Advanced High Strength Sheet Steels

Nina Fonstein

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Physical Metallurgy, Design, Processing,
and Properties

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Foreword

A book coauthored by N.M. Fonstein and S.A. Golovanenko under the title “Dual-phase low-alloy steels” was published in 1986 in Russia. Deep and wide research conducted for various applications of dual-phase steels with ferrite–martensite structure, including intensive trials of cold-rolled sheet steels for cars and long products for fasteners, laid the foundation for this book. It reflected the results of numerous studies by graduate students and engineers of laboratory of formable steels, which was led by Dr. Fonstein, and the analysis of world literature, spanning research methods of structure investigation of multiphase steels, the relationship of parameters of the structure and mechanical properties, and the fundamentals of heat treatment and characteristics that are important for the application of these steels such as formability, weldability, fatigue, etc. It was the first and so far, it seems, the only monograph devoted to dual-phase steel. However, the extensive presented information, including industrial development, was limited to the strength levels between 500 and 700 MPa.

Later on, when Nina Fonstein and a couple of her former graduate students joined the research center of ArcelorMittal, where Nina for over 10 years led the development of steels for the automotive industry, they had to develop dual-phase steels of higher and higher strength, 780, 980, 1180 MPa, TRIP steels, new martensitic steels, complex phase steels, to explore ways of various structural approaches to meet the requirements for the third-generation steels.

This book is once again the world’s first attempt to outline the fundamental features of structure and mechanical properties of all modern Advanced High-Strength Steels families. It is important not only that, in contrast to numerous works of multiple conferences on the subject, this book provides a comparative analysis and synthesis of existing literature and author’s data, but also that results are summarized from the position of the researcher with the dual responsibilities for not only fundamental understanding of physical metallurgy but also for the industrial implementation of developed grades.

The volume and quality of the data interpreted in this book came about not only because of Nina’s individual ability, which itself is quite remarkable, but also due to

major contributions of the postgraduate students and young engineers of Research Center at ArcelorMittal whom Dr. N. Fonstein continues to lead. Information presented in this book is transcending geographical boundaries and fully capitalizing of the global nature of ArcelorMittal research organization with 12 centers around the world and close cooperation with Academia. It should be noted, however, that the major contribution came from North America and European Centers.

I am thoroughly convinced that the published book will be a useful reference and guiding tool for engineers engaged in the development, production, and use of AHSS, as well as students of Universities and graduate students involved in the creation of new automotive products.

VP, Head of Global R&D, ArcelorMittal, Europe

Greg Ludkovsky

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About the Author

Dr. Nina Fonstein is currently a scientific advisor of automotive product development group, Global R&D, ArcelorMittal, in East Chicago labs, USA, being for more than 10 years the manager of that group, leading investigations, development, and commercialization of various grades of AHSS. Before joining ArcelorMittal in 1999, she had been working in the I.P. Bardin Central Research Institute of Ferrous Metallurgy in Moscow, Russia, as a senior research associate and later as a head of the laboratory of formable steels working on dual-phase steels since 1979 and on TRIP steels since 1988. She graduated from the Moscow Institute of Steel and Alloys and holds Ph.D. in solid state physics from I.P. Bardin Central Research Institute of Ferrous Metallurgy (1968) and Dr. Science degree in physical metallurgy from Moscow Institute of Steel and Alloys (1986) as well as the title of Professor from the Supreme Attestation Commission of Russian Federation (1990). She is the author of the book “Dual-phase low alloyed steels” (in Russian) and more than 100 publications in English. She has supervised 16 PhD students in Russia and is supervising PhD students—employees of ArcelorMittal.

List of Abbreviations

AHSS	Advanced high strength steels
B	Bainite
Bcc	Body centered cubic lattice
Bct	Body centered tetragonal lattice
BH	Bake hardening
BIW	Body in white
CAL	Continuous annealing line
CCT	Continuous cooling transformation
CE	Carbon equivalent
CFB	Carbide free bainite
CGL	Continuous galvanizing line
CP	Complex phase steels
CR	Cold rolled
DP	Dual phase steels
EBSD	Electron back scattering diffraction
F	Ferrite
Fcc	Face centered cubic lattice
GJC	Gas jet cooling temperature
HE	Hole expansion
HER	Hole expanding ratio
HR	Hot rolled
HSLA	High strength low alloyed steels
IBT	Isothermal bainitic transformation
IQ	Image quality
LOM	Light optical microscopy
MP	Multi-phase steels
P	Pearlite
PAGS	Prior austenite grain size
PHS	Press hardening steels
PM	Partial martensitic steels (DP steels with %martensite ≥ 50)
Q&P	Quenching and partitioning

Q&T	Quenching and tempering
RA	Retained austenite
RA	Reduction of area
RD	Rolling direction
ReX	Recrystallization
RT	Room temperature
SEM	Scanning electron microscopy
SS	Stress–strain curve
TBF	Trip steels with bainitic ferrite
TD	Transverse direction
TE	Total elongation
TEM	Transmission electron microscopy
TRIP	Transformation induced plasticity
TS	Tensile strength
TTT	Time temperature transformation
UE	Uniform elongation
UFG	Ultra fine grains
ULC	Ultra low carbon
UTS	Ultimate tensile strength
WH	Work hardening
wt%	Weight percent
XRD	X ray diffraction
YPE	Yield point elongation
YS	Yield strength

List of Symbols

ΔG	Mechanical driving force
A_{c1}	Temperature at which austenite formation starts during heating
A_{c3}	Temperature at which austenite formation is completed during heating
A_{e1}	Equilibrium temperature for the lower boundary of the $\alpha + \gamma$ range
A_{e3}	Equilibrium temperature for the upper boundary of the $\alpha + \gamma$ range
A_{r1}	Temperature at which austenite disappears during cooling
A_{r3}	Temperature at which austenite starts to transform during cooling
B_S	Bainite start temperature
C_M	Martensite lattice parameter
C_{tot}	Total carbon content [wt%] in steel
C_α	Ferrite C content [wt%] in the final microstructure
C_γ	Austenite C content [wt%]
f_B	Bainitic ferrite fraction in the final microstructure
f_M	Martensite volume fraction
f_α	Ferrite fraction in the final microstructure
f_γ	Austenite volume fraction
M_d	Temperature above which austenite is stable and no deformation-induced transformation to martensite takes place
M_F	End of martensitic transformation
M_S	Martensite start temperature
M_S^σ	Temperature at which the mode of transformation of austenite to martensite changes from stress-assisted to strain-induced
n	Strain hardening coefficient
v	Velocity
V_M	Martensite volume fraction in percentage in the final microstructure
$V_{\gamma ret}$	Retained Austenite volume fraction in percentage in the final microstructure
YS	Yield stress
α	α -phase, ferrite
α'	Martensite
γ	Austenite

γ_{res}	Residual austenite in the process of transformation
ε	True strain
ρ	Dislocation density
σ	True stress