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STEEL ALLOY

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This invention relates to steel alloys which are particularly adapted for use in pieces of relatively large or heavy sections such as die blocks used for hot work forging processes, and other steel items requiring great hardness, durability and strength, and has for its principal objects to produce a steel alloy of the class described, combining with other characteristics necessary for such usage increased facility in manufacture whereby the tendency to develop internal thermal ruptures or cracks is practically eliminated, and the resulting piece is capable of being hardened to a substantially uniform hardness throughout its mass by proper heat treatment.

The present invention is an improvement over my prior United States Letters Patent No. 1,464,174 issued August 7, 1923, in which the principal alloying elements are chromium, nickel and molybdenum. Alloy steels made in accordance with this patent have demonstrated their superiority for hot work dies and similar forging work. At present, approximately ninety per cent of the dies used in the drop forging industry are made from chromium-nickel-molybdenum steel alloy in one or another of its various forms.

The present application is a continuation in part of my prior applications Serial No. 33,331 filed July 26, 1935, and Serial No. 35,104, filed August 7, 1935.

Among the many methods of mass production used in modern industry, there are none more important than that of drop forging and its near relation, upsetting. By these two processes, which may both be referred to generally by the term "drop forging", it is possible to duplicate accurately metal parts of surprisingly intricate design in large quantities with remarkable speed. The method in general consists of heating the metal (usually steel) to a plastic condition and forming it in dies which contain the desired shape in negative. The dies are operated by powerful hammers in the case of drop forging, and by forging machines in the case of upsetting.

In order that the drop forger may do his job well and profitably, his dies must produce thousands of duplicate parts without any great wear or deterioration. This calls for a die steel having great strength and durability since the dies are subjected to extremely heavy shocks and high temperatures. The dies are usually furnished to the drop forger in the form of blocks in either the annealed or tempered condition. If annealed, the dies must be hardened and tempered after being machined. If tempered, the dies are used in the hammer immediately after machining without further heat treatment.

Over 60% of the dies used in the industry today are thus tempered. The block is heat-treated in the rough condition by the die block manufacturer, then machined by the die maker, and then put to use by the forger without further heat-treatment. After the initial die impression is worn out from use, it is machined off the die block, and a new impression remachined in the fresh metal surface of the block, and the block is used again without further heat-treatment. This remachining operation may be repeated several times, often as many as seven times, until the block becomes too thin for economical use.

One of the principal difficulties encountered by the manufacturers of alloy steels of the nickel-chromium-molybdenum class is that of avoiding thermal ruptures when the alloy is first produced at the mill. Thermal rupture (also known as "flaking") should not be confused with "center porosity" which occurs in a wide variety of metals, in the form of small voids and segregations. Thermal rupture consists in the formation of minute cracks which develop on the interior of the heavy mass of metal, when it is cooled from its original solidification temperatures. As these cracks or flakes are entirely confined to the interior of the block, their presence is practically impossible of detection without cutting into the body of the block, and even then they sometimes cannot be visually detected unless the exposed surface is etched to show its grain. Hence such ruptures will not usually become apparent until after the block has been rough-machined, and perhaps given its final heat treatment, The defect may not even be discovered when the first impression or die is cut, but such defects soon show up when in the hammer, and the particular piece is rendered useless as a die-block. In instances where such alloys are used for heavy structural purposes, the defect usually does not become evident until an unexpected failure or breakage occurs.

The exact cause of thermal ruptures or flaking does not seem to have been definitely ascertained, and heretofore the only practical method of control has been through great care in the manufacture of alloy steels of this general character whereby cooling of the massive sections from their original rolling or forging temperatures is carefully retarded in cooling pits by various methods well known to those skilled in the art. But even such great care in cooling has proved in-

sufficient to eliminate frequent recurrence of thermal rupture or flaking when least expected.

In the broader aspect of my invention, with respect to the control of thermal ruptures in large sections, I find that the addition of copper to the melt in amounts ranging from .25 to 6.50% is effective generally in chromium-molybdenum alloys of the types heretofore used for die blocks and other relatively heavy sectioned masses. Such steels may have their principal alloying elements substantially within the following ranges:

	Per cent
Carbon	.25 to 1.10
Chromium	.25 to 1.50
Molybdenum	.05 to 2.00
Copper	.25 to 6.50

Such alloys may also have nickel in amounts up to 3.00%, manganese in amounts up to 1.00%, and silicon in amounts up to 1.00%. In alloy steels coming within the above ranges having copper added in the amounts indicated, the tendency to thermal ruptures or flaking can be effectively controlled so as to greatly reduce the care in handling these steels during their manufacture, and thereby insuring practical freedom from such internal defects.

Another desirable characteristic heretofore unattained in steel alloys of the types generally used for die blocks, is that of maintaining substantially the same hardness throughout the entire mass of a die block so as to permit several successive "sinkings" of dies therein, without requiring re-heat treatments, and without reducing the effectiveness of each such successive die sinking. In steel die blocks heretofore employed, there is usually a substantial reduction in hardness toward the center of the block, with a resulting loss in production from such softer die faces, and a greater tendency to cracking or breakage of the die due to the variation in hardness from the outside edge to the middle of such center sinkings.

I find that the addition of copper in certain proportions to alloy steels used in die blocks or similar heavy-sectioned masses gives a substantially uniform depth of hardnesses at die-working values, which uniformity of hardness has hitherto been considered unattainable. I find further that the addition of copper appreciably increases resistance to checking or surface cracking from heat, which are also common faults of alloy die steels used in hot work.

Summarizing the ideal requirements for a hot work die steel, it must have the following properties to a marked degree:

1. Resistance to internal thermal cracking during cooling from high temperatures.
2. Complete hardenability in large sections (the ability to harden with complete uniformity of hardness throughout the mass of the piece).
3. Resistance to heat cracking (surface cracking due to heat).
4. Resistance to washing (localized wear).
5. Ease and simplicity of manufacture in either the open hearth or electric furnace processes to produce sound ingots and billets with practically the total absence of segregation, center porosity, and "hot shortness".
6. Easy forgeability into the necessary size and shape.
7. Simple heat treatment to required hardness.
8. Great strength and density of fibre combined with high ductibility and high impact values.
9. Machinability at high (working) hardnesses.

The importance of properties Nos. 1 and 2 has already been set forth. Alloy steels heretofore employed in heavy sections for die block purposes are especially subject to internal rupture cracks or flaking. Property No. 2 is most important in a tempered die block, whereas successive recuts or "sinkings" are made, the center of the block is approached and used. In most die steels that have been hardened, the hardness drops off toward the center of the block.

As to properties Nos. 3 and 4, these are opposing characteristics. When the die is too soft it will wash, when too hard it may heat-check. A compromise hardness where these opposite faults are at a minimum is usually necessary. Obviously a steel that will resist heat-checking at any and all hardnesses is the ideal, since washing may be overcome by simply raising the hardness sufficiently.

Property No. 5.—In the large sizes in which the modern die block is made, it is important that the total alloy content be low, since the higher this content goes the more difficult it is to produce sound ingots in such large sizes.

Property No. 6.—It is obvious that to produce die blocks commercially, the steel must be readily forged. This is another reason for low alloy content. In general, the higher the alloy content, the greater are the difficulties in forging.

Property No. 7.—Heat treating processes are expensive in their simplest forms, and therefore complicated treatments are to be avoided.

Property No. 8.—Die blocks must undergo extreme conditions of shock, heat and abrasion, a combination of opposing conditions very difficult to meet.

Property No. 9.—In the tempered die block it is necessary to leave the steel at the relatively high hardness suitable for use as a die, yet it must be machinable at this high hardness.

The nickel-chromium-molybdenum die steels heretofore used possess the property numbered above 5 to 9, both inclusive, to a high degree. Other types of steels, of course, have been developed having one or more of these characteristics. I have demonstrated, however, that the alloy of my present invention combines all of the qualities to an unusual degree never found in any other steels. This is particularly so with the properties of resistance to internal thermal ruptures, and complete or uniform hardness at relatively high working hardnesses.

Referring now more specifically to the analysis of die block steels in which substantial uniformity of hardness at high working hardnesses is desired, together with the other desirable properties of such steels hereinbefore listed, I find that the ranges of the principal alloying elements should be restricted substantially as follows:

	Per cent
Carbon	.30 to 1.00
Chromium	.25 to 1.25
Molybdenum	.05 to 2.00
Nickel	.50 to 2.50
Copper	.25 to 4.00

Manganese in fractions to 1.00% and silicon in fractions to 1.00% may also be present, the remainder being substantially all iron.

I find that the addition of certain other ele-

ments commonly used in special alloys such as tungsten, cobalt, vanadium or titanium seem to have no appreciable effect in improving the alloy when used for a hot work die steel, and only add to the expense and difficulties of manufacture.

For best results consistent with economy in drop forging dies, the principal elements are preferably limited even further to the following ranges:

	Per cent
Carbon	.30 to .70
Nickel	.50 to 2.50
Chromium	.25 to 1.25
Molybdenum	.05 to 2.00
Copper	.50 to 3.50

The ranges above specified are critical to the economical production of a hot work die steel having the nine necessary characteristics mentioned above to an exceptional degree. Of particular importance is its remarkable resistance to thermal rupture, or flaking, its complete or uniform hardenability at working hardnesses, and its resistance to heat-checking.

I have yet to encounter thermal ruptures or flakes in the many melts of this improved alloy so far prepared, even though in some instances deliberate attempts have been made to produce them. This characteristic, therefore, permits less expensive methods of handling during fabrication from the ingot to the billet, and ultimately to the die block. It also shortens the time required for cooling the steel, and thus saves in the equipment space and labor in handling heretofore required for the slow cooling processes.

As an example of the remarkable uniformity and depth of hardness obtainable with my improved copper-bearing steel alloy, a hardened and tempered 11-inch cube block having the following analysis may be cited.

	Per cent
Carbon	.50
Manganese	.75
Chromium	.75
Copper	2.00
Nickel	1.00
Molybdenum	.25

The block was cut through the middle, and hardness readings taken on the cut surface at intervals from the center to all sides thereof. It was found that the hardness was uniform throughout the surface within a total range of .05 mm. Brinell ball diameter at 350 Brinell hardness number. This substantial uniformity is remarkable; greater uniformity than this could hardly be expected, even over the outside surface of the block.

The improved resistance to heat checking noted in the alloy makes it possible to employ a higher hardness than normal, thus improving resistance to washing. In those applications to dies in which this alloy has been used, heat checking has been practically unknown.

The presence of copper seems to be largely responsible for the important properties of resistance to thermal rupture and complete hardenability, as well as increasing the air hardening effect heretofore noted in nickel-chromium-molybdenum alloys and raising their tensile properties. Nickel of .50% or more is necessary to contribute the required toughness. Nickel also helps to overcome the tendency for copper-bearing steels to roughen at the surface or to become "hot short" during forging or rolling, but I find that the addition of molybdenum in small quantities seems to intensify this action of nickel to a marked degree, thereby reducing the amount of nickel necessary in alloys of this character, and also making it possible to use more copper with its attendant advantages. Over 2.50% nickel makes the steel difficult to fabricate and adds greatly to the expense of the alloy.

The air hardening qualities of my improved alloy appear to follow substantially the same laws disclosed in my prior Patent No. 1,464,174 in so far as variation in the principal alloying elements is concerned. That is to say, superior air hardening qualities may be maintained by varying the carbon content inversely with the chromium or molybdenum content, and the amount of chromium and molybdenum may also be varied inversely with each other within the ranges indicated. In the present improved alloy, however, copper can be used to produce a more economical product by partially replacing both the nickel and molybdenum, and with the new and added results of resistance to thermal rupture, and greatly increased uniformity of hardening.

My alloy can be annealed by heating to above the critical range and cooling slowly in the furnace. Hardening is accomplished by heating to above the critical range and cooling in still air, in an air blast, or by quenching in a liquid medium. The more rapid the cooling method, the harder will be the steel. The steel may be tempered to the desired point after hardening by reheating to the necessary temperature below the critical range. But within the normal working ranges, the hardness will be substantially uniform throughout the mass of the piece.

I claim as my invention:

1. A die block for hot forging characterized by its resistance to thermal rupture and substantial uniformity of hardness at working hardnesses, which comprises as its principal alloying elements carbon ranging from .30 to 1.00%, chromium from .25 to 1.25%, molybdenum from .05 to 2.00%, nickel from .50 to 2.50%, and copper from .25 to 4.00%, the remainder being substantially all iron.

2. A die block for hot forging characterized by its resistance to thermal rupture and heat checking, and its substantial uniformity of hardness at working hardnesses, which comprises as its principal alloying elements carbon ranging from .30 to .70%, nickel from .50 to 2.50%, chromium from .25 to 1.25%, molybdenum from .05 to 2.00%, and copper from .50 to 3.50%, and the balance substantially all iron.

3. A steel alloy characterized by its resistance to thermal rupture, and by substantial uniformity of depth hardening, and containing carbon ranging from .25 to 1.10%, nickel from .50 to 3.00%, chromium from .25 to 1.50%, molybdenum from .05 to 2.00%, copper from .25 to 6.50%, and the balance substantially all iron.

4. A steel alloy characterized by its resistance to thermal rupture, and by substantial uniformity of depth hardening, and containing carbon ranging from .30 to 1.00%, nickel from .50 to 2.50%, chromium from .25 to 1.25%, molybdenum from .05 to 2.00%, copper from .25 to 4.00%, and the balance substantially all iron.

5. A steel alloy characterized by its resistance to thermal rupture, and by substantial uniformity of depth hardening, and containing carbon from .30 to .70%, nickel from .50 to 2.50%, molybdenum from .05 to 2.00%, chromium from .25 to

1.25%, copper from .50 to 3.50%, and the balance substantially all iron.

6. A steel alloy characterized by its resistance to thermal rupture, and by substantial uniformity of depth hardening, and containing carbon approximately .50%, nickel approximately 1.25%, chromium approximately .75%, molybdenum approximately .25%, copper approximately 2.00%, and the balance substantially all iron.

7. A new article of manufacture, a die block for hot forging made of steel alloy characterized by substantial uniformity of depth hardening and its practical freedom from thermal rupture, said steel alloy containing carbon ranging from .25 to 1.10%, nickel ranging from .50 to 3.00%, chromium ranging from .25 to 1.50%, molybdenum ranging from .05 to 2.00%, copper ranging from .25 to 6.50%, and the balance substantially all iron.

8. A steel alloy characterized by its resistance to thermal rupture and by substantial uniformity of depth hardening, and containing carbon ranging from .30 to 1.00%, nickel from .50 to 2.50%, chromium from .25 to 1.25% molybdenum from .05 to 2.00%, copper from .25 to 4.00%, and the balance substantially all iron, the molybdenum content varying approximately in inverse proportions to the carbon content.

9. A steel alloy characterized by its resistance to thermal rupture and by substantial uniformity of depth hardening, and containing carbon ranging from .30 to .70%, nickel from .50 to 2.50%, chromium from .25 to 1.25%, molybdenum from .05 to 2.00%, copper from .50 to 3.50%, and the balance substantially all iron, the molybdenum content varying approximately in inverse proportions to the carbon content.

10. A steel alloy characterized by its resistance to thermal rupture and by substantial uniformity of depth hardening, and containing carbon ranging from .25 to 1.10%, nickel from .50 to 3.00%, chromium from .25 to 1.50%, molybdenum from .05 to 2.00%, copper from .25 to 6.00%, and the balance substantially all iron, the molybdenum and chromium contents, respectively, varying in approximately inverse proportions to the carbon content.

11. A steel alloy characterized by its resistance to thermal rupture and by substantial uniformity of depth hardening, and containing carbon ranging from .30 to .70%, nickel from .50 to 2.50%, chromium from .25 to 1.00%, molybdenum from .05 to 2.00%, copper from .50 to 3.50%, and the balance substantially all iron, the molybdenum and chromium contents, respectively, varying in approximately inverse proportions to the carbon content.

12. A new article of manufacture, a tempered die block for hot forging made of steel alloy containing carbon ranging from .25 to 1.10%, nickel from .50 to 2.50%, chromium from .25 to 1.50%, molybdenum from .05 to 2.00%, copper from .25 to 6.50%, and the balance substantially all iron.

13. A new article of manufacture, a tempered die block for hot forging made of steel alloy containing carbon ranging from .30 to .70%, nickel from .50 to 2.50%, chromium from .25 to 1.25%, molybdenum from .05 to 2.00%, and copper from .50 to 3.50%.

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