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PROCESS FOR HARDENING METALS USING EXPLOSIVE MEANS

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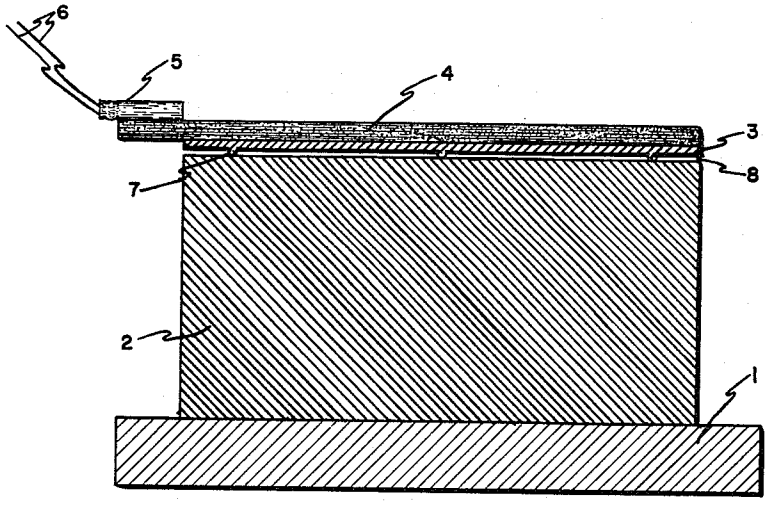

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PROCESS FOR HARDENING METALS USING EXPLOSIVE MEANS

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7 Claims. (Cl. 148—4)

This application is a continuation of our application Serial No. 87,053, filed February 2, 1961, now abandoned, which in turn, is a continuation of our application Serial No. 38,261 filed June 23, 1960, now abandoned.

The present invention relates to a process for hardening metal surfaces.

In U.S. Patent 2,703,297 to N. A. MacLeod a process is described for hardening the surface of manganese steel. This process comprises placing a layer of explosive material contiguous to the surface to be hardened and detonating the explosive. This process is capable of providing a hardness of about 400 on the Vickers scale on the surface of manganese steel, this hardness gradually decreasing to a value of 200 Vickers at a depth below the surface of one inch. This process is quite satisfactory for many applications. However in other instances a greater increase in hardness, both in magnitude and in depth, than can be attained by this process is desirable.

We have found that we are able to harden metallic surfaces to a substantially greater degree and depth than has been heretofore possible when we position a metal sheet parallel to the surface to be hardened and separated therefrom by an air space, place a layer of explosive on the outside surface of the said metal sheet, and initiate the explosive. Moreover, we have determined that through the use of the above-described process we are able to harden not only manganese steel, as described in the aforesaid MacLeod patent, but other steel alloys, such as stainless steel, vanadium steel and the like, and also non-ferrous metals and alloys thereof, such as nickel, niobium, cobalt, and their alloys.

A more completed understanding of the process of the present invention may be had by reference to the accompanying figure which is a schematic representation of an assembly for carrying out the hardening process. In the figure, **1** represents a supporting means of a shock-transmitting material, for example, alloy steel. The metallic specimen, the upper surface of which is to be hardened, is indicated by **2**. **3** is a flexible metal sheet, for example, a brass or steel shim, that is supported above the surface of specimen **2** at a uniform spacing therefrom by small projections **7** in the surface of the sheet. The air space separating sheet **3** from the surface of the specimen is indicated at **8**. **4** is a layer of explosive on the outer surface of sheet **3** and which preferably extends somewhat beyond the steel in at least one direction to provide a convenient portion for attachment of an electric initiator as at **5**. Energy is carried to initiator **5** by lead wires **6**.

The following examples further describe the process of our invention. They are illustrative only, however, and are not to be considered as limiting the invention in any manner. In all cases, unless otherwise specified, the explosive composition used was prepared by blending 85 parts of PETN, 7.5 parts of butyl rubber, and 7.5 parts of a thermoplastic terpene resin (mixture of polymers of β-pinene having the formula $(C_{10}H_{16})_n$, commercially available as "Piccolyte" S–10 manufactured by the Pennsylvania Industrial Corporation), and rolling the blend into sheet, the thickness of the sheet determining the weight per unit area. The composition has a velocity of detonation of about 7200 meters per second, and the sheets are strong, flexible, and nonresilient. Compositions of this type and their preparation are described in detail in U.S. Patent 2,999,743 which is incorporated herein by reference.

EXAMPLE 1

A rectangular block of Hadfield's manganese steel was placed on a supporting plate of stainless steel. A thin (0.002 in.) sheet of shim steel having dimension corresponding to those of the manganese steel block was cemented to a 0.165 inch-thick sheet of the above-described explosive having a weight per unit area of 4 grams per square inch. Convex protrusions of 0.01 inch were located in the surface of the shim steel as a convenient means of providing the required air space. This composite layer was placed, shim-side down, on the steel block, and an electric initiator was taped to the explosive layer, and subsequently actuated. Before detonation of the explosive, the manganese steel had a uniform hardness of 200 Vickers; after detonation of the explosive the hardness at 0.005 inch below the surface was 550 Vickers an increase of 350 in the hardness value. The hardened surface was smooth and free of contamination by the shim layer. The hardness at 0.025 inch below the surface was 430 and at 0.035 inch 375. After a second treatment, following the same steps, the hardness of the Hadfield's steel sample near the surface was not noticeably increased, the surface hardness obtained with the first shot being approximately the maximum hardness known for Hadfield's steel. However, at a depth of 0.25 inch below the surface the hardness had been increased from a value of 280, obtained by the initial treatment, to a value of 380.

EXAMPLE 2

In experiments done for comparative purposes, the conditions of Example 1 were reproduced, i.e., the explosive and manganese steel sample were identical, however no thin layer of steel was employed, the explosive being placed directly on the surface to be hardened, as described in the aforementioned U.S. Patent 2,703,297 to MacLeod. After detonation of the explosive, the steel at a depth of 0.005 inch had a hardness value of 370 Vickers. At a depth of 0.025 inch the hardness was 320 and at 0.035 inch 310. Similarly, in other experiments, the surface hardness of a nickel specimen was observed to be only 200 when the explosive was detonated directly on the surface, whereas a surface hardness value of 310 Vickers was obtained when the technique of Example 1 was applied to a second nickel specimen.

EXAMPLE 3

The procedure of Example 1 was repeated except that the air space between the surface to be hardened and the thin flexible steel sheet was increased from 0.010 inch to 0.040 inch. The hardening effect obtained was somewhat less than that obtained in Example 1. At a depth of 0.005 inch the hardness of the Hadfield's steel was 460, and at 0.025 inch 380. When a gap of 0.020 inch was employed, hardening results intermediate between those from the gaps of 0.010 inch and 0.040 inch were obtained.

EXAMPLE 4

Table I, which follows, shows the results obtained with a series of shots carried out on Hadfield's steel with various explosive loadings. The steel shim was 0.005 inch thick, and the air space was 0.020 inch.

Table I

	Vickers hardness of Hadfield's steel sample at depth of			
	in.	in.	in.	i.n
Explosive loading (g./sq. in.)	0.005	0.075	0.150	0.250
2	540	320	275	240
4	550	340	300	285
8	550	355	320	305

Thus it is apparent that, as the amount of explosive was increased, the degree of the hardening effect also increased.

EXAMPLE 5

Table II, which follows, shows the effect on the metal hardening of variations in thickness of the flexible steel shim. The explosive was that of Example 1, the metal sample was Hadfield's steel, and the air space provided was 0.020 inch.

Table II

Thickness of shim (in.)	Vickers hardness of Hadfield's steel at—	
	Surface	Depth of 0.100 in.
0.002	480	300
0.005	525	340
0.008	480	350
0.012	440	360
0.020	425	395
0.032	420	400

As indicated by the above example, the depth of the hardening effect is increased by an increase in the thickness of the flexible metal sheet. Consequently, by varying the thickness of this sheet and the mass of the explosive employed it is possible to exercise great control over the hardness profile of the metal or alloy.

As we have demonstrated in the foregoing examples, our process is applicable to both ferrous and non-ferrous metals and alloys, and the hardening effect which is achieved is surprisingly and materially increased over that which results when the evplosive is placed directly on the surface to be hardened according to prior known techniques. Moreover, we have shown that increasing hardening at a substantial depth below the surface of the metal is achieved by successive shots in accordance with the novel process.

Naturally, the physical conditions requisite for optimum results will depend somewhat on the nature of the metallic surface to be hardened. Generally speaking, the greatest increase in hardness for any metallic surface will result when the air space provided is between 0.010 and 0.025 inch. As an alternative to the exemplified projections in the metal sheet, the air space may be provided by small metallic particles or other supporting means. Such alternatives are within the purview of the invention.

It is preferably that the metal sheet be flexible for reasons of facile contouring to surfaces of irregular configuration. Hence, its thickness will preferably not exceed a value of a few mils. Sometimes it is beneficial to lubricate the surface to be hardened slightly, e.g., by applying a thin coating of petrolatum, to insure against adherence of the thin metal sheet, although this is not usually necessary.

The thickness of the explosive layer will, of course, depend upon the depth of the hardening effect that is desired to be attained. The only maximum parameter imposed on the amount of explosive used, is that it must not be so great as to cause disintegration of the thin metal sheet or extensive deformation or fracture of the specimen. Obviously, the explosive layer must be of at least sufficient thickness to propagate a detonation. Usually, explosive loadings of about from 1 to 10 grams per square

inch, corresponding to thicknesses of about from 40 to 420 mils, are employed.

We have determined that the detonation velocity of the explosive composition must exceed by at least 25% the sonic velocity of both the metal specimen to be hardened and the metal sheet adjacent the explosive for satisfactory hardening results, and this represents a critical feature of the invention. At lower detonation velocities, the hardening is substantially diminished, and the metal sheet invariably tends to adhere to the substrate despite efforts to discourage this, as for example, by the use of a lubricant described above. Those skilled in the art will recognize that the term "sonic velocity of the metal" referred to in this paragraph has somewhat different meanings in differing circumstances. For example, this term will have a different significance to the physicist when dealing with plastic shock wave phenomena in solids as contrasted with elastic shock wave phenomena. It is the former with which we are concerned for purposes of the present invention. The term "sonic velocity" as used throughout this application in connection with metals and metallic compositions refers to the velocity of the plastic shock wave which forms when a stress which is applied just exceeds the elastic limit for unidimensional compression of the particular metal or metallic system involved. The value of this sonic velocity may be obtained by means of the relation.

$$V=\sqrt{K/d}$$

where V is the sonic velocity in cm./sec.; K is the adiabatic bulk modulus in dynes/cm.^{2}; and d is the density in g./cm.^{3}. Values of K may be obtained from values of Young's modulus, E and Poisson's ratio, ν by means of the relation

$$K=E/(1-2\nu)$$

Values of d and K or E and ν are readily available in the literature (see for example American Institute of Physics Handbook, McGraw-Hill, New York, 1957).

Alternatively, the sonic velocity may be ascertained from published values of the velocity of the plastic shock wave as a function of the particle velocity imparted to the metal by the shock wave in the manner described by R. G. McQueen and S. P. Marsh, Journal of Applied Physics 31 (7), 1253 (1960).

In those cases where literature data are unavailable, values of V may be obtained by carrying out shock wave measurements as described by R. G. McQueen and S. P. Marsh (loc. cit.) in the references cited by them. Alternatively, V may be ascertained from the relation

$$V=\sqrt{C_L^2-(4/3)C_s^2}$$

where C_L is the velocity of elastic compressional waves and C_s is the velocity of elastic shear waves in the metal. The required velocities of the elastic waves may be measured by well-known methods. For illustration purposes, sonic velocity values as used herein for representative metals are set forth in the following table:

Metal:	Sonic velocity, m./sec.
Zinc	3000
Copper	4000
Magnesium	4500
Niobium	4500
Austenitic stainless steel	4500
Nickel	4700
Titanium	4800
Iron	4800
Molybdenum	5200
Aluminum	5500

The explosive layer may be initiated by any conventional means, and the positioning of the initiating means on the explosive layer is not critical. Thus, the layer of explosive may be initiated at a corner, in the center, or at any point along an edge. If desired, a line-wave initi-

ator may be used to initiate simultaneously an entire edge of the explosive layer. In the Examples the explosive used was in the form of a coherent, flexible, self-supporting sheet, and this represents a preferred form of explosive for purposes of the present invention inasmuch as uniformity of loading and ease of application are greatly facilitated therewith. However, if desired, the explosive could be applied in a paste or gelled form, or could be in a packaged form suitable for this particular use. The explosive layer may be bonded to the metal sheet prior to the positioning of the metal sheet over the surface to be hardened or simply may be rested on the metal sheet after the metal sheet has been positioned.

No limitations are imposed on the dimensions or nature of the metallic specimen that may be hardened by the described process. Those metals whose ductility is so slight that they fracture after only a 5% or less elongation in tension are, in general, so brittle that they do not lend themselves readily to hardening. Thus, it is with those metals which may be elongated in tension to an extent greater than 5% without fracture that this invention wil find its greatest utility.

Although we have illustrated the use of a steel block as a shock-transmitting support for the specimen, it is to be noted that such is not critical to the invention. Further, although we have exemplified, and for economic reasons generally prefer, steel as the material of the thin metal sheet, other materials, e.g., lead or brass, may be employed. The nature of the composition of the thin metal sheet is not critical; because it functions solely as an impact means its metallurgical properties are of little significance.

Having described our invention fully, we intend to be limited only by the following claims.

We claim:

1. A process for hardening metallic surfaces which comprises positioning a thin, flexible metal sheet parallel to the metal surface to be hardened and adjacent thereto but separated therefrom to provide an air space between said surface and said sheet, placing a layer of a detonating explosive on the exterior surface of said metal sheet, said layer of explosive having a velocity of detonation greater than about 125% of the sonic velocity of the said metals, and initiating said explosive layer, the amount of said explosive being sufficient to propagate a detonation but insufficient to disintegrate said metal sheet.

2. A process according to claim 1 wherein the said metallic surface is of a metal which can be elongated in tension to an extent greater than 5% without fracture.

3. A process according to claim 1 wherein the said metallic surface is austenitic manganese steel.

4. A process according to claim 3 wherein said metal sheet is a flexible sheet of steel.

5. The process of claim 1 wherein said air space is between about 0.010 and 0.025 inch in thickness.

6. The process of claim 1 wherein said air space is maintained prior to initiation of said explosive layer by scattering small metallic particles on said surface to be hardened prior to positioning said metal sheet and explosive layer thereover.

7. The process for hardening metallic surfaces which comprises applying a thin coating of petrolatum to the metal surface to be hardened, applying a plurality of small metal particles to said surface having said petrolatum coating, positioning a sheet of resilient metal parallel to said surface and spaced therefrom by said metallic particles a distance of about from 0.010 to 0.025 inch, placing a layer of detonating explosive on the exterior surface of said metal sheet, said layer of explosive having a velocity of detonation greater than about 125% of the sonic velocity of said metal sheet and said metal to be hardened, and initiating said explosive layer, the amount of said explosive being sufficient to propagate a detonation but insufficient to disintegrate said metal sheet.

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HYLAND BIZOT, *Primary Examiner.*