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# Influence of Retained Austenite on 52100 Steel

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**ABSTRACT*:*** The influence of retained austenite on the mechanical behaviour of steels is a controversial subject. In automotive applications, traditions from different companies recommend different 'optimum' amounts of retained austenite. The studies on the influence of retained austenite on bainitic structure of SAE 52100 steel are very limited. This study aims to investigate the influence of retained austenite content on mechanical properties of SAE 52100 steel with a view to optimize the amount of retained austenite to achieve best combination of mechanical properties.

Bainitic or martensitic microstructures are often obtained together with retained austenite. The amount and the morphology of retained austenite in bearings is an important issue. Austenite can often be retained in two forms: blocky and film types [3]. The former is unstable, which significantly influences the dimensional stability of the material. The film like austenite, located between bainitic ferrite plates, is very fine and stable due to the carbon enrichment. Such a fine microstructure consisting of bainitic ferrite and film austenite gives an excellent combination of strength and toughness. Moreover, the retained austenite islands can act as additional obstacles for crack propagation leading to enhanced toughness.

**KEYWORDS:** Martensite, Austenite, Bainite, Spherodize

## I.INTRODUCTION

SAE 52100 steel is a low alloy, high hardenable steel and is the most widely used material for ball bearing applications in rotating devices, machines and automobile applications [2]. Commonly, SAE 52100 steel is used in hardened and tempered condition having spheroidized carbides that yields attractive combination of low cost, high hardenability, high hardness (61– 63 Rc), high yield/tensile strength (2000/2200 MPa), and good machinability and formability. However, contact fatigue and bulk toughness are found to be inadequate at times in heavy duty/load applications. Recently, it has been suggested that bainite instead of tempered martensite may offer greater toughness and fatigue strength in this steel. Attempts have been made to develop a bainitic microstructure in SAE 52100 steel either by controlled tempering or by austempering.

Bainitic or martensitic microstructures are often obtained together with retained austenite. The amount and the morphology of retained austenite in bearings is an important issue. Austenite can often be retained in two forms: blocky and film types [3]. The former is unstable, which significantly influences the dimensional stability of the material. The film like austenite, located between bainitic ferrite plates, is very fine and stable due to the carbon enrichment. Such a fine microstructure consisting of bainitic ferrite and film austenite gives an excellent combination ofstrength and toughness. Moreover, the retained austenite islands can act as additional obstacles for crack propagation leading to enhanced toughness.

The influence of retained austenite on the mechanical behaviour of steels is a controversial subject. In automotive applications, traditions from different companies recommend different 'optimum' amounts of retained austenite [4]. The studies on the influence of retained austenite on bainitic structure of SAE 52100 steel are very interesting. This study is conducted from different journals and books to investigate the influence of retained austenite content on mechanical properties of SAE 52100 steel with a view to optimize the amount of retained austenite to achieve best combination of mechanical properties.

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## II. MATERIALS AND METHODS

**A)** SAE 52100 is a high carbon, chromium containing low alloy steel. Machinability of 52100 alloys is good and improvedby conventional methods [2-4, 5]. To improve the overall machinability of the SAE 52100 steel spherodizing annealing is done at 648$^0$C before machining. Generally for ball and roller bearings SAE grade 52100 steel is used in large scale. It contains normally 1%C and 1.3% to 1.6%Cr. The microstructure of fine spherical carbides in a martensitic matrix is generally produced by austenitizing a spheroidized microstructure at 840$^0$C to 860$^0$C, oil quenching, and tempering at 160$^0$C to 180$^0$C. In the bearing applications of 52100 steel, a number of investigations have related microstructural features to rolling contact fatigue performance. Finer carbides enhance bearing fatigue life; oxide inclusion particles are significantly more detrimental to fatigue life than are sulfides are less detrimental to fatigue life than the oxide inclusion. In the light microscope very fine microstructural changes are observed which is produced by rolling contact fatigue. Another area of investigation is the evaluation of heat treatments that incorporate pearlite as the starting structure for hardening rather than the spheroidized structure generally used for 52100 steel.
SAE 52100 bearing steel is subjected to repeatedly compressive and impact load for a long time. As a result high rolling contact fatigue life is affected by this repeatedly compressive and impact load. Martensitic structure and carbide morphology [2] as well as the retained austenite percentage in SAE 52100 bearing steel are significantly affected by the rate of quenching which have direct impact for mechanical property control in commercial practice. The heat treatment of the steel significantly influences the characteristics of the quenched products.
***Forging:*** The alloy may be supplied as forgings and also may be subsequently forged at 1204.44$^0$C down to 926.67$^0$C .
***Cold Working***: The alloy has good ductility and may be cold worked in the annealed or normalized conditions by conventional methods.
***Annealing:*** Anneal is done at 871.12$^0$C and slow cool to relieve cold working strains.
***Tempering:*** Normally tempering is done at 204.45$^0$C

**B) Composition:**
High strength high carbon martensitic SAE 52100 bearing steel is one of the main alloys used for rolling contact applications where high wear and fatigue resistance are required.

**Table: 1 Composition of SAE 52100 steel in weight percentage is as following:**

| C | Cr | Mn | Si | Ni | Cu | Mo | Al | S | P | Fe |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.01 | 1.36 | 0.32 | 0.25 | 0.16 | 0.12 | 0.04 | 0.03 | < 0.02 | < 0.01 | Rest |

**C) Heat treatment:**
To make the ball-bearing, the steel should have high hardness, wear resistance, resistance to contact fatigue, and high crushing strength. To achieve these properties the steel is often heat treated to obtain either martensite or bainite microstructures. Procedure of heat treatment of SAE 52100 Steel having composition as follows [4]:
Firstly, the steel is heated up to 860$^0$C with a rate of 120 $^0$C/min and hold at this temperature for 30 min. The microstructure of austenite having volume fraction of 0.95 and a cementite volume fraction of 0.05 is obtained. Then the steel is quenched to bainitic region and hold at a temperature of 230$^0$C, and annealed for different times (0-120 minute) followed by quenching at room temperature. This heat treatment process after soft annealing is shown in the Fig. 2.1.

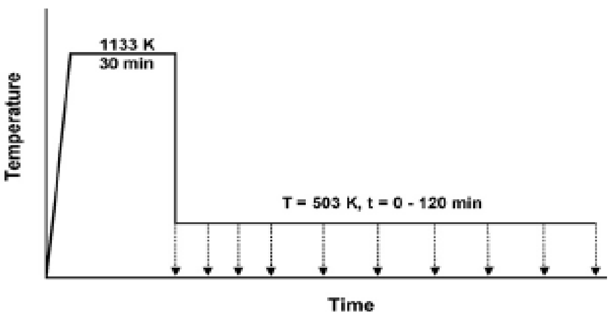


**Figure 2.1: Schematic representation of heat treatment.**

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Rao *et al*. [5] has shown that corrosion resistance of the SAE 52100 steel may be enhanced by nitrogen PIII. They have applied PIII on AISI 52100 and got a maximum hardness increase of 21%. The PIII process is carried out at high implantation energy (>20 keV). Ion implantation from nitrogen plasma at low energy may be more economical, independent control of the substrate temperature during implantation may offer an added benefit of attaining a greater case depth in a shorter time, due to the superimposed effect of thermally activated diffusion during implantation.

**D) Microstructure:**

SAE 52100 Steel is basically high hardenable and low alloy steel. In the Annealed condition its micro structure is consist of uniformly distributed spherodised carbides in a ferritic matrix.

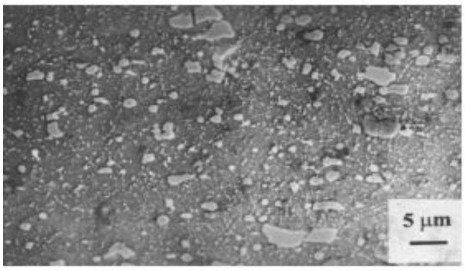


**Figure 2.2: A typical as-received (annealed) microstructure of the AISI 52100 steel in unimplanted condition. Uniformly distributed spherodised carbides in the ferrite matrix are evident [5].**

The microstructure of SAE 52100 steel is changed with the variation of holding temperature in heat treatment process (Fig. 2.2). Four different phases are observed during the variation of holding temperature in heat treatment process: martensite, bainite, retained austenite, and spheroidized cementite. The white particles in all figures are spheroidized cementite.

**E) Tempered martensite :**

The Fig. 2.3a shows the microstructure of specimen which is quenched directly from 860$^0$C to room temperature. The light grey area shows the retained austenite and the rest is martensite. Fig. 2.3b shows the microstructure of specimen held at 230$^0$C for 20 minutes. The microstructure consists of martensite, retained austenite, and a small amount of bainite (black niddle) in Fig. 2.3b. The Fig. 2.3c shows the microstructure of specimen at holding time of 45 minutes. The microstructures consist of slightly increased bainite and significant amount of retained austenite. The Fig. 2.3d shows the microstructure of specimen at holding time of 120 minutes. After this holding time the bainite formation become fully completed and the microstructure consist of bainite and very small amount of retained austenite.

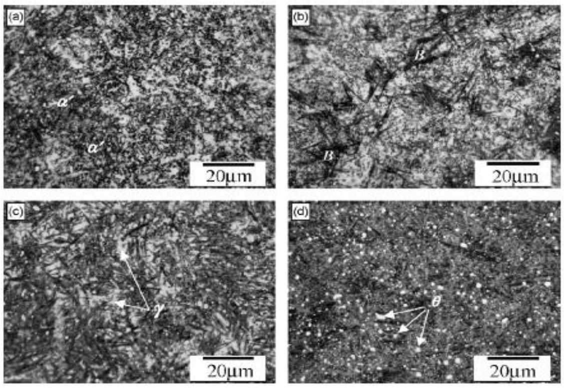


**Fig. 2.3: Optical microstructures SAE 52100 steel isothermally annealed at 230 $^o$C for (a) o min, (b) 20 min, (c) 45 min and (d) 120 min. Symbols - α': martensite, β: bainite, γ: retained austenite, θ: spheroidized cementite [3].**

**F) 52100 Steel: Bainite**

The 52100 type steels (Table 1) can be made bainitic by isothermal transformation in the temperature range 200–450$^0$C, with lower bainite dominating the microstructure when the transformation temperature is less than 350$^o$C [5]. The carbide in the lower bainite is cementite [6], which is in contrast to tempered martensite where it is e-carbide [8, 9]. The difference arises because there are two demands on the initial excess carbon dissolved in the bainitic ferrite, i.e., partitioning into the residual austenite and precipitation. When the former dominates, the precipitation is predominantly from carbon-enriched austenite [10]. The lower bainitic microstructure observed in 52100 following isothermal transformation at 230$^0$C is illustrated in Fig. 2.3 [11].

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**Figure 2.3. Lower bainite generated by isothermal transformation of 52100 steel at 230°C for 10 h [11].**

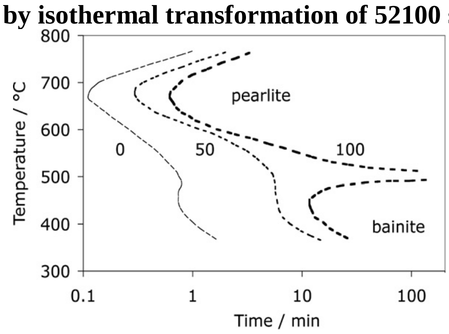


**Figure 2.4 Isothermal transformation diagram for Fe–1.04C–0.32Mn–0.19Si–1.35Cr wt% steel, fully austenitised at 1040°C for 30 min. The austenite grain size is 40–60 μm. The numbers indicate the percentage of transformation, at the austenite grain boundaries when T > 450°C [10].**

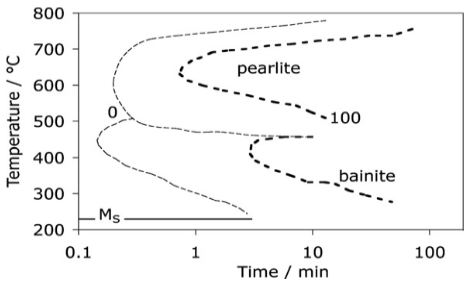


**Figure2.5.Isothermal transformation diagram for Fe–0.95C–0.44Mn–0.21Si–1.42Cr wt% steel,austenitised at 845°C for 20 min. The numbers indicate the percentage of transformation [13].**

A measured time–temperature transformation diagram for 52100 steel is illustrated in Fig. 2.4. Fig. 2.5 shows an alternative diagram, plotted on the same horizontal scale for an almost identical steel which has been austenitised at a lower temperature so that the carbon concentration in the austenite would be reduced; the consequent increase in driving force for transformation leads to an acceleration of the bainite reaction [12]. On the other hand, the formation of pearlite is faster when the austenitisation temperature is greater because of the larger concentration of carbon dissolved in the austenite

## III. RESULTS AND DISCUSSIONS

Martensite is a fine needle like structure and it is very hard and brittle. It is a magnetic substance. To obtain the desired properties like high hardness, relieving internal stress and refinement of grain size several heat treatment process are performed. When the steel is heated above the austenitizing range then it converted into the austenite. Different cooling rate is used to getting different phase/ structure. When steel is cooled rapidly from the austenitizing temperature to below Ms Temperature and proceeds over a range of temperatures, then austenite is transformed to martensite [2]. This transformation of austenite to martensite is temperature dependent, and diffusion less transformation. During transformation some amount of austenite remains untransformed even at room temperature. This untransformed

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austenite is called retained austenite. The sub-structure of retained austenite is differing from that of original austenite. It has higher density of imperfection, like dislocation, stacking faults, etc.

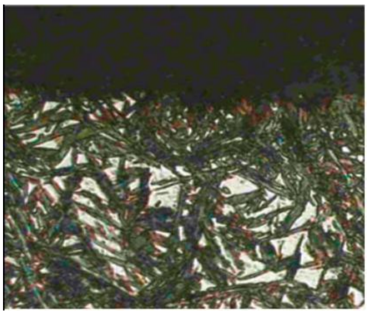

**Figure 2.6: Microstructure of case carburized steel component exhibiting retained austenite (white color) and tempered martensite (dark color) [3].**

The full transformation of austenite to martensite is not possible. Certain amount of retained austenite is always present in steel after quenching unless steel has been quenched at subzero temperature. In addition to martensite and retained austenite, hardened steel may contain carbide which is not dissolved in austenite during austenitizing. Therefore, microstructure of hardened steel may consist of martensite, retained austenite and carbides. Relative amount of these phases depends upon the composition of steel, austenitizing temperature, time and soaking temperature.

In the Fig. 2.6, the dark-colored needles show tempered martensite crystals and the light-colored areas are retained austenite crystals. The amount of retained austenite is a function of the carbon content, alloy content, quenching temperature and subsequent thermal and/or mechanical treatments. Depending on the steel composition and specific heat treatment, the amount of retained austenite can vary from over 50% of the structure to nearly zero. While large amounts of retained austenite (>15%) can be detected and estimated by optical microscopy. Some specialized equipment and techniques, such as x-ray diffraction methods, are used to accurately measure the amount of retained austenite to as low as 0.5%.

Normally 10% retained austenite is desirable as its ductility relives some internal stresses developed during hardening. This reduce the danger to distortion and cracks. Non–distorting tools owe their existence to retained austenite. It tries to balance transformational volume changes during heating as well as cooling cycles of heat treatment to produce little overall change in size of the tools [2-5, 14].

The characteristics that give retained austenite of its unique properties are those responsible for significant problems in most applications. Austenite is the normal phase of steel which is stable at high temperatures, but it is not stable at room temperature. Because retained austenite which exists outside of its normal temperature range, are metastable. This means that when get the opportunity, it will change or transform from austenite to martensite. During transformation, a volume change (increase) occurs which induces the internal stress in a component, often manifesting itself as cracks [5, 15]. Hardness of hardened steel is decreases in the presence of soft austenite. The retained austenite also decreases the magnetic properties of steel because it is non-magnetic.

## IV. CONCLUSIONS & RECOMMENDATIONS

In view of the above literature review it is apparent that the properties of 52100 steel crucially depends on retained austenite contained in both martensitic and bainitic structure, therefore it may be of interest to study the possibility of variation of volume fraction, size, morphology and stability of austenite in the microstructure of 52100 steel by designing the suitable process schedule to study of the mechanical properties, particularly the wear behavior of such microstructure will allow to determine the optimum combination of volume fraction, size, morphology and stability of retained austenite. Researchers are working for development of 52100 steel.

It is suggested that bainite instead of tempered martensite may offer greater toughness and fatigue strength in steel. Recently, attempts have been made to develop a bainitic microstructure .However, the relatively lower hardness and poor wear resistance of bainite compared with that of tempered martensite are considered serious drawbacks that prevent SAE 52100 steel with a bainitic microstructure from being utilized for bearing application.

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To improve the wear resistance of 52100 steel, many methods have been adopted, such as (a) laser treatment and (b) surface mechanical attrition treatment. Basu*et al.* [2] studied the improvement in wear resistance of 52100 steel treated with laser surface hardening. Similar to laser surface remeltingprovides many advantages, such as rapid solidification and self quenching which result in fine martensitic structures. SAE 52100 steel, hardened and tempered with spheroidized carbides. Laser surface hardening is a directed energy beam assisted surface hardening engineering technique in which laser beam is used to heating the surface of specimen and self-quenching of specimen is done by surrounding unheated portion.Due to absence of quenching medium surface hardening occurs up to a limited depth without affecting the bulk.

The SAE 52100 steel is widely used in above application due to good combination of low cost, high hardenability, high hardness, high yield/tensile strength.(2000/2200 MPa), and excellent machinability and formability. However, premature failure takes place due to the generation of noise, vibration and enhancement of friction by the high abrasive/wear. It is investigated that bainite posses greater toughness and fatigue strength than tempered martensite in steel.

Hardened and tempered with spheroidized carbide SAE 52100 steel is the most widely used [2-4, 5, 6] in the following applications.

- Thrust bearings.
- Ball and roller bearings
- Bearing raceways
- Machines for ball bearing and automobiles
- Rotating devices
- Balls and needles rollers

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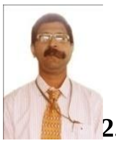

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