DEVELOPMENT OF DUCTILE MARTENSITIC TUBES AND ITS APPLICATION IN AUTOMOTIVE PARTS

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ABSTRACT

Advanced high strength steels are increasingly used in the automotive parts on account of its unique high strength and ductility. Generally, martensitic tubes are used in the automotive part as a resilient member. With the recent evolution of induction hardening and induction tempering of tubes has resulted 'ductile' martensitic tubes. The martensitic microstructure produced out of this technology in the steel tube provides ultra high strength and moderate ductility. Four grades of the steels SAE1026, SAE1035, SAE1541 and SAE15B25 have been taken for the investigation. Effect of steel chemistry on the martensite morphology and its impact on the mechanical properties of the quenched and tempered tubes are assessed. The boron treated steel (SAE 15B25) tube has shown very high tensile strength coupled with higher ductility than the other grades of the steels. Further, the effects of tempering temperature on the martensite morphology are studied. Martensite needles are refined as the tempering temperature is increased. A correlation has been obtained between the induction tempering temperature, tensile strength and ductility. Bending (Intrusion) test has been conducted on the four grades of steel tubes. Further, the potential applications of the ductile martensitic steel tubes in automotive parts are discussed in detail in this paper.

KEYWORDS

Induction hardening, Tempering, Martensitic microstructure, Steel tubes, Intrusion test, Automotive applications

INTRODUCTION

Steels quenched and tempered to martensitic microstructures are frequently referred to as hardened steels. Induction heating offers a very cost effective, rapid, in-line manufacturing method to harden steels for many automotive applications [1-6]. With the advent of induction heating systems, heat treating of tubular parts to achieve various strength levels through this system becomes very attractive for the component manufacturers. Traditionally, side impact beams are being produced with quenched & tempered (Q&T) steels that normally consist tempered martensitic microstructures. Recently, advanced high strength steels are looked into as an alternate to conventional Q&T steel for the impact systems on account of its high strength and high ductility [3-4]. Tempering is an important step in hardening process and is increasingly being performed by induction heating. The function of tempering, especially at low temperatures, between 150 and 200^{0}C, is to improve toughness and fracture resistance while minimizing decreases in hardness and strength. In order to utilize the strengthening benefit of carbon in martensitic microstructures, induction hardened machine parts are typically made from medium carbon steels. Generally, to compensate for short times associated with induction heating, temperatures are increased relative to those used in conventional tempering. Using induction heat treatment, with appropriate tempering temperatures for the medium carbon steel tubes, it is possible to achieve higher tensile strength and higher ductility. This unique combination of the martensitic microstructures offers huge potential for the automotive industries.

EXPERIMENTATION

Four grades of popular automotive hardenable steels have been taken for the investigation (Table 1). High frequency induction welded tubes are manufactured out of these steel grades and these tubes are cold drawn to 25.4 mm diameter with 3 mm thickness. Induction heating system with high pressure water quenching facility has been used to harden the steel tubes. Induction tempering is adopted to produce ductile martensitic tubes. The tempering temperatures used for this investigation are 180^{0}C, 400^{0}C and 550^{0}C. Conventional tempering is carried out using muffle furnace.

Table 1 Chemical composition of the steel tubes

Sl. No	%C	%Mn	%Si	%S	%P
SAE1026	0.23 - 0.28	0.7 - 0.9	0.1	0.03	0.03
SAE1035	0.18 - 0.23	0.4 – 0.6	0.2	0.03	0.03
SAE1541	0.36 – 0.46	1.35 – 1.65	0.35	0.06	0.03
SAE15B24**	0.23 – 0.28	0.9 – 1.3	0.3	0.03	0.03

** Boron is in the range of 0.0005 to 0.003 %.

Tensile samples are prepared as per ASTME8-99 standard. Tensile properties are evaluated using Shimadzu universal testing machine (AG250-IS model) with 50mm

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gauge length. The typical sample location and its configuration of the test specimen are illustrated in Fig.1.

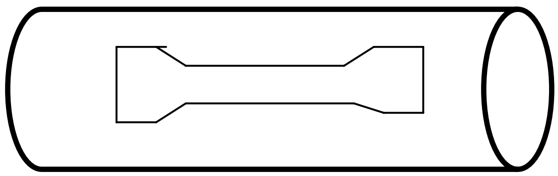


Fig. 1 Tensile sample location

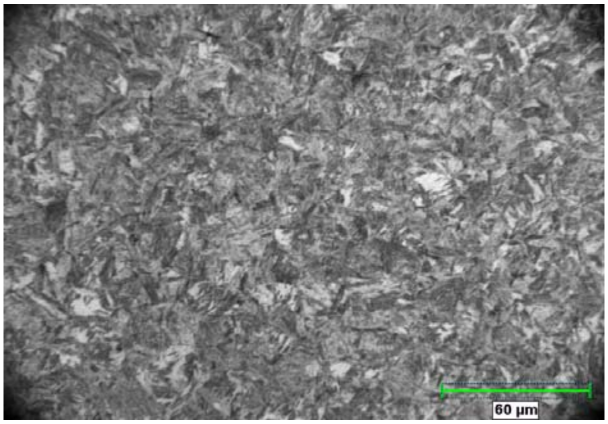
Bend (Intrusion) test has been conducted to ascertain the intrusion resistance capability of these hardened tubes. The typical testing setup is given in Fig.2. Image analyzer is used to characterize the microstructures. Micro Vickers hardness tester is used to measure the hardness of the martensite using 100g load.

Fig.2 Bend (intrusion) test set up

RESULTS AND DISCUSSION

EFFECT OF TEMPERING TEMPERATURE ON MARTENSITE MORPHOLOGY

Induction tempering is a process that has inherently high heating rate and lesser soaking time than the conventional tempering process. In the present investigation, three tempering temperatures are chosen and the induction tempering is carried out on the four grades of tubes. It is a known fact that as the tempering temperature increases, martensite morphology also changes. The effect of induction tempering temperature on the martensite morphology for the different grades is illustrated through optical microstructures (Fig.4, 5 and 6). It is observed that martensite morphology changes with higher induction tempering temperature. However, the chemistry is playing role in retarding the effect of tempering temperature. SAE1541 has higher induction tempering resistance than SAE1026.



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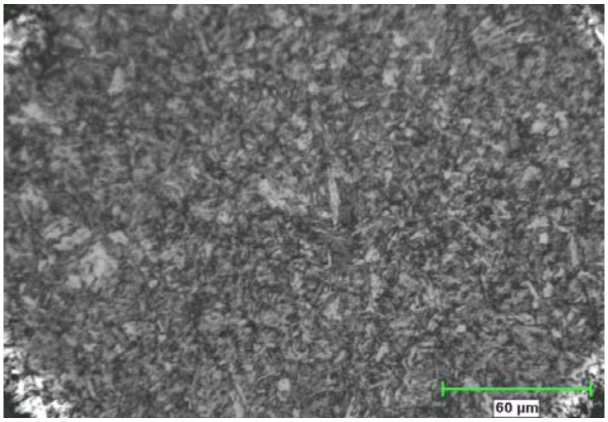

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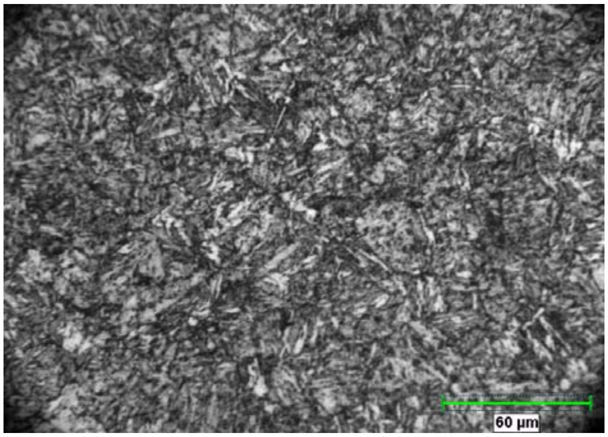

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Fig. 4 Optical micrographs for the tube samples of SAE1026 tempered at a) 180^0C b) 400^0C and c) 550^0C

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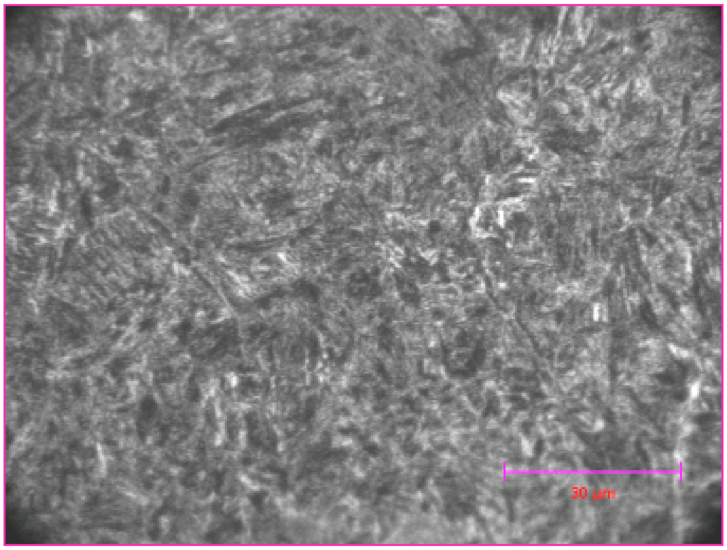

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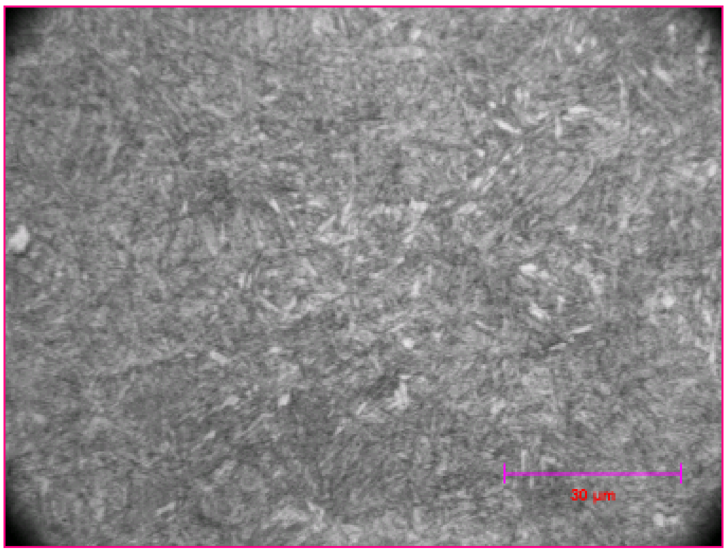

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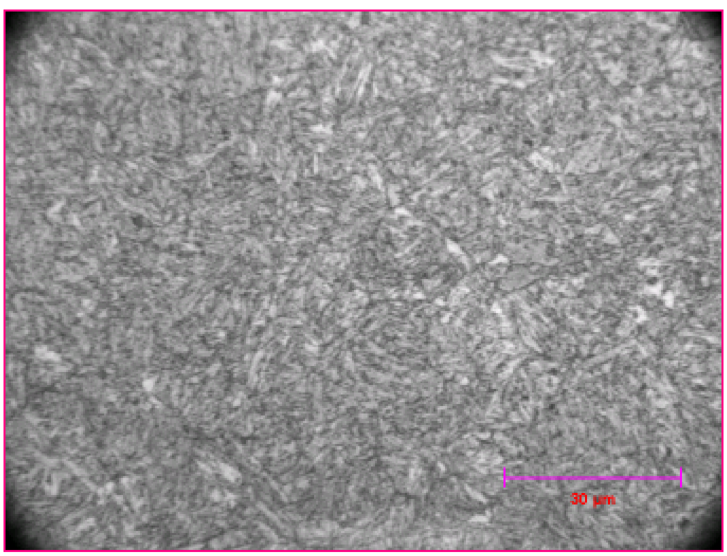

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Fig.5 Optical micrographs for the tube samples of SAE1541 grade steel tempered at a) 180^0C b) 400^0C and c) 550^0C

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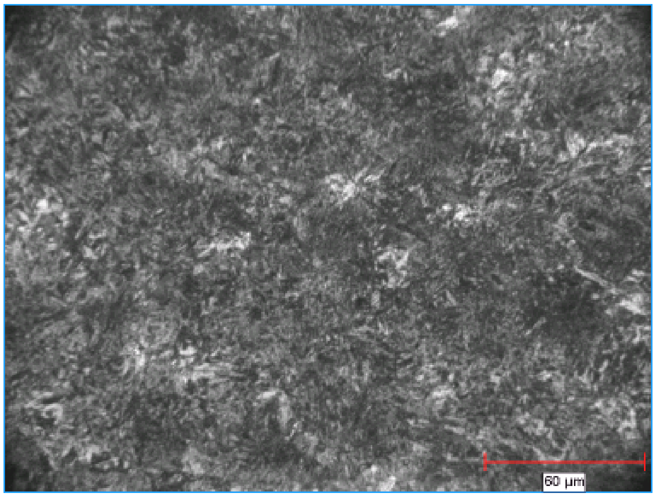

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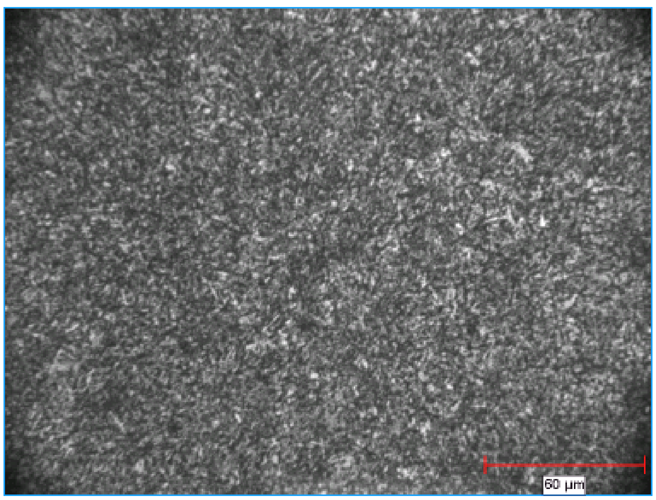

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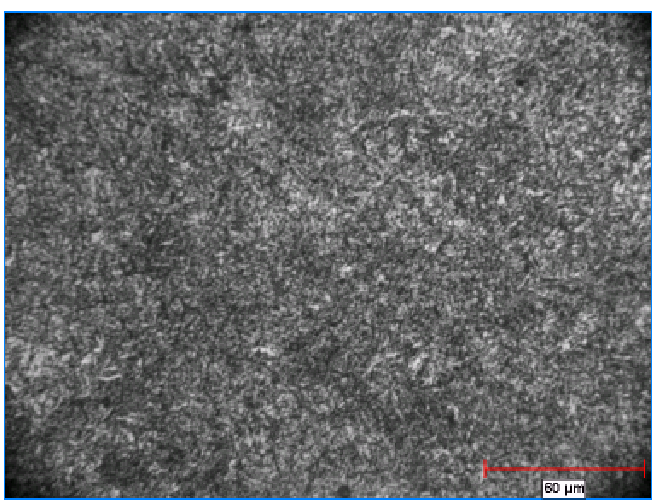

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Fig.6 Optical micrographs for the tube samples of SAE1035 grade steel tempered at a) 180^{0}C b) 400^{0}C and c) 550^{0}C

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INDUCTION TEMPERING TEMPERATURE EFFECTS ON MECHANICAL PROPERTIES

The consolidated mechanical properties data obtained from the tensile test for the four grades of steel tubes are given in Table 2. In order to understand the induction tempering effect, a conventional tempering also carried out on these steel grades separately in a muffle furnace and compared the mechanical properties. In all the grades, hardened tubes tempered at 180ºC shows lower elongation. This may be on an account of quench embrittlement. The quench embrittlement is as a result of cementite formation and phosphorus segregation at the austenite grain boundaries during austenitizing and or quenching [7].

Table 2 Mechanical properties for the various grades of steel with respect to tempering temperature

Steel grades	Tempering Temperature	Induction Tempering			Conventional Tempering		
		UTS (Mpa)	YS (Mpa)	El (%)	UTS (Mpa)	YS (Mpa)	El (%)
SAE1026	180ºC	1490	1290	8	1523	1280	5
	400ºC	1120	1000	7	1025	1017	4
	550ºC	990	880	10	836	827	8
SAE1541	180ºC	1978	1606	7	1563	1369	6
	400ºC	1493	1429	8	1562	1368	7
	550ºC	1236	1195	8	956	885	10
SAE1035	180ºC	1784	1439	8	1406	---	---
	400ºC	1439	1376	7	1391	1391	6
	550ºC	1114	1060	6	945	945	7
SAE15B25	400ºC	1521	1445	7	---	---	---

UTS – Ultimate tensile strength
YS – Yield strength
El – Elongation
'n' – Strain hardening exponent

As the tempering temperature increases, the ductility also increases. However, there is a drop in tensile strength as well as yield strength. It is evident from the table 2 that the improved ductility with tempering temperature indicates that the embrittlement is getting eliminated. Further, YS/UTS ratio is getting affected with increasing tempering temperature. The higher the carbon content of the steel, the more the

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tempering required to reduce the brittle behaviour. SAE1541 tube tempered at 550^0C results higher tensile strength when comparing to SAE1026 and SAE1035.

Among the induction tempering and conventional tempering processes, induction tempered tubes have shown higher tensile strength and ductility. Specifically, induction tempered at 180^0C results good combination of higher strength and elongation.

Bend toughness data obtained from the intrusion test for the three grades of tubes are given in table 3. Intrusion depth has been maintained at 150mm for the all the grades. It is evident that SAE1541 demonstrates high bend toughness for all the tempering temperatures compared to SAE1035 and SAE1026.

Table 3 Intrusion test data

Steel grades	Tempering Temperature	Bend toughness (Joules)	
		Induction Tempered	Conventional Tempered
SAE1026	180ºC	2741	1513*
	400ºC	1632	1714*
	550ºC	1824	1447
SAE1541	180ºC	4370	4098
	400ºC	3137	3076
	550ºC	2540	2091
SAE1035	180ºC	2932	355*
	400ºC	2262	1874
	550ºC	1834	1284
SAE15B25	400ºC	2415	---

* - Premature failure

The art and science of heat treated martensitic steels are deeply related to hardness. The effect of induction tempering temperature on hardness is illustrated in Fig.8.

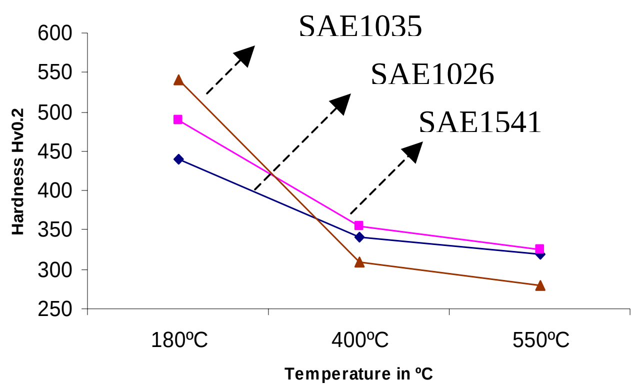

Fig. 8 Tempering temperature effect on hardness

Hardness is progressively decreases with increasing tempering temperature. After 400^0C, the drop in hardness is sluggish. It appears that tempering of hardened steel tubes around 180^0C preserves high hardness of quenched martensite. This low temperature tempered steel tubes may be used for applications that require high strength, wear resistance, bending fatigue resistance and contact fatigue resistance. Higher temperature (beyond 400^0C) tempered steel tubes may be used for the applications where plastic deformation is mandatory in the component.

AUTOMOTIVE APPLICATIONS

The ductile martensitic tubes provide an opportunity to enhance the product performance through higher energy absorption coupled with higher intrusion resistance. Some of the potential applications are given below

a) Side impact beam.
b) Torsion bar
c) Anti-roll bar
d) Cowl bar
e) Cam shaft
f) B-pillar

CONCLUSION

1) Induction tempered tubes have shown higher tensile strength and elongation compared to conventional tempered tubes.
2) Higher the carbon content of the steel, the greater the effect of quench embrittlement, and the greater the amount of tempering required eliminating the embrittlement.
3) Higher induction tempering temperature promotes finer grain size.
4) At high temperatures of induction, even for short times, accelerate microstructural changes and softening.
5) Boron treated steel tubes gives good combination of high strength and higher ductility.
6) Ductile martensitic tube has a potential in automotive suspension and impact product systems.

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