydrogen at between 1400°C and 1600°C.

4. A process according to claim 1 or claim 2 characterised in that the blank of suitable shape is a blank which is obtained from a mixture of powders belonging to the group formed by powders of W-Ni-Fe and W-Ni-Cu which was compressed in a mould in accordance with a simple geometrical shape such as a cylindrical or parallelepipedic shape and then machined.



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