JMEPEG (2005) 14:792-798
DOI: 10.1361/105994905X75637

Properties and Processing of *TIMETAL* LCB

Yoji Kosaka, Stephen P. Fox, Kurt Faller, and Steven H. Reichman

(Submitted August 24, 2005)

***TIMETAL* LCB was introduced more than 10 years ago targeting automotive suspension spring applications. The alloy development aim was to use a low-cost formulation by selecting less expensive raw materials than typical beta titanium alloys. Following the first successful application of *TIMETAL* LCB suspension springs to series production vehicles, the 2000 Volkswagen Lupo FSI, the springs have been used for Ferrari Challenge Stradale since 2003. The most recent development effort was focused on the generation of metallurgical and mechanical service data for the alloy, and the implementation of efficient low cost processing of coils. This paper will introduce various properties of *TIMETAL* LCB products that can be useful in the design and the consideration of spring applications. Recent progress in the processing of *TIMETAL* LCB will also be introduced and discussed.**

Keywords β titanium alloy, LCB, properties, spring

1. Introduction

A number of successful applications of titanium and titanium alloys to original equipment manufacturing (OEM) automotive and motorcycle parts have been reported. Cost is considered to be one of the key factors for OEM applications as well as numerous benefits in use of titanium and its alloys as a replacement of conventional materials, which normally are steels.

TIMETAL LCB was designed to be used for automotive spring applications unlike other β titanium alloys (Ref 1), which were primarily for aerospace application. Although improvement of properties is important, recent development efforts have also been focused on the processing of ingot to spring winding to reduce manufacturing cost, in addition to less expensive formulation cost compared with other β titanium alloys such as Beta C. Following the first OEM application to Volkswagen Lupo FSI (Ref 2-4), *TIMETAL* LCB springs have been applied to Ferrari Challenge Stradale (2003 and later) and Ford Focus FCV (C264 Program). This paper will introduce processing of *TIMETAL* LCB coils and provide physical and mechanical properties of wires that should be useful for designing with the material and its applications (Ref 5-10).

2. Chemical Composition

The chemical composition of *TIMETAL* LCB is given in Table 1. The chemistry was designed to achieve the stability of β phase with the least amount of alloying elements. Less expensive ferromolybdenum master alloy can be used as a β stabilizer, which contributes to reducing its formulation cost.

Table 1 Range of chemical composition (wt.%)

Element	Minimum	Nominal	Maximum
Aluminum	1.25	1.5	1.75
Iron	4	4.5	5
Molybdenum	6.3	6.8	7.3
Oxygen	0.12	0.15	0.18
Silicon	…	…	0.15
Carbon	…	…	0.05
Nitrogen	…	…	0.03
Hydrogen	…	…	0.03
Residual, each	…	…	0.1
Residual, total	…	…	0.3

3. Manufacturing Process

A brief manufacturing process of *TIMETAL* LCB springs is shown in Fig. 1. The material can be rolled to straight bars or coils, depending on the applications. It should be noted that elastically wound coils as heavy as 200 kg are available now (Fig. 2), which enable spring manufacturers to use the equipment for steel springs with a minor modification. Hot winding is an option when it is more appropriate.

4. Physical and Mechanical Properties

4.1 Physical Properties

Physical properties of *TIMETAL* LCB and spring steel SAE 9254 are summarized in Table 2. Weight saving can be achieved not only by density but also by lower modulus (rigidity) compared with steel in spring applications. Physical properties at elevated temperature are given in Fig. 3.

4.2 Room-Temperature Tensile Properties

Table 3 shows specification values of *TIMETAL* LCB coils and bars with the diameter of approximately 8.5-25 mm for spring applications. Strength can be adjusted by aging; however, ductility changes with strength inversely, as shown in Table 4. Tensile properties of wires and bars that fall outside of the range are given in Table 5, indicating fairly consistent strength regardless of large differences in size.

4.3 Elevated Temperature Tensile Properties

Elevated temperature tensile properties are shown graphically in Fig. 4.

This paper was presented at the Beta Titanium Alloys of the 00's Symposium sponsored by the Titanium Committee of TMS, held during the 2005 TMS Annual Meeting & Exhibition, February 13-16, 2005 in San Francisco,CA.

Yoji Kosaka and **Stephen P. Fox,** TIMET Henderson Technical Laboratory, P.O. Box 2128, Henderson, NV 89009; **Kurt Faller** and **Steven H. Reichman,** TIMET Automotive, 900 Hemlock Road, Morgantown, PA 19543. Contact e-mail: yoji.kosaka@timet.com.

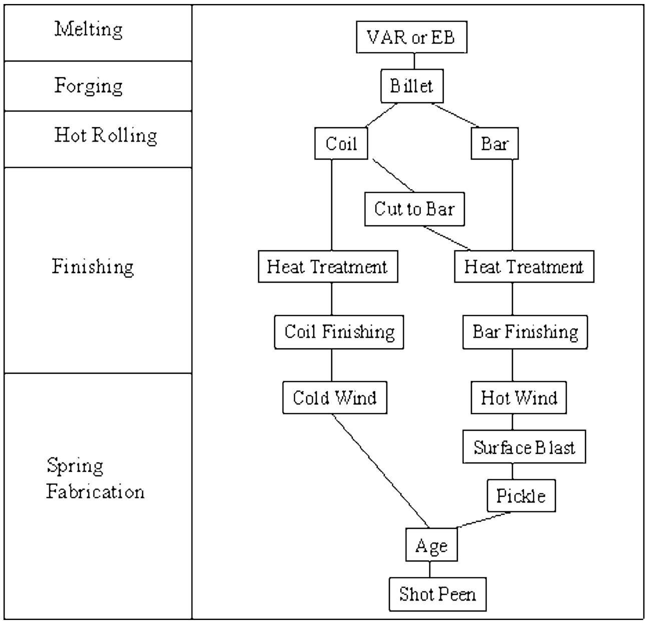

Fig. 1 Manufacturing process of wires and springs of *TIMETAL* LCB

Fig. 2 Example of large elastic wound coils

Table 2 Physical properties

	Unit	*TIMETAL* LCB	SAE 9254
Density, 22 °C	g/cm^2	4.79	7.84
Thermal conductivity, 24 °C	W/m-K	9.3	51.9(a)
Specific heat, RT	J/kg-K	519	486(a)
Electric resistivity, 24 °C	μΩ cm	134	22(a)
Thermal expansion coefficient, 38 °C	°C^{-1}	8.1×10^{-6}	11.3×10^{-6}(a)
Modulus of elasticity, RT	GPa	110 ~ 117	209
Modulus of rigidity, RT	GPa	38 ~ 46	81

(a) For SAE 1042

4.4 Torsional Properties

Results of room temperature torsion tests are given in Table 6. Torsional strength decreases with aging temperature, similar to tensile strength.

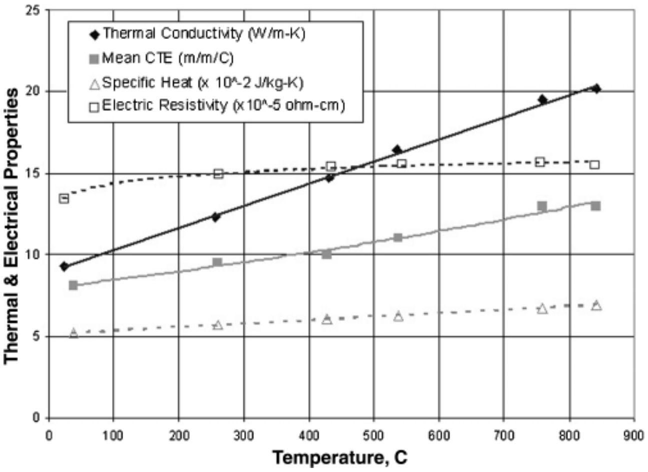

Fig. 3 Change of selected physical properties with temperature in solution treat and aged wire: ST, 760 °C; aging, 538 °C/4 h

Table 3 Specification of RT tensile properties for *TIMETAL* LCB coils and bars

Condition		UTS, MPa (ksi)	0.2% PS, MPa (ksi)	Elongation, %
Solution-treated	Min	1020 (148)	986 (143)	13
	Max	1150 (167)	1103 (160)	…
Solution-treated and aged	Min	1296 (188)	1241 (180)	6

Note: PS, proof strength

Table 4 Change of RT tensile properties by aging temperature (ST, 760 °C; aging, 4 h)

Aging temperature °C (°F)	UTS MPa (ksi)	0.2% PS MPa (ksi)	Elongation, %	Reduction of area, %
520 (968)	1502 (217.9)	1469 (213.0)	9	30.5
550 (1022)	1382 (200.5)	1338 (194.0)	12	45.1
580 (1076)	1296 (187.9)	1269 (184.0)	15	54.4

Note: PS, proof strength

4.5 Notch Tensile Properties

Results of notch tensile tests are shown in Table 7. The degradation of strength is not observed up to $K_t = 5$.

4.6 Fracture Toughness and Impact Properties

Fracture toughness and Charpy impact properties are given in Table 8.

4.7 Axial Fatigue Properties

Axial fatigue properties of elastically wound coils produced for spring applications are shown in Fig. 5. The fatigue limit of the wires is 965 MPa (140 ksi) or higher with $R = 0.1$.

4.8 Torsional Fatigue Properties

Shear-strain controlled torsional fatigue properties are shown in Fig. 6, indicating *TIMETAL* LCB exhibits equivalent torsional fatigue property to spring steel.

Table 5 Tensile properties of small-diameter wires and large-diameter bars after solution treatment and age (ST, 760 °C; aging, 538 °C/4 h)

Diameter, mm (in.)	Position	UTS, MPa (ksi)	0.2% PS, MPa (ksi)	Elongation, %	Reduction of area, %
3.7 (0.145)	Center	1396 (202.5)	1289 (187)	20	51
4.3 (0.169)	Center	1386 (201)	1296 (188)	16	43
5.4 (0.212)	Center	1393 (202)	1303 (189)	13	28
20.7 (0.82)	Center	1445 (209.5)	1425 (206.7)	10	36
30.0 (1.18)	Center	1422 (206.2)	1331 (193.0)	8	27
50.8 (2.0)	M/R	1358 (196.9)	1306 (189.4)	9	26
	50.8 (2.0)Center	1469 (213.0)	1376 (199.5)	7	15

Note: MR, mid-radius; PS, proof strength

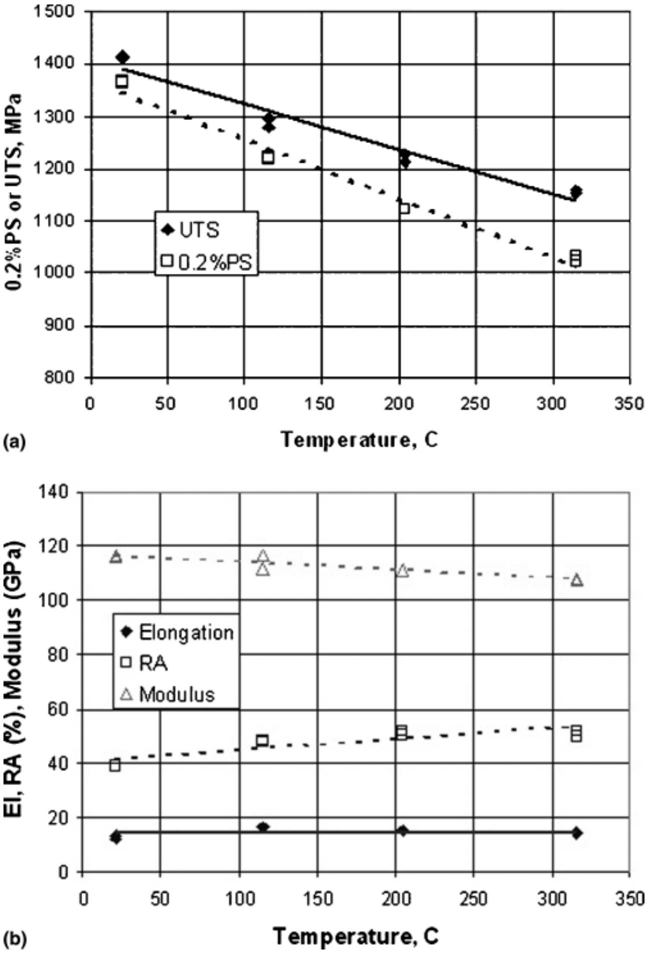

Fig. 4 Elevated temperature tensile properties of solution treat and aged wire: ST, 760 °C; aging, 538 °C/4 h

Table 6 Torsional properties of solution treat and aged wire (ST, 760 °C; aging, 4 h)

Aging temperature, °C (°F)	Ultimate shear strength, MPa (ksi)	YS at 0.2% shear strain, MPa (ksi)	Shear strain at fracture, %	Shear modulus, GPa (msi)
520 (968)	1200 (174.0)	996 (144.5)	6.0	41.0 (6.0)
550 (1022)	1131 (164.1)	942 (136.7)	6.9	40.7 (5.9)
580 (1076)	1034 (150.0)	827 (120.0)	13.8	38.3 (5.6)

Table 7 Notch tensile properties of solution treat and aged wire (ST, 760 °C; aging, 538 °C/4 h)

K_t	Notch radius, mm (in.)	UTS, MPa (ksi)	0.2% PS, MPa (ksi)	Elongation, %	NSR
1	Smooth	1389 (201.4)	1378 (199.8)	10	…
2.9	0.254 (0.010)	1724 (250.0)	…	…	1.25
5	0.076 (0.003)	1506 (218.4)	…	…	1.08

Note: NSR = UTS (notch)/UTS (smooth)

Table 8 Fracture toughness and Charpy impact properties of solution treat and aged wire (ST, 760 °C; aging, 538 °C/4 h)

Diameter, mm (in.)	Charpy absorbed energy, J (ft-lb)	K_{Ic}, MPa √m (ksi√in.)
14.2 (0.56)	10.2 (7.5)	N/A
26.7 (1.05)	12.6 (9.3)	40.6 (37.3)

Table 9 Tensile properties and double-shear strength of as cold-drawn and cold-drawn plus aged wires (ST, 760 °C; aging, 538 °C/8 h)

	Wire diam, mm (in.)	Cold draw, %	UTS, MPa (ksi)	0.2% PS, MPa (ksi)	Elongation, %	RA, %	Double-shear strength, MPa (ksi)
As cold-drawn	5.59 (0.220)	0	1044 (151.4)	956 (138.7)	15.6	54	737.1 (106.9)
	5.31 (0.209)	9.75	1207 (175.1)	1050 (152.3)	12.5	46	770.2 (111.7)
	4.87 (0.188)	27	1294 (187.7)	1145 (166.1)	6.2	38	814.3 (118.1)
	4.29 (0.169)	41	1332 (193.2)	1150 (166.8)	6.2	40	817.7 (118.6)
	3.86 (0.152)	52.3	1374 (199.3)	1204 (174.6)	6.2	38	788.1 (114.4)
Cold-drawn and aged	5.59 (0.220)	0	1306 (189.4)	1254 (181.9)	12.5	40	811.5 (117.7)
	5.31 (0.209)	9.75	1285 (186.4)	1242 (180.1)	15.6	51	832.9 (120.8)
	4.87 (0.188)	27	1306 (189.4)	1259 (182.6)	12.5	52	868.8 (126.0)
	4.29 (0.169)	41	1350 (195.8)	1316 (190.9)	10.0	51	827.4 (120.0)
	3.86 (0.152)	52.3	1385 (200.9)	1353 (196.2)	10.0	51	877.7 (127.3)

Note: PS, proof strength

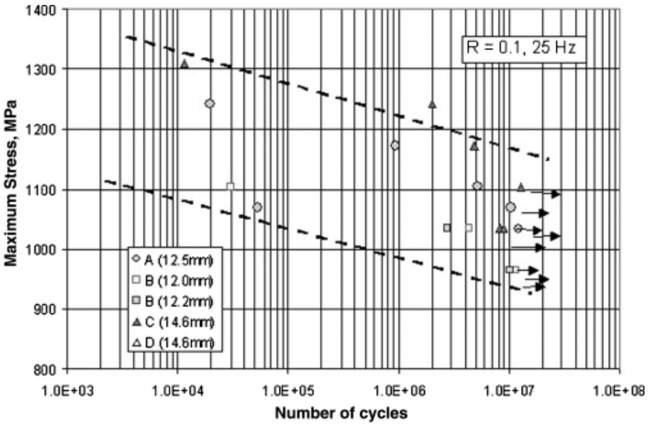

Fig. 5 Axial fatigue properties of solution treat and aged wires processed from various heats: ST, 760 °C; aging, 538 °C/4 h

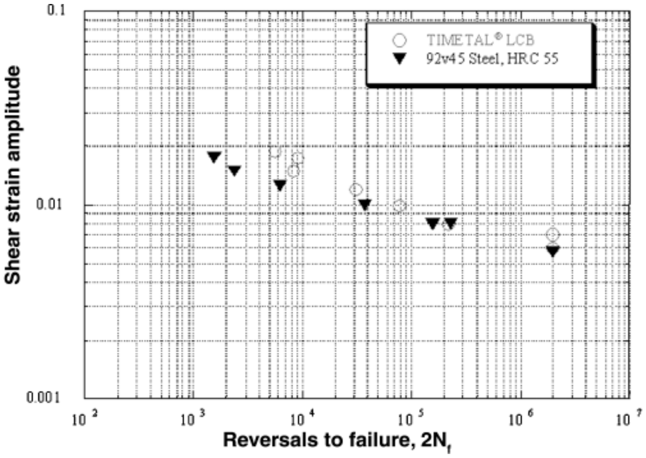

Fig. 6 Torsional fatigue properties of solution treat and aged wire (strain controlled)

4.9 Double-Shear Properties of Cold-Drawn Wires

Table 9 shows double-shear properties of *TIMETAL* LCB wires. Double-shear strength shows consistent values in as cold-drawn and cold-drawn plus aged conditions regardless of cold-drawn percentage.

4.10 Microstructure

Figure 7 shows microstructures of *TIMETAL* LCB wires solution-treated below β transus and aged. It is normally recommended to solution treat below β transus to maintain fine grain structures that result in a desired combination of strength and ductility as well as fatigue properties. Figure 8 shows a typical SEM micrograph of solution-treated wires. After solution treatment with continuous process, the surface is covered with a thin oxide film and an oxygen-enriched layer, which do not negatively impact the properties (Fig. 9).

4.11 Texture

A (0002) pole figure of a typical solution treat and aged wire is shown in Fig. 10. A high intensity of the (0002) plane is observed in the rolling direction.

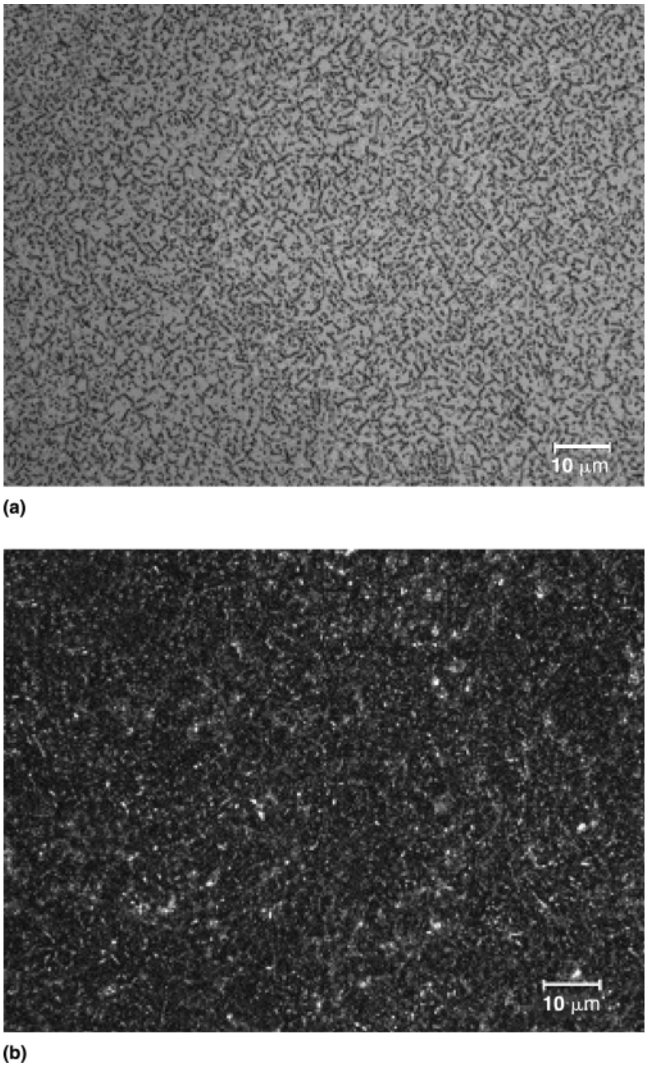

Fig. 7 Typical optical micrographs of (a) solution-treated and (b) solution treated and aged wire: transverse direction; ST, 760 °C; aging, 538 °C/4 h

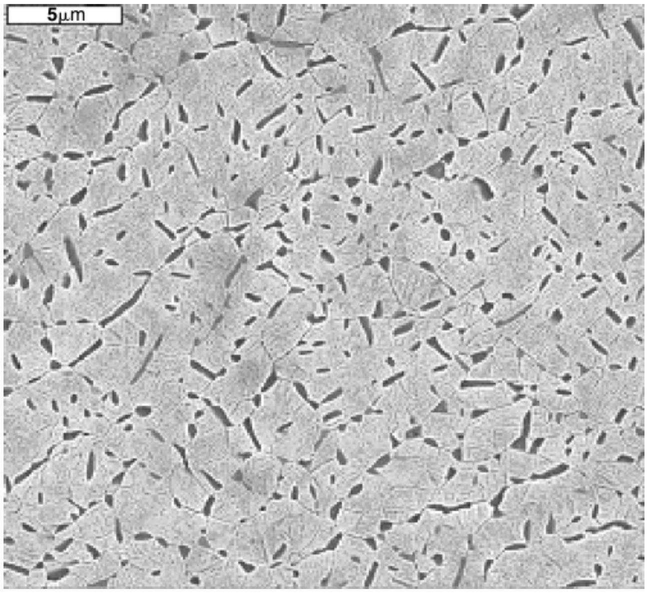

Fig. 8 SEM micrograph of solution-treated wire: transverse; ST, 760 °C

5. Heat Treatment and Finishing

5.1 Heat Treatment Variables

Figure 11 and 12 show the effect of heat treatment on tensile properties after aging. The condition should be selected to attain appropriate strength and ductility. Figure 13 shows aging curves for four different temperatures. A peak age is obtained after 1-4 h of aging, depending on the temperature, which is much faster than other β titanium alloys. The recommended aging condition is 538 °C/4 h or 549 °C/2 h, where time and temperature can be adjusted slightly depending on the applications and requirements.

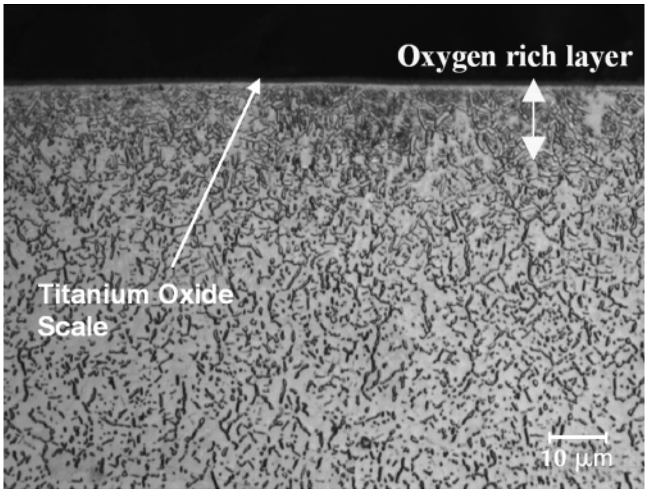

Fig. 9 Cross-section of surface of solution-treated wire: transverse; ST, 760 °C

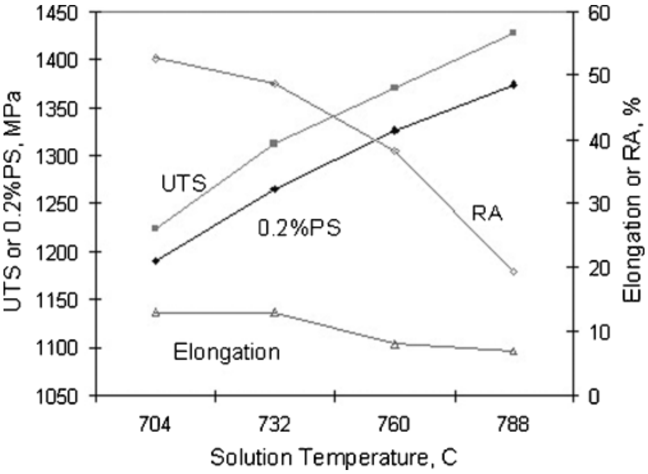

Fig. 11 Change of tensile properties with solution treatment temperature: aging, 538 °C/1 h

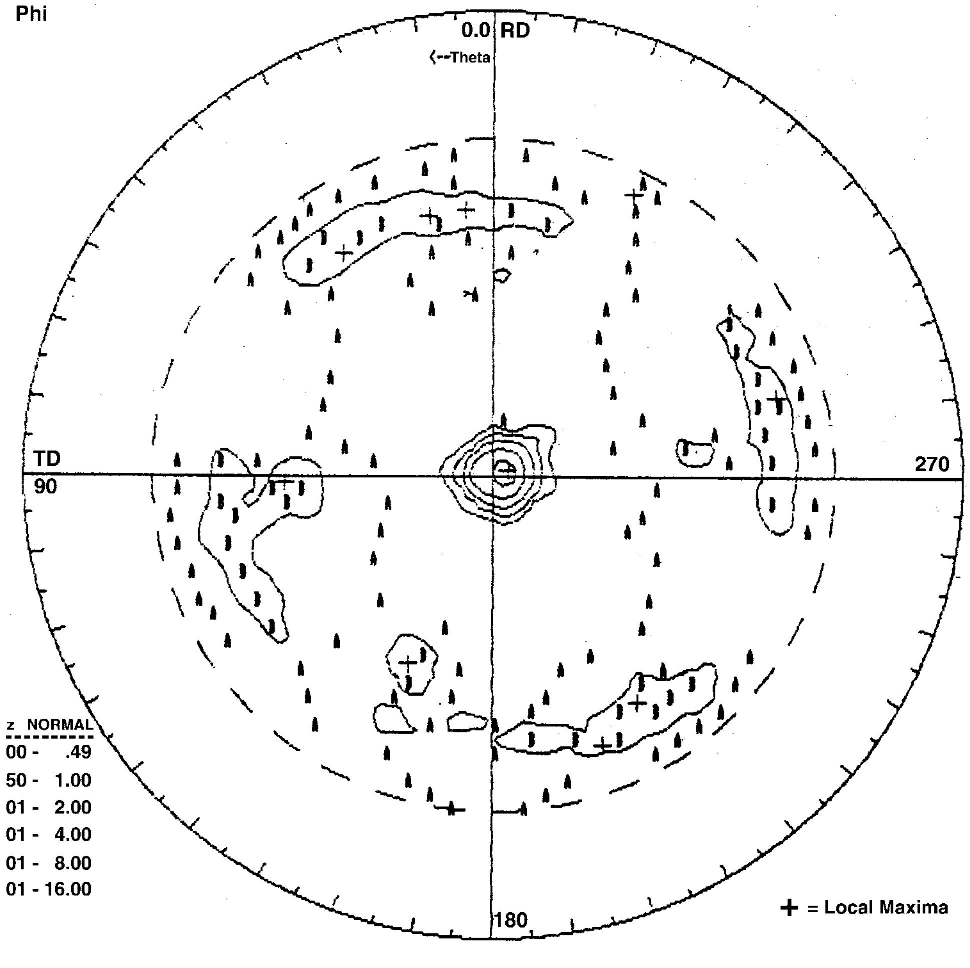

Fig. 10 (0002) pole figure of typical solution-treated and aged wire: ST, 760 °C; aging, 538 °C/4 h

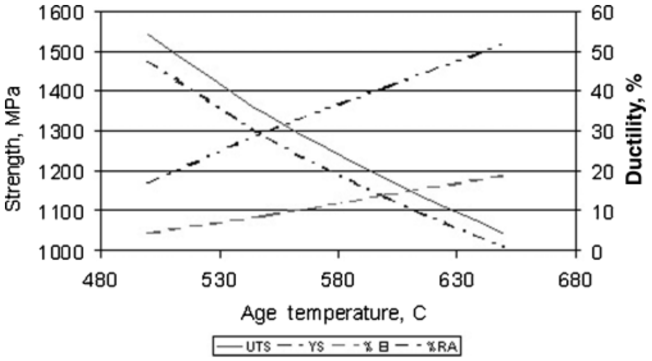

Fig. 12 Change of tensile properties with aging temperature: ST, T_β – 42 °C; aging, 8 h

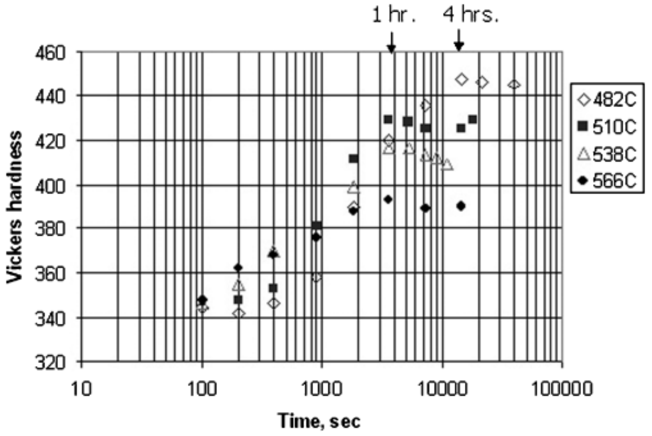

Fig. 13 Typical aging curves after subtransus solution treatment

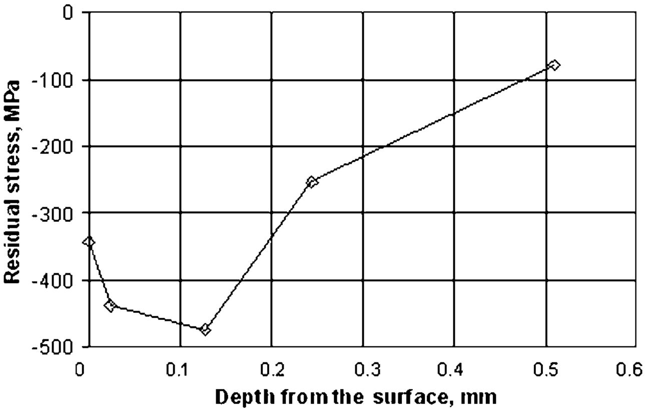

Fig. 14 Example of residual stress profile after shot peening on solution-treated and aged wire: ST, 760 °C; aging, 538 °C/4 h

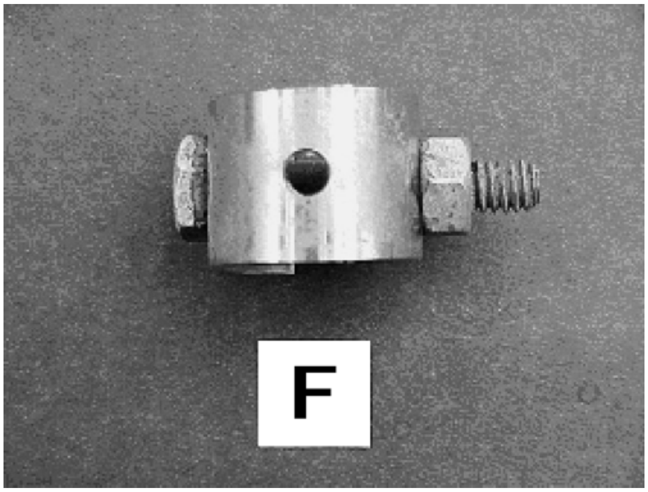

Fig. 15 Appearance of C-ring SCC specimen tested with condition F

Table 10 Conditions of C-ring stress corrosion cracking tests (heat treatment: ST, 760 °C; aging, 538 °C/4 h)

ID	Solution	PH	Temperature, °C (°F)	Drill hole	Bolt	Stress, % of YS	Remarks
B	5% NaCl	…	37.8 (100)	No	Ti	90	Insulation
C	Synthetic seawater	…	37.8 (100)	No	Ti	90	Insulation
F	5% NaCl	5	65.6 (150)	Yes	Steel	70	SCF = 1.5
G	Saturated NaCl	2	76.7 (170)	No	Steel	90	Ar gas stirring

Note: SCF, stress concentration factor; duration: 30 days (G: 30 days and 6 months)

5.2 Shot Peening

Shot peening with the intensity of 0.46 mm (0.018 in.) Almen is recommended. Double shot peening may improve fatigue properties when the condition is carefully selected. Figure 14 shows an example of a residual stress profile.

6. Environmental Properties

6.1 Stress Corrosion Cracking (SCC)

Stress corrosion cracking (SCC) tests were performed on solution treated and aged 30 mm diam bar. C-ring SCC test specimens were machined, and tests were conducted in accordance with ASTM G38. Table 10 shows some results of the tests. No crack was observed in any specimens after 30 days of immersion. No cracks were seen even after 6 months with the condition G. Figure 15 represents an example of tested specimens. Excessive hydrogen absorption was not measured in any tested specimens.

7. Summary

- *TIMETAL* LCB offers substantial weight savings and design advantages over steel in the application of suspension springs due to its unique mechanical and physical properties.
- Titanium springs in automobiles and motorcycles will be

used more often as suppliers and users gain experience with them.

References

1. P.G. Allen, P.J. Bania, A.J. Hutt, and Y. Combres, A Low Cost Beta Alloy for Automotive and Other Industrial Applications, *Titanium '95 Science and Technology,* P.A. Blenkinsop, W.J. Evans, and H.M. Flower, Ed., The Institute of Metals, 1995, p 1680-1687
2. O. Schauerte, D. Metzner, R. Krafzig, K. Bennewitz, and A. Kleemann, Fahrzeugfedern Federleicht—Erster Serieneinsats einer Achesschraubenfeder aus Titan, *ATZ Automobiltechn. Z.,* Vol 103, 2001, p 654-660 (in German)
3. K. Faller, Titanium Springs Make Production Car Debut, *Spring Technol.,* Vol 40 (No. 4), 2001, p 25-27
4. J. Kiese, W. Walz, and B. Skrotzki, Influence of Heat Treatment and Shot Peening on Fatigue Behavior of Suspension Springs Made of *TIMETAL* LCB, *Ti2003 Science and Technology,* G. Lutjering and J. Albrecht, Ed., Wiley-VCH Verlag GmbH & Co., 2004, p 3043-3050
5. P.G. Allen and A.J. Hutt, Low Cost Beta Automotive Applications, *Proceedings 1994 International Titanium Conference,* Coronado, CA, ITA, 1994, p 179-188
6. S.P. Fox and Y. Kosaka, Titanium Suspension Springs—An Update, *SAE Technical Paper Series,* No. 02M-96, Society of Automotive Engineers, 2002
7. Y. Kosaka and S.P. Fox, Recent Developments in the Manufacturing of Low Cost Titanium Alloys, *High Performance Metallic Materials for Cost Sensitive Applications,* F.H. Froes, E.Y. Chen, R.R. Boyer, E.M. Taleff, L. Lu, F.L. Zhang, C.M. Ward-Close, and D. Eliezer, Ed., TMS, 2002, p 35-42
8. Y. Kosaka, Properties of *TIMETAL* LCB for Automotive Suspension Spring Applications, *Titanium Jpn.,* Vol 52, 2004, p 1-6 (in Japanese)
9. Y. Kosaka and S.P. Fox, Properties and Production Experiences of *TIMETAL* LCB for Automotive Spring Applications, *SAE Technical Paper Series,* No. 2003-01-1181, Society of Automotive Engineers, 2003
10. Y. Kosaka, S.P. Fox, K. Faller, and S.H. Reichman, Low Cost Processes for Automotive Titanium Materials, *Cost Affordable Titanium,* F.H. Froes, M.A. Inam, and D. Fray, Ed., TMS, 2004, p 77-84