

Optimizing the Morphology of Primary Carbides and Mechanical Properties during Processing Of Cast-Steel (Din Gx210crv12 1) Press-Forming Dies

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Submitted: 07 Feb 2018; Accepted: 14 Feb 2018; Published: 19 Mar 2018

Abstract

Cold work tool steels are used for punching, cutting, forming, cold forging, cold extrusion, cold rolling...etc. Those steels have hard microstructure compared to most other steels, but the everlasting challenge is the enough strength to toughness relation, without immediate fracture. Carbides provide the wear resistance, acting as the hard phase of the material. Variation in size and fraction of the carbides, depending of manufacturing route, alloy content, hot working/forging and heat treatment, will give the tool steel the desired mechanical properties. However, conventional cast-tooling is the major production route used, which could be followed by a process called electro slag refining/re-melting (ESR) where the non-metallic inclusion content is lowered. Conventional casting has a lower production cost per unit than the conventional processing routes. The disadvantage though is a more heterogeneous material, due to segregation of primary or leduburitic carbide net cells.

In this investigation a trial was made to control the distribution and morphology of primary carbides in the matrices of marten site by spheroidizing them through molten metal treatment or heat treatment processes. Types and distributions of different carbides in the matrix was measured using X-ray diffraction and SEM/EDX units. Industrial performance has been recorded for the optimized pressing dies as compared with the same imported dies created through the conventional forged or rolled-machined ones. Hardness and fracture toughness were measured for both experimental specimens and the actual working die.

Introduction & Aim of Research

Cold work tool steels are essentially high carbon steels, which may contain additions of tungsten, manganese, chromium and molybdenum. These alloy additions increase harden ability, permitting oil quenching with less distortion than with the water quenched series. The oil quenched series consists of relatively inexpensive steels, and their high carbon content produces adequate wear resistance for short run applications. The whole group of cold work tool steels are summarized as in the following (Table 1) [1-2].

Table: 1 Classification of cold work tool steels, UNS, AISI, SAE [1]

Tool Steel Type	Prefix	Specific Types
Cold Work	W - Water Hardening	W1, W2, W5
	O - Oil Hardening	O1, O2, O6, O7
	A - Medium alloy Air Hardening	A2, AS, A6, A7, A7, A8, A9, A10, A11
	D - High Carbon High Chromium	D2, D3, D4, D5, D7

In this group of steels, many manufacturers market steels of composition adjusted to meet specific requirements. Undoubtedly, this group of steels can be classed among the largest tonnage used for tool manufacture, the reason being that it is the least expensive; affording a high degree of non-distortion in heat treatment and for short run application cannot really be rivaled. It is used for all types of blanking and forming dies, gauges, collets, etc. In the annealed condition, these steels consist of ferrite and carbide, essentially Fe₃C but with a portion of the carbide formers present. If we consider the D series as typical cold work tool steels, the presence of manganese, chromium, molybdenum and cobalt in solution in the matrix considerably increase the depth of hardening, enabling sections up to 200 mm diameter to harden throughout [2-4]. Today tools made of cold-work and high-speed steels need to fulfill ever-increasing requirements. On the one hand, this is a consequence of more modern production facilities and optimized manufacturing processes. On the other, these stem from constantly increasing demands made on the quality of the products to be manufactured. As a consequence, the use of the right steel with the best performance for the tool application is decisive and ensures a length of the tool's

service life and an economic production with reduced unit costs. However, the technological characteristics of these family are summarized as in (Table2) [1-3].

Table: 2 Characteristics of Cold-Work tool steel Family [1-3]

Water Hardening Tool Steels	Oil Hardening Tool Steels	Medium Alloy Air Hardening Steels	High Carbon High Chromium Steels
(W-Series)	(O-Series)	(A-Series)	(D-Series)
Essentially these are carbon steels with 0.60 to 1.10 % carbon	0.90 to 1.45 % Carbon with Mn, Si, W, Mo, Cr.	5 to 10 % alloying elements (Mn, Si, W, Mo, Cr, V, Ni) to improve the hardenability, wear resistance, toughness.	All D-series contain 12% Cr and over 1.5 % C.
Lowest cost tool steels.	They contain graphite in the hardened structure along with martensite. (Graphite acts as a lubricator and also makes machining easier		Air or oil quench
	Tungsten forms tungsten carbide which improves the abrasion resistance and edge retention in cutting devices.		Low distortion, high abrasion resistance.

Fortunately, cold-work tool steels include the high-carbon, high-chromium steels are designated as group D steels and consist of D2, D3, D4, D5, and D7 steels. These steels contain 1.5 to 2.35% of carbon and 12% of chromium. Except type D3 steel, all the other group D steels include 1% Mo and are air hardened. Type D3 steel is oil-quenched; though small sections can be gas quenched after austenitization using vacuum. As a result, tools made with type D3 steel tends to be brittle during hardening. However, type D2 steel is the most commonly used steel among the group D steels which contains carbon up to 2%, chromium up to 13%, molybdenum up to 1.5%, cobalt up to 1%, vanadium up to 1.2% and Mn+Si in the range. Those steels have hard microstructure compared to most other steels, but the everlasting challenge is the enough strength to toughness relation, without immediate fracture. Carbides provide the wear resistance, acting as the hard phase of the material. Variation in size and fraction of the carbides, depending of manufacturing route, alloy content, hot working/forging and heat treatment, will give the tool steel the desired mechanical properties [5-8]. However, conventional cast-tooling is the major production route used, which could be followed by a process called electro slag refining/re-melting (ESR) where the non-metallic inclusion content is lowered. Conventional casting has a lower production cost per unit than the conventional processing routes. The disadvantage though is a more heterogeneous material, due to segregation of primary or ledeburitic carbide net cells [9-12].

In this investigation a trial was made to control the distribution and morphology of primary carbides in the matrices of D-cold work tool steel by spheroidizing them through molten metal treatment process and heat treatment. Types and distributions of different carbides in the matrix were measured using X-ray diffraction and SEM/EDX units. Industrial performance has been recorded for the optimized pressing dies as compared with the same imported dies created through the conventional forged or rolled-machined ones. Hardness and fracture strength were measured for experimental specimens representing the actual working die.

Material Preparation

In this research standard strips 40x40x300mm of DinGX210Cr12 - CrMoVCo124 which equivalent nearly to AISI D3 to D7-cold

work tool steel were re-melted in coreless medium frequency, first-heat high alumina lined induction furnace. The furnace was covered with a lid during melting to minimize the oxidation process that can happen from the atmospheric air. After complete melting and final analysis control, (1)-the melt (1520°C) was tapped into intermediate preheated experimental ladle, skimmed and poured into the cast designed-moulds required, or (2)-the melt was poured upon 5%Mg+3%REM+ 35%Si (FeSiMgRem) granulates (1-3mm) in the bottom of the ladle using sandwich method as shown in the schematic representation of melting logs, (Figure1). The REM alloy melts and evaporates causing exothermic reaction which increases the melt temperature to about 1560°C, at which the ladle was left to calm and cool down to about 1520°C, skimmed and then poured into the casting cavities.

Some samples from the cast steels were cleaned with shot blast machine and then prepared for further microstructure and properties examinations, while other samples were subjected to spheroidize-annealing heat treatment and then prepared for further examinations.

After casting the experimental specimens were cleaned thoroughly using blast shooting, trimming all gating system and then prepared for heat treatment. The heat treatment comprises low temperature spheroid-annealing at 450°C (high temperature tempering) to help in more Spheroidize eutectic carbides which in turn increases ductility of high carbon steel, spheroid structure reduces energy needed for subsequent operations and machinability is increased [13].

Results & Discussion

Microstructure changes

The transformation happened during cooling cold work tool steels starts with formation of saturated-carbon primary austenite, which rejects some of its carbon as temperature decreases to form series of carbides such as (FeCr)₇C₃, (FeCr)₃C, (FeCr)₄C as shown in Fe-C phase diagram at 12%Cr, (Figure 2). The microstructure of slowly cooled sand-castings (40mm thick) is mainly composed of austenite + ferrite + eutectic carbides (Figure 3), however some martensite is found due to the depression in Ms and deviation of pearlite and bainite transformation start far to the right of the continuous cooling transformation diagram (about after 1,45h), (Figure 4) [14].

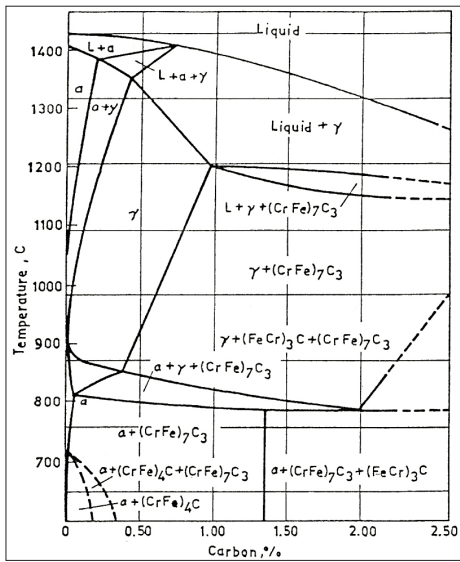


Figure 2: Equilibrium diagram of Iron-Carbon at 12%Chromium steel.

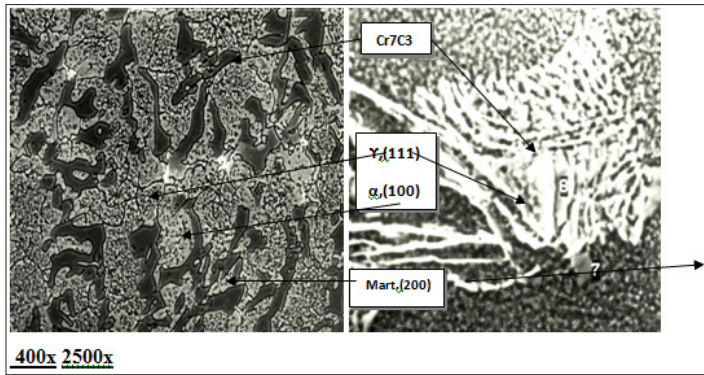


Figure 3: Microstructure of slowly sand-cooled cast D3 tool steel.

It is evident from Fig.(2) that the high C-Cr alloys solidify as primary austenite dendrites with a network of inter-dendrite eutectic carbides and during cooling some of the eutectic austenite around the eutectic carbides transforms to martensite.

In order to break down these eutectic, continuous and interacted carbide nets, an experimental idea to change the equilibrium conditions of the molten steel was applied. The molten steel was poured onto a sandwich bed of FeSiMgRe granulates which immediately melted and evaporate at pouring temperature creating exothermic reaction and a huge amount of gaseous pressure which alters the equilibrium conditions that creating another morphologies of carbides during cooling. These induced non-equilibrium conditions create new carbide morphologies as depicted in Fig. (5). The primary purpose is to harden the whole matrix without heat treatment by destabilizing the austenite *via* precipitation of Cr-rich secondary carbides generally at over 1100°C for time of 1-2 hours depending on the alloy content and then air quenching of the cast tool to room temperature. During forced air-quenching the austenite with less Cr and C content is forced to transform to martensite without any dimensional distortions as in case of conventional heat treatment.

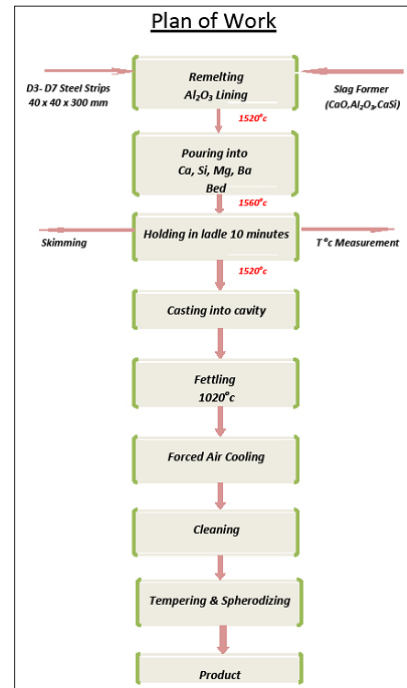


Figure 1: Flow diagram of melting and processing cast-D3&D7 cold work tool steel.

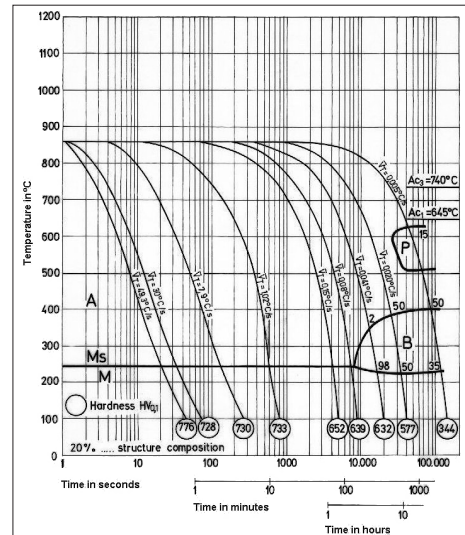


Figure 4: Continuous cooling transformation diagram of D3-D7 cold work tool steel

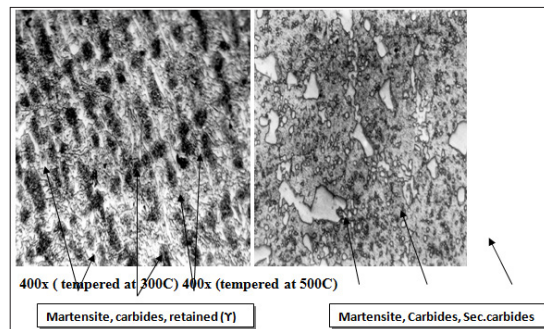


Figure 5: Distribution and morphology of carbides after treatment of molten D-cold work tool steel.

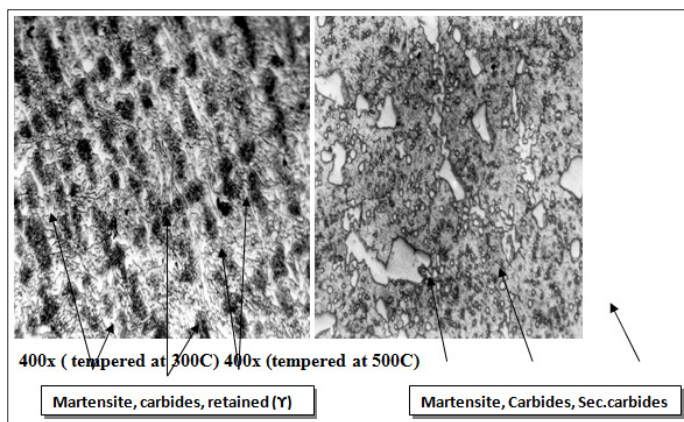


Figure 6: Microstructures of air-quenched-tempered, treated D3-cold work tool steel samples.

This gives a distribution of secondary carbides in a marten site matrix with small amounts of residual austenite and the hardness levels are increased to about 62-65 HRC. This is so called destabilization heat treatment. Tempering heat treatment after destabilization at 450-550 °C for normally 3-5 hours is to reduce the amount of the retained austenite in the matrix. Fig.(6) shows the distribution of carbide and martensite of forced air-quenched-tempered matrix, it is evident that the whole matrix consisted of well distributed carbides in martensitic base with ferrite and some retained austenite (tempered at 300-450C) if compared with that of conventionally quenched forged or rolled D3-D7 cold work tool steels or Cr-cast iron tooling, Fig(7).

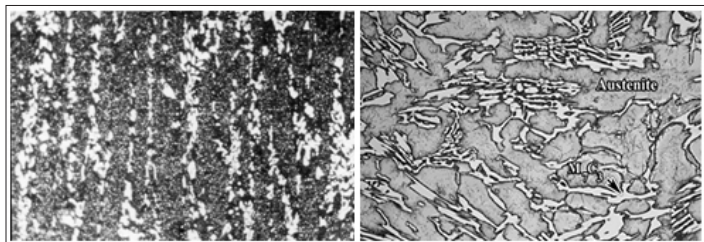


Figure 7: Appearance of banded eutectic carbides in conventional forged D3- steel and Cr-cast tooling (400x).

Distribution of martensite, carbide and retained austenite in these treated, hardened and tempered samples were detected using X-ray diffract-meter aided with comparison programs for pure phases. The measured reflections were automatically sorted as for austenite (111) between 48.5-52.5 degrees and martensite (200) between 75.5-79.5 degrees at step of 0.05 degrees and measuring time of 20 seconds, as in (Figure 11).

Mechanical Properties

Hardens

The hardness of the as-air quenched matrix was in the range 60 to 65HRC for D3 and D7 respectively due to the transformation of austenite to martensite and the high density interacted dislocations, however as the matrix subjected to tempering ordering of dislocations took place and transformation of retained austenite to martensite happens depending on the tempering temperature and holding time as shown in Fig.(8). The holding time was chosen to be 5h, while tempering temperatures were chosen to be between 100-700°C.

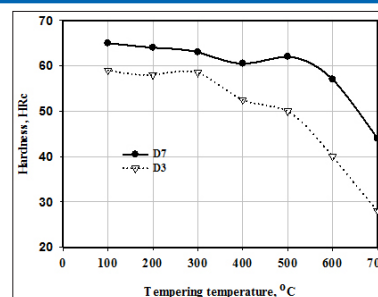


Figure 8: Dependency of hardness on tempering temperature of D3-D7 forced air-quenched, treated tool steels.

Maximum softening was encountered at 400°C while a gain of hardness of about 4HRC was observed for D7 steel, however continuous softening in D3 steel was measured to reach 50HRC after tempering at 500°C. The designers of dies from such steels must choose the optimum hardness they require and from which steel type. In all cases the optimum tempering temperature in this case 300°C which in turn give hardness of about 63HRC for D7 and 60HRC for D3 steels.

Fracture Toughness

Failure of dies used for blanking and forming is always due to fatigue fracture if the amplitude intensities approaches the fracture toughness critical factor (K_{ic}). Figure (9) illustrates the measured fracture and Charpy impact toughness for D3 produced experimental steel as a function of their different hardness after tempering. It is evident that as the hardness lowered the resistant to cracks increased and vice-versa, however at 55-60HRC hard matrix of D3 steel the K_{ic} factor reached to 70-60 MPa.√m and impact energy 54-35 Joules which are good if compared with those for high chromium cast steel or cast irons (20-30J).

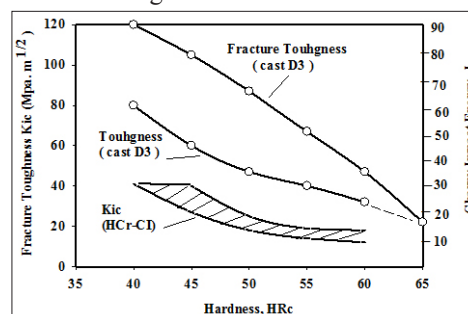


Figure 9: Toughness measurements of hardened-tempered, treated D3-cast steel at different hardness, as compared with high chromium cast iron [15].

The presence of some dimpled and ductile facets in the fracture surfaces of treated D3 experimental die steel advocates the improvement in its microstructure and toughness, Fig.(10).

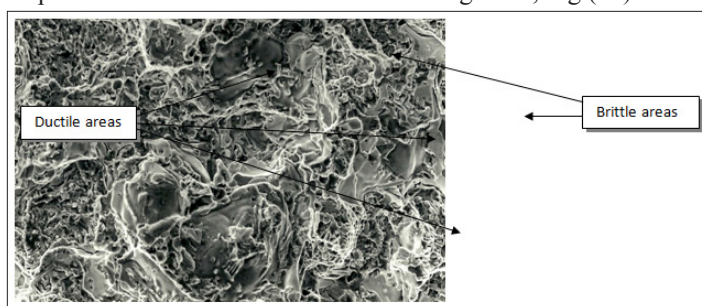


Figure 10: Fracture mode of hardened-tempered, treated D3-cast steel

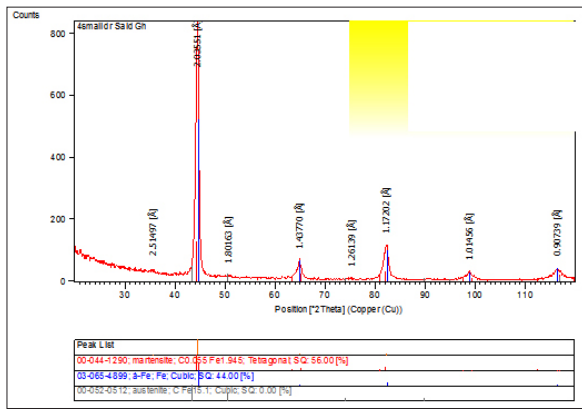


Figure 11: Phases distribution in treated-tempered D3-D7 cast-steels as revealed by X-ray diffraction.

The experimental dies manufactured from that treated D3 or D7 steels proved to have 1.3-1.5 times more life-time than the same dies manufactured from the same conventional rolled or forged steel as practiced by Universal group for engineering and household-Appliances manufacturer.

Conclusion

1. In order to break down the eutectic, continuous and interacted carbide nets, the equilibrium conditions of molten steel were altered through pouring it onto a sandwich bed of FeSiMgRe granulates which immediately melted and evaporated at pouring temperature. This induced turbulence and pressure increase helped to change the morphology of carbides during cooling.
2. Hard matrices of about 55-60HRC of D3-D7 steel together with fracture index K_{ic} 70-60 MPa. \sqrt{m} and impact energy 54-35 Joules were achieved which are higher if compared with those for high chromium cast steel or cast irons (20-30J).
3. The fracture mode of the experimental D3-D7 cast treated steels revealed the presence of some ductile areas that upgraded their lifetimes to be 1.3-1.5 times more than the same dies manufactured from the same conventional rolled or forged steel.

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