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Vanitec is a technical and scientific committee, which brings together representatives of companies and organisations involved in the mining, processing, manufacture, research and use of vanadium and vanadium-containing products.

Vanitec establishes, collects and makes available information on vanadium, its use, availability, new scientific and technical developments and trends in its application. The object of V-Technology is to provide up to date information and to initiate discussion through the medium of short articles on subjects to the use of vanadium.

2014 Vanadium Award

The Vanadium Award was endowed by Vanitec to The Metal Society (now The Institute of Materials, Minerals and Mining) in 1981 to celebrate the 150th anniversary of discovery of vanadium. The award has been made annual since that time. The winners of the award for 2014 were Shahrooz NAFISI and Laurie COLLINS of EVRAZ Research and Development, Canada, Muhammad ARAFIN and Jerzy SZPUNAR of McGill University and University of Saskatchewan, Canada and Robert GLODOWSKI of EVRAZ, East Metals North America, USA, for their paper "Impact of Vanadium Addition on API X100 Steel", published in ISIJ International, Vol. 54, No.10, 2014, pp. 2404–2410.

In this study, API X100 steels were made by controlled hot rolling of a laboratory melted 127 mm thick cast ingot to 14 mm final plate. The steels contained (wt.%) 0.06%C, 1.95%Mn, 0.41%Mo, 0.16%Cr, 0.03%Nb, 0.005%Ti, 0.0055%N and two levels of vanadium - one with a residual level of 0.004%V (0V) and the other with 0.063%V (0.06V). Mechanical properties were determined for various rolling and pipe axis orientations. Microstructural analyses were performed, including Optical Microscopy, Electron Backscatter Diffraction (EBSD) and Transmission Electron Microscopy (TEM). The texture of the two steels was also compared.

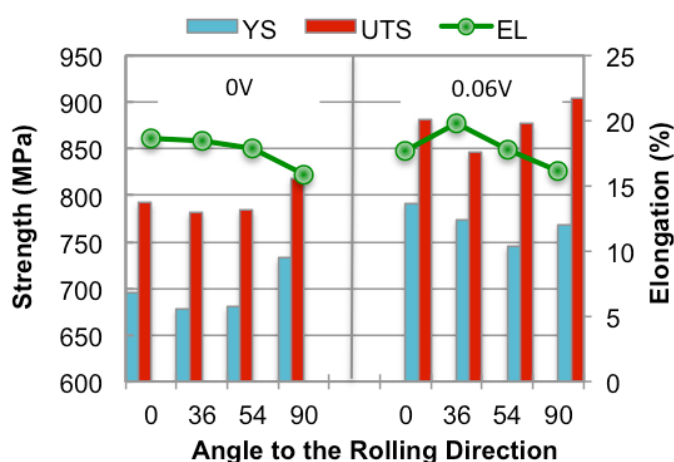


Fig. 1 Effect of vanadium on tensile properties of the API X100 steel

The addition of 0.063%V resulted in an increase of both yield strength and tensile strength of 60 to 95 MPa in all tested directions, 0°, 36°, 54° and 90° from the rolling direction, without adverse effects on ductility or toughness, as shown in Figs. 1 and 2. In addition, only the 0.063%V steel satisfied the yield strength and tensile strength criteria (690<YS<820 MPa and 620<YS<750 MPa in the transverse to pipe axis, i.e. 36° and the longitudinal to pipe axis, i.e. 54° directions respectively. Both of the steels met the elongation and toughness requirements.

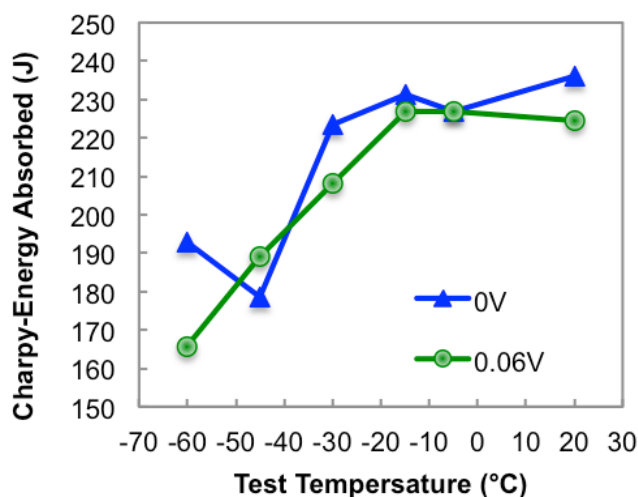


Fig. 2. Charpy toughness of the API X100 steels

For both of the steels, the final plate contained mainly bainitic ferrite with small amount of polygonal ferrite and Martensite-Austenite constituents. Texture analysis showed very similar results, with some slight indications of more desirable components in the vanadium added steel, i.e. $\{332\}\langle 113 \rangle$ and $\{554\}\langle 225 \rangle$. EBSD analysis indicated the presence of higher fraction of low angle boundaries (misorientation between 2 and 15 degree) as well as smaller grain size in the vanadium added steel than the steel without vanadium. TEM observation revealed that the carbonitride particles in the 0.063%V steel were smaller in size, with a much higher number of particles less than 10 nm than those in the V-free steel. It is suggested that the superior strength of the vanadium added steel may be due to the contributions of vanadium on precipitation strengthening and retarding the recovery of the dislocation structure in bainitic ferrite. The authors concluded that the vanadium addition was necessary in the X100 pipeline steel to ensure meeting the required strength properties.

Recent Vanadium Related Publications Review

Vanadium Improves Strength and Formability of Dual Phase Steels

Dual phase (DP) steels are characterised by a microstructure consisting of a dispersion of hard martensite particles in a soft, ductile ferrite matrix, which gives a number of unique properties including continuous yielding, high initial work hardening rate, low yield-to-tensile strength ratio and large uniform and total elongation. DP steels have been used extensively in automobiles for weight saving applications. However, compared with other advanced high strength steels, DP steels exhibit poor post-uniform elongation, which indicates low stretch flangeability, due to the large difference in strength between the ferrite and martensite phases in DP steels. Strain incompatibilities generated at ferrite/martensite interfaces during deformation can promote local boundary decohesion, resulting in void formation and fracture. Therefore, there is limitation of applying DP steels to the manufacture of auto parts, which involve complex edge stretching processes. A recent study (Tensile Behavior of Ferrite-martensite Dual Phase Steels with Nano-precipitation of Vanadium Carbides, ISIJ International, Vol. 55, No. 8, 2015, pp. 1781-1790) by Naoya KAMIKAWA and the co-authors presented that vanadium addition improved the post-uniform elongation as well as increased the strength of DP steels.

A 0.095%C-1.49%Mn-0.43%V steel (V-added steel) was used to produce ferrite-martensite DP steel with dispersion of nano-sized vanadium carbides. After austenitizing at 1100°C for 600 s, the samples were isothermally transformed at 690°C for different holding periods followed by quenching to obtain DP microstructures with different volume fractions of ferrite phase. Conventional DP steels (V-free steel) were also prepared for comparison. The heat treatment conditions

and chemical composition of the V-free steel were chosen to produce the DP steel samples with different volume fraction of ferrite and similar carbon content (~0.1 mass%C) in the martensite.

Optical microscopy revealed that volume fraction and distribution of ferrite/martensite phases were similar in the DP steels with or without vanadium addition, but the ferrite grain size was smaller in the V-added steel. Interphase precipitated vanadium carbides with an average diameter of ~10 nm in ferrite phase of the V-

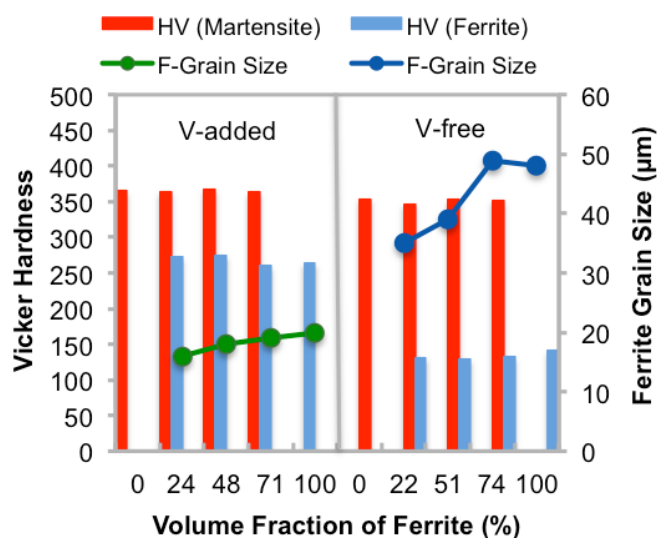


Fig. 3 Vickers hardness of ferrite and martensite phases and ferrite grain size in the DP steels

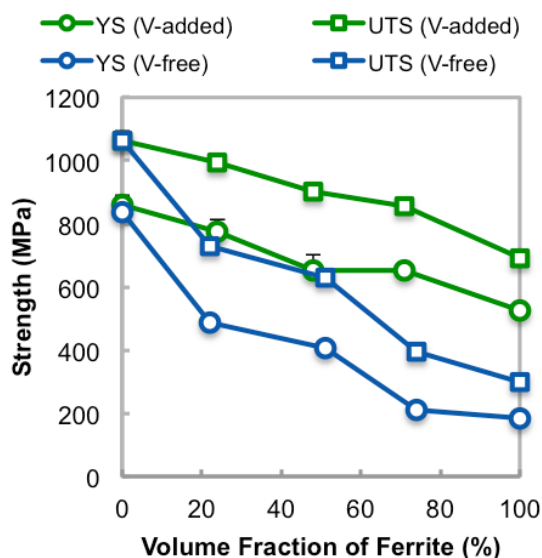


Fig. 4 Strength of the DP steels as a function of volume fraction of ferrite

Vickers hardness tests indicated (Fig. 3) that in the V-free steel the hardness was ~130 HV for the ferrite and ~350 HV for the martensite. In contrast for the V-added steel, the hardness of the ferrite was ~260-270 HV, much higher than that of the V-free steel due to the precipitation strengthening contribution of vanadium. The hardness of the martensite in the V-added steel was 360 HV, similar to that of the V-free steel. Fig. 4 shows the strength of the V-added and V-free samples as a function of volume fraction of ferrite. It is seen that the strength of the V-added steel was higher than that of the V-free steel due to precipitation strengthening of ferrite by nano-sized VC particles in the V-added steel. Strength-ductility balance is compared between the V-added steel and the V-free steel in Fig.5 and it demonstrates that vanadium addition improved simultaneously both the strength and the strength-ductility balance of the DP steel, particularly the strength-post uniform elongation balance. A digital

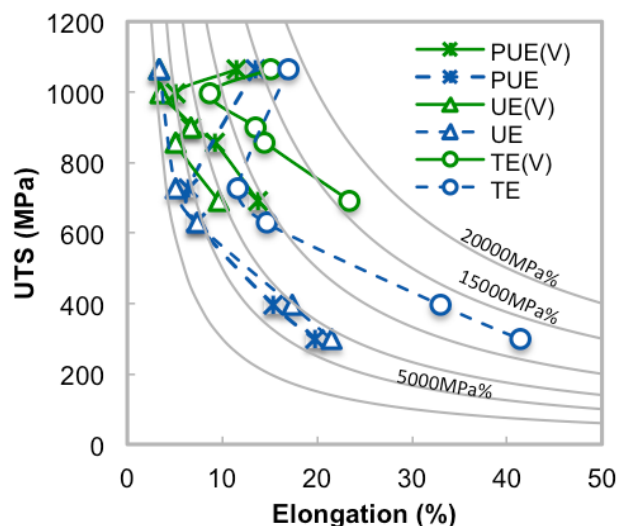


Fig. 5 Strength-ductility balance of the V-added steel (V) and the V-free steel, Post-Uniform Elongation (PUE), Uniform Elongation (UE), Total Elongation (TE)

image correlation (DIC) technique is used to quantify strain partitioning between ferrite and martensite phases during the tensile tests and it revealed that strain distribution was heterogeneous and in particular the strain was more concentrated on soft ferrite phase in the V-free steel. However, it was clearly shown that a more homogeneous deformation pattern was achieved in the V-added steel. It was suggested that strain partitioning between ferrite and martensite phases in the V-added steel was greatly suppressed by nano VC precipitates in ferrite. In addition, more homogeneous deformation due to VC dispersion may also inhibit formation voids or crack in the later stage of tensile deformation, resulting in better post uniform elongation in the V-added steel.

Vanadium Microalloying Opens the Way for Producing Hot-dip Galvanized Ultra-high Strength Steels

Ultra-high martensitic steel sheets are increasingly being used in automobile body construction to achieve significant improvements in crashworthiness and auto-body weight reduction for higher fuel economy and lower CO₂ gas emission. Martensitic steel sheets possess ultra-high strength and remarkably high stretch-flangeability and good bendability due to the homogeneity and uniformity of the martensitic microstructure, which is not conducive to the nucleation of cavities, unlike dual phase structures. In addition to the needs for strength and formability, the corrosion resistance must also be ensured for martensitic steels used as automotive components to guarantee long-term

vehicle durability. Hot-dip galvanizing (GI) and galvannealing (GA) are widely used to meet this need. Hot-dip galvanizing involves immersing steel into a bath of molten zinc for 4-5 minutes at a temperature of around 460°C and the steel undergoes an additional heating step to 500/550°C prior to cooling for galvannealing. During hot-dip galvanizing and galvannealing operations the steel is reheated, which may result in the significant loss of strength in martensitic steels due to tempering of the martensite. This raises a challenge of producing ultra-high strength martensitic grades in hot-dip lines. A possible solution would be to develop steels that are resistant to softening during tempering.

Vanadium in steel is well known to be extremely effective in reducing softening and providing secondary hardening during tempering of quenched steels. A recent paper from Swerea KIMAB (Vanadium Microalloyed High Strength Martensitic Steel Sheet for Hot-dip Coating, Hutchinson, Bevis, Jacek Komenda, and David Martin, Conference Proceedings of HSLA Steels 2015, Microalloying 2015 & Offshore Engineering Steels 2015, pp. 533-540) presented that vanadium microalloying, especially combination with nitrogen provides a possibility of retaining strength in martensitic steel after the simulated hot-dip galvanizing and galvannealing treatments.

In this study, six steels with base composition of 0.2%C, 1.2%Mn, 0.4%Cr and 0.03%Al were used. Three levels of vanadium, 0%, 0.05% and 0.1% in combination with

low and high nitrogen contents of 0.003% and 0.012% were chosen to study the combination effect of vanadium and nitrogen additions on strength when cold rolled martensitic steel sheet is exposed to the simulated galvanising and galvannealing treatments. The 40 mm square ingots were hot rolled to 4.5 mm plate using a soaking temperature of 1100°C and finishing in the range 850-900°C followed by air cooling. After picking, the samples were cold rolled to a final thickness of 12 mm. Heat treatment to produce fully martensitic microstructure was carried out at 900°C for 3 minutes followed by quenching into cold water to simulate the industrial processing in continuous annealing lines. A total annealing time of 5 minutes at 460°C in a salt both was adopted to simulate Hot dip galvanising and a further heat treatment of 550°C for 15 seconds in a salt both was used to simulate the galvannealing.

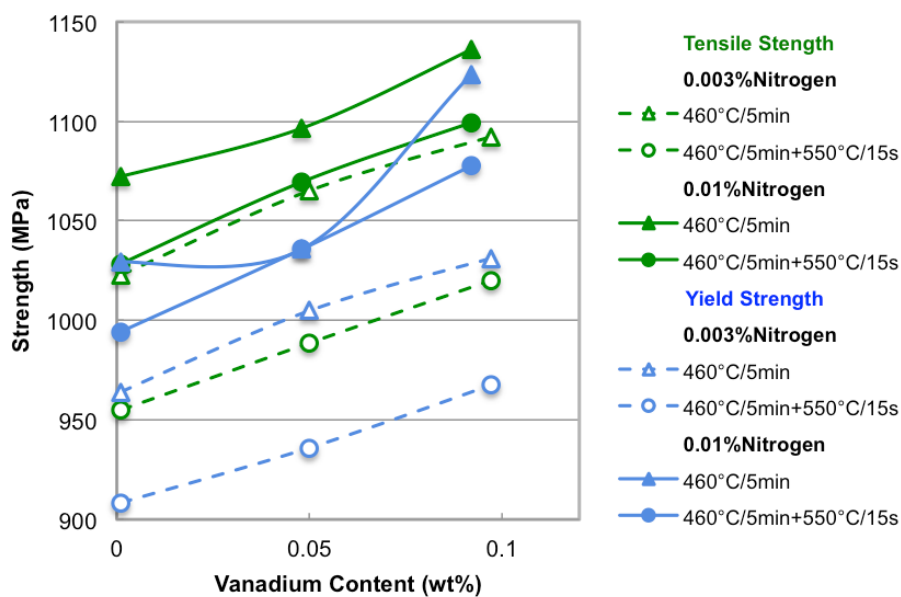


Fig. 6 Effect of V and N on strength of the martensitic steels after hot dip galvanising and galvannealing

The tensile tests showed that all the steels had very similar strength (UTS≈1550 MPa, YS (0.2% proof stress)≈1155 MPa) in the as-quenched condition. However, following the heat treatments simulating galvanising and galvannealing, the results clearly demonstrated that increasing the vanadium content raised the tensile strength and yield strength and so did the higher nitrogen level (figure 6). This indicates that vanadium, especially when in combination with nitrogen provides a possibility of retaining strength in martensitic steel after hot dip galvanising and galvannealing. For a steel containing 0.05%V + 0.012%N, the yield strength of ≥1000 MPa could be comfortably obtained after the simulated galvanising and galvannealing treatments. The ductilities were improved after the simulated galvanising and galvannealing compared to those relative to the as-quenched condition. In addition, there was small variation of the ductility values with the steel compositions except for the steel with the highest V and N levels, as shown in figure 7.

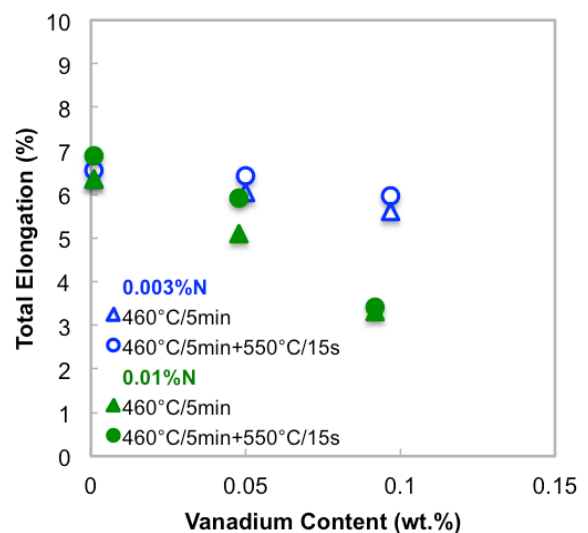


Fig. 7 Effect of V and N on ductility of the martensitic steels

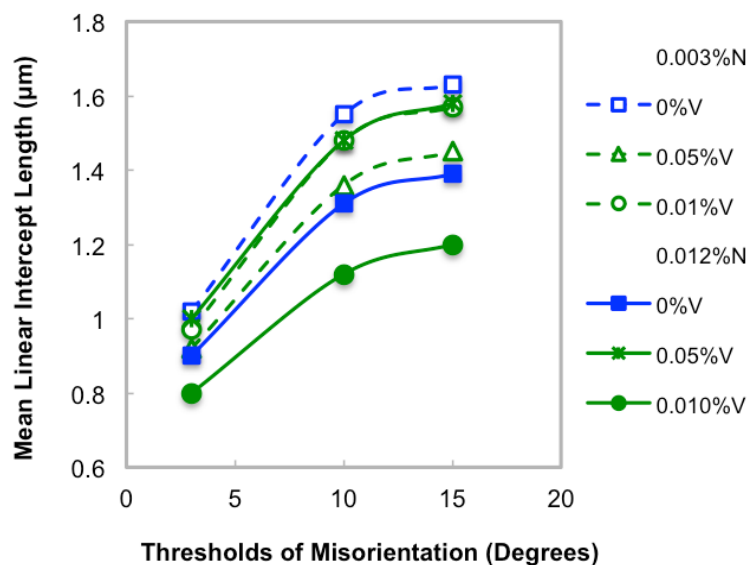


Fig. 8 Grain sizes (MLI) for the steels tempered at 460°C/ 5minutes

Microstructures of the steels were examined by scanning electron microscope (SEM) and Electron Backscatter Diffraction (EBSD) following the heat treatment simulating the galvanising. The effective ferrite grain size in the tempered martensite was defined in terms of different grain boundary misorientations from EBSD analysis and was measured as mean linear intercept lengths for all boundaries which had misorientations of $>3^\circ$, $>10^\circ$ and $>15^\circ$. Figure 8 shows that the steel containing 0%V and 0.003% N had the largest grain size and the steel containing the highest V and N had the smallest grain size for all of the three grain boundary misorientations. In addition, increasing nitrogen content resulted in finer grain sizes. The authors suggested that the influence of vanadium and nitrogen on grain refinement could contribute to the higher strength, and there is also a possibility that precipitation of V(C,N) may be occurring despite the shot annealing time and relatively low temperatures used for simulating the galvanising and galvannealing.

2015 Vanadium Award Shortlisted Papers

Effect of Nitrogen on the Microstructures and Mechanical Properties in Simulated CGHAZ of Vanadium Microalloyed Steel Varied with Different Heat Inputs, Zhongran Shi, Caifu Yang, Ruizhen Wang, Su Hang, Feng Chai, Juefei Chu, Qingfeng Wang, Materials Science and Engineering A, Vol. 649, 2016, pp. 270-281.

Effect of V and N on Microstructures and Properties of Grade G70 Tire Cord Steel during Cold Drawing, Hong Gyu LIU, Bao Gyi WAN, Xiao Gyu ZENG, Chong LIN, Hong Gjun WANG, Journal of Iron and Steel Research, International, Vol. 22, No. 2, 2015, pp. 171-178.

Heat Affected Zone Microstructures and Their Influence on Toughness in Two Microalloyed HSLA Steels, Hutchinson, Bevis, Jacek Komenda, Gregory S. Rohrer, and Hossein Beladi, Acta Materialia, Vol. 97, 2015, pp. 380-391.

Hot Deformation Behavior of Vanadium-microalloyed Medium-carbon Steel for Fracture Splitting Connecting Rod, Wei-jun HUI, Si-lian CHEN, Cheng-wei SHAO, Yong-jian ZHANG, Han DONG, Journal of Iron and Steel Research, International, Vol. 22, No. 7, 2015, pp. 615-621.

Microstructural Effects on High-cycle Fatigue Properties of Microalloyed Medium Carbon Steel 38MnVS, Weijun Hui, Yongjian Zhang, Chengwei Shao, Silian Chen, Xiaoli Zhao, Han Dong, Materials Science and Engineering A, Vol. 640, 2015, pp. 147-153.

Relationship Between Microstructure and Mechanical Properties in Nb–V microalloyed TRIP Steel, D. Krizan, K. Spiradek-Hahn and A. Pichler, Materials Science and Technology, Vol. 31, No. 6, 2015, pp. 661-668.

Stress–strain Behavior of Ferrite and Bainite with Nano-precipitation in Low Carbon Steels, Naoya Kamikawa, Kensuke Sato, Goro Miyamoto, Mitsuhiro Murayama, Nobuaki Sekido, Kaneaki Tsuzaki and Tadashi Furuhashi, Acta Materialia, Vol. 83, 2015, pp. 383-396.

Tensile Behavior of Ferrite-martensite Dual Phase Steels with Nano-precipitation of Vanadium Carbides, Naoya KAMIKAWA, Masahiro HIROHASHI, Yu SATO, Elango CHANDIRAN, Goro MIYAMOTO and Tadashi FURUHARA, ISIJ International, Vol. 55, No. 8, pp. 1781-1790.

Recent Vanadium Related Publications

- Determination of Processing Maps for the Warm Working of Vanadium Microalloyed Eutectoid Steels**, H. Rastegari, A. Kermanpur, A. Najafizadeh, M. C. Somani, D. A. Porter, E. Ghassemali and A. E. W. Jarfors, Materials Science and Engineering A, Vol. 658, 2016, pp. 167-175.
- Effect of Increased N Content on Microstructure and Tensile Properties of Low-C V-microalloyed Steels**, Shuming Zhang, Ke Liu, He Chen, Xiping Xiao, Qingfeng Wang and Fucheng Zhang, Materials Science and Engineering A, Vol. 651, 2016, pp. 951-960.
- Effect of Nb-Mo Additions on Precipitation Behaviour in V Microalloyed TRIP-assisted Steels**, E. Abbasi and W. M. Rainforth, Materials Science and Technology, Published online: 16 Feb 2016.
- Effect of Nitrogen Content on the Second Phase Particles in V-Ti Microalloyed Shipbuilding Steel During Weld Thermal Cycling**, Zhongran Shi, Ruizhen Wang, Hang Su, Feng Chai, Qingfeng Wang, Caifu Yang, Materials & Design, Vol. 96, 2016, pp. 241–250
- Effect of Nitrogen on The Microstructures and Mechanical Properties in Simulated CGHAZ of Vanadium Microalloyed Steel Varied With Different Heat Inputs**, Zhongran Shi, Caifu Yang, Ruizhen Wang, Hang Su, Feng Chai, Juefei Chu, Qingfeng Wang, Materials Science and Engineering: A, Vol. 649, No. 1, 2016, pp. 270–281.
- Effect of Vanadium Addition on the Strength of API X100 Linepipe Steel**, Nafisi, S., Amirkhiz, B. S., Fazeli, F., Arafin, M., Glodowski, R., & Collins, L, ISIJ International, Vol. 56, No. 1, 2016, pp. 154-160.
- Effects of Vanadium on the Continuous Cooling Transformation of 0.7%C Steel for Railway Wheels**, S. T. Fonseca, A. Sinatora, A. J. Ramirez, D. J. Minicucci, C. R. Afonso and P. R. Mei, Defect & Diffusion Forum, Vol. 367, 2016, pp. 60-67.
- Effect of Vanadium on the Mechanical and Service Properties of Weldable Reinforcement Steels in Strength Classes A500C and A600C**, D. V. Domov, I. I. Frantov, A. N. Seregin, A. N. Bortsov, A. A. Fofanov, O. O. Tsyba, N. V. Vlasjuk, I. N. Surikov, I. P. Savrasov and M. S. Vostrov, Metallurgist, Vol. 59, No. 9, 2016, pp. 1-7.
- Evolution of Bainitic Microstructure in Vanadium-bearing Microalloyed Steel with Two-step Cooling**, A. Bhattacharya and S. Sangal, Materials Science and Technology, Published online: 22 Jan 2016.
- Hot Deformation and Static Softening Behavior of Vanadium Microalloyed High Manganese Austenitic Steels**, L. Llanos, B. Pereda, B. Lopez and J.M. Rodriguez-Ibabe, Materials Science and Engineering A, Vol. 651, 2016, pp. 358-369.
- Hot Ductility of Medium Carbon Steel with Vanadium**, Chang-Hoon Lee, Jun-Young Park, JunHo Chung, Dae-Bum Park, Jin-Young Jang, Sungyul Huh, Sung Ju Kim, Jun-Yun Kang, Joonoh Moon and Tae-Ho Lee, Materials Science and Engineering A, Vol. 651, 2016, pp.192-197.
- Influence of Vanadium Microalloying on the Microstructure of Induction Hardened 1045 Steel Shafts**, Lee M. Rothleutner, 23rd IFHTSE Congress, 18-21 April 2016, Savannah, Georgia, USA.
- Microstructural Evolution, Coarsening Behavior of Vanadium Carbide and Mechanical Properties in the Simulated Heat-affected Zone of Modified Medium Manganese Steel**, Xinjie Di, Miao Li, Zhenwen Yang, Baosen Wang, and Xiaojiang Guo, Materials & Design, Vol. 96, 2016, pp. 232-240.
- Microstructural Evolution During Bainite Transformation in a Vanadium Microalloyed TRIP-assisted Steel**, E. Abbasi and W. M. Rainforth, Materials Science and Engineering A, Vol. 651, 2016, pp. 822-830.
- Precipitation Characteristics During Isothermal γ to α Transformation and Resultant Hardness in Low Carbon Vanadium–titanium Bearing Steel**, J., M. Y. Chen, Lv, S. Tang, Z. Y. Liu, and G. D. Wang, Materials Science and Technology, Vol. 32, 2016, pp. 1-7.
- Prevention of Hydrogen Embrittlement in Steels**, Harshad Kumar Dharamshi Hansraj BHADESHIA, ISIJ International, Vol. 56, No. 1, 2016, pp. 24–36.
- Processing Maps for the Analysis of Hot Workability of Microalloyed Steels 38MnSiVS5 and 0.39 C1. 47Mn**, Rudimylla da Silva Septimio, Sergio Tonini Button, and Chester John Van Tyne, Journal of Materials Science Vol. 51, 2016, pp. 2512-2528.
- Very High Cycle Fatigue Properties of Cr–Mo Low Alloy Steel Containing V-rich MC Type Carbides**, W. Hui, Y. Zhang, X. Zhao, C. Zhou, K. Wang, W. Sun and H. Dong, Materials Science and Engineering A, Vol. 651, 2016, pp. 311-320.

Calendar of Technical Conferences and Seminars

2016	Events
6-19 May 2016 Pittsburgh, USA	AISTech 2016 The Iron & Steel Technology Conference and Exposition
25-27 May Brno, Czech Republic	METAL 2016 25th Anniversary International Conference on Metallurgy and Materials
29 May - 3 June Graz, Austria	THEMEC 2016 International Conference on Processing & Manufacturing of Advanced Materials
June 6 - 9 AUSTRIA, Graz	10th International Rolling Conference (IRC) and 7th European Rolling Conference (ERC)
17-21 July Pittsburgh, Pennsylvania, USA	ReX&GG 2016 6th International Conference on Recrystallization and Grain Growth
1-5 August Kyoto, Japan	RICM9 9th Pacific Rim International Conference on Advanced Materials and Processing
11-15 September 2016 Quebec City, QC, Canada	COM 2016 Conference of Metallurgists 2016
26-28 October 2016 Milan, Italy	TMP2016 5th International Conference on ThermoMechanical Processing
23-27 Oct. 2016 Salt Lake City, USA	M&T2016 Materials Science & Technology (MS&T) 2016
16-18 Nov. 2016 Chengdu, China	The 1st International Conference on Automotive Steel (AutoSteel 2016)

2017	Events
08 - 11 May 2017 Tennessee, Nashville, USA	AISTech 2017 The Iron & Steel Technology Conference and Exposition

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