THE INFLUENCE OF HOT ROLLING AND HEAT TREATMENT PARAMETERS ON Q&P-STEEL MICROSTRUCTURE

A.A. NAUMOV, E.V. CHERNIKOV, A.I. SHAMSHURIN

St.Petersburg State Polytechnical University, St.Petersburg, Russisan Federation,
[a]a.a.naumov@gmail.com, [b]evgnchernikov@gmail.com, [c]sham_a@mail.ru

Abstract

A microstructure of 3-rd generation advanced high strength steel treated by Q&P (quenching and partitioning) process was obtained. Numerical simulation of hot rolling on 2000 continuous mill by means of HSMM software (Hot Strip Mill Model) was utilized. Developed by numerical simulation schedules were realized on Gleeble-3800 system using tension-compression technique. The maximum retained austenite volume fraction 12.22% located on ferrite-martensite-bainite boundaries was observed. Received after physical simulation samples were tested, maximum measuring tensile elongation 24.7% and tensile strength about 1270 MPa were received.

Keywords: Q&P process, Gleeble testing, physical simulation, numerical simulation, retained austenite

1. INTRODUCTION

Growing up rivalry and consumers requirements, strict laws governing compel automotive producers to guide their forces on quality and reliability increasing with additional safety, fuel economy and influence on environment. The Q&P-process was developed in Colorado School of Mines by J.G. Speer [1, 2]. Q&P-steels belong to third generation of advanced high strength steel (AHSS) and take intermediate place regarding to mechanical properties between 1-st and 2-nd generations. Ultimate strength for these steels should be at least more than 1000 MPa for a good ductility. Q&P-steel material structure consists of martnensitic matrix with retained austenite. Carbon retained austenite enrichment in final structure increases the strength and plastic properties by means of retained austenite transformation into martensite during a subsequent stamping. The heat treatment process is shown in **Fig. 1**. Metal is reheated up to austenite region than quenched to temperature QT (quench temperature) and held at PT (partition temperature), after that undergoes the final stage - quenching. Q&P-process heat treatment main parameters are quenching temperature, partitioning time and temperature.

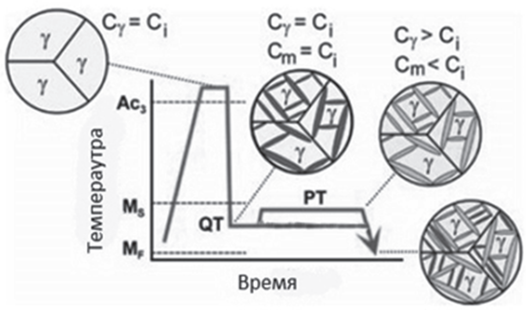


Fig. 1 Scheme of Q-P-process

Q&P-steels typical chemical composition consists of Mn about 1.8 % and Si about 1.4 % (wt pct). Si restrains the carbon precipitation providing austenite stability at a room temperature. Mn increases strength by means of solid solution strengthening.

Ingots were cut and subsequent hot rolled by 4 passes on laboratory mill 210 to 15 mm thickness for porosity elimination. Afterwards, plates were exposed to 2 hours annealing for austenite grain growth. The chemical composition of steel used in this study wt. % is shown in **Table 1**.

Table 1 Chemical composition of steel used in this study

C	Si	Mn	P	S	Cr	Ni	Cu	V	Nb	Mo
0.19	1.6	1.8	0.003	0.013	0.15	0.13	0.17	0.008	<0.01	0.02

2. NUMERICAL SIMULATION

CCT diagram was obtained by means of AusTran+ and AusEvol+ software [3] and it is shown in **Fig. 2**. Licensed Hot Strip Mill Model software for hot rolling numerical simulation was used [4]. After calculations in HSMM deformation schedules were chosen to achieve the final thickness less than 3 mm applicable for subsequent stamping (**Table 2**). Initial slab thickness was 150 mm.

It is necessary to have very slow cooling rates after rolling to obtain enough ferrite volume fractions. Deformation cycles should shift a ferrite region thus two schedules for hot rolling on 2000 mill were developed.

After reheat up to temperature 1200 °C and subsequent rolling the controlling heat treatment in spray cooling area was set as:

- Schedule #1: free cooling down to temperature achieved at mill (for 2.65 mm thickness strip it is 550 °C);
- Schedule #2: cooling down by first sprayer section to 662 °C, cooling rate CR = 80 °C/sec, subsequent free cooling to 540 °C.

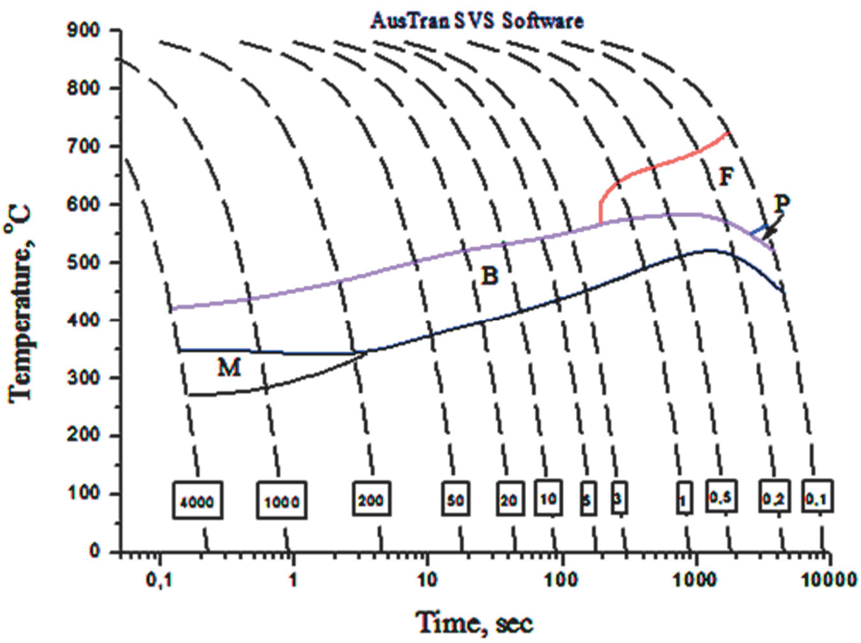


Fig. 2 Equilibrium CCT diagram

Table 2 Calculated deformation schedules

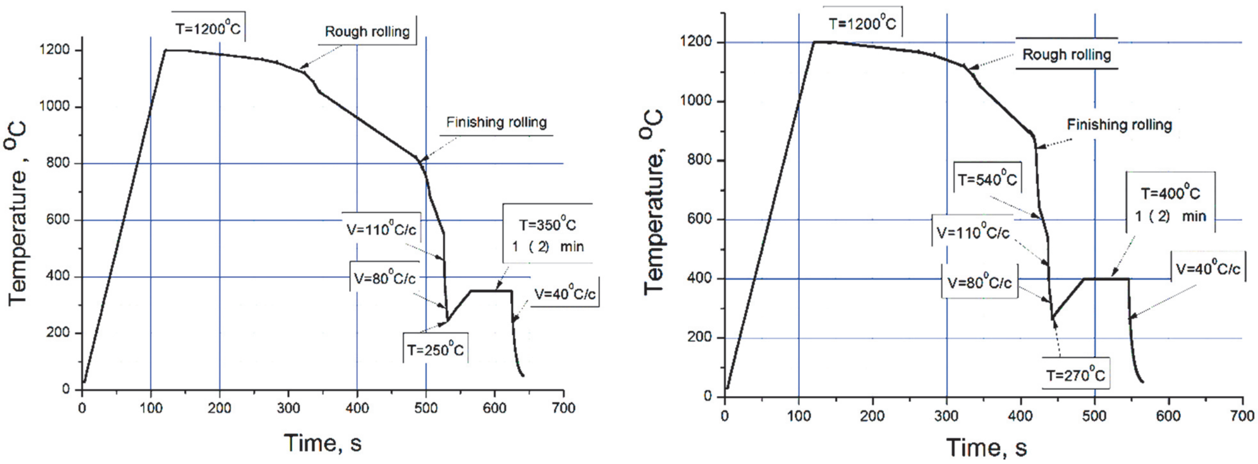
Schedule #1			
# pass	Thickness	Temperature	Reduction
	mm	°C	%
1	107.5	1168	29.55
2	58.3	1156	45.76
3	33.3	1119	42.88
4	20.5	1085	38.43
5	13.5	1053	34.14
6	10.4	821	22.96
7	7.8	800	25
8	5.7	780	2.92
9	4.3	762	24.56
10	3.4	737	20.93
11	2.85	714	16.17
12	2.65	685	7.01

Schedule #2			
# pass	Thickness	Temperature	Reduction
	mm	°C	%
1	107.5	1168	29.55
2	58.3	1156	45.76
3	33.3	1119	42.88
4	20.5	1085	38.43
5	13.5	1053	34.14
6	10.4	895	22.96
7	7.8	890	25
8	5.7	884	26.92
9	4.3	879	24.56
10	3.4	870	20.93
11	2.85	859	16.17
12	2.65	844	7.01

3. PHYSICAL SIMULATION

Samples geometry developed in previous work [5] were used for physical simulation via Gleeble-3800 by tension-compression technique. Quenched and partitioned temperature was chosen based on [2]. First experiment with achieving QT and PT was made with water quenching. This experiment shows that using of water quench leads to lack of process parameters precise control. Therefore air cooling was proposed to cool samples. Sample deformation zone was cooled down to required temperature with variable cooling rate (CR) from 110 °C/s to 80 °C/s in first quenching stage, was held at PT = 350 °C and 400 °C for each schedule, and was cooled down at finish quenching stage with CR = 40 °C/s. Partitioning time was 1 and 2 minutes for each deformation schedule.

The realized temperature schedules are shown in **Fig. 3**.



Schedule #1 Schedule #2

Fig. 3 Realized on Gleeble-3800 schedules

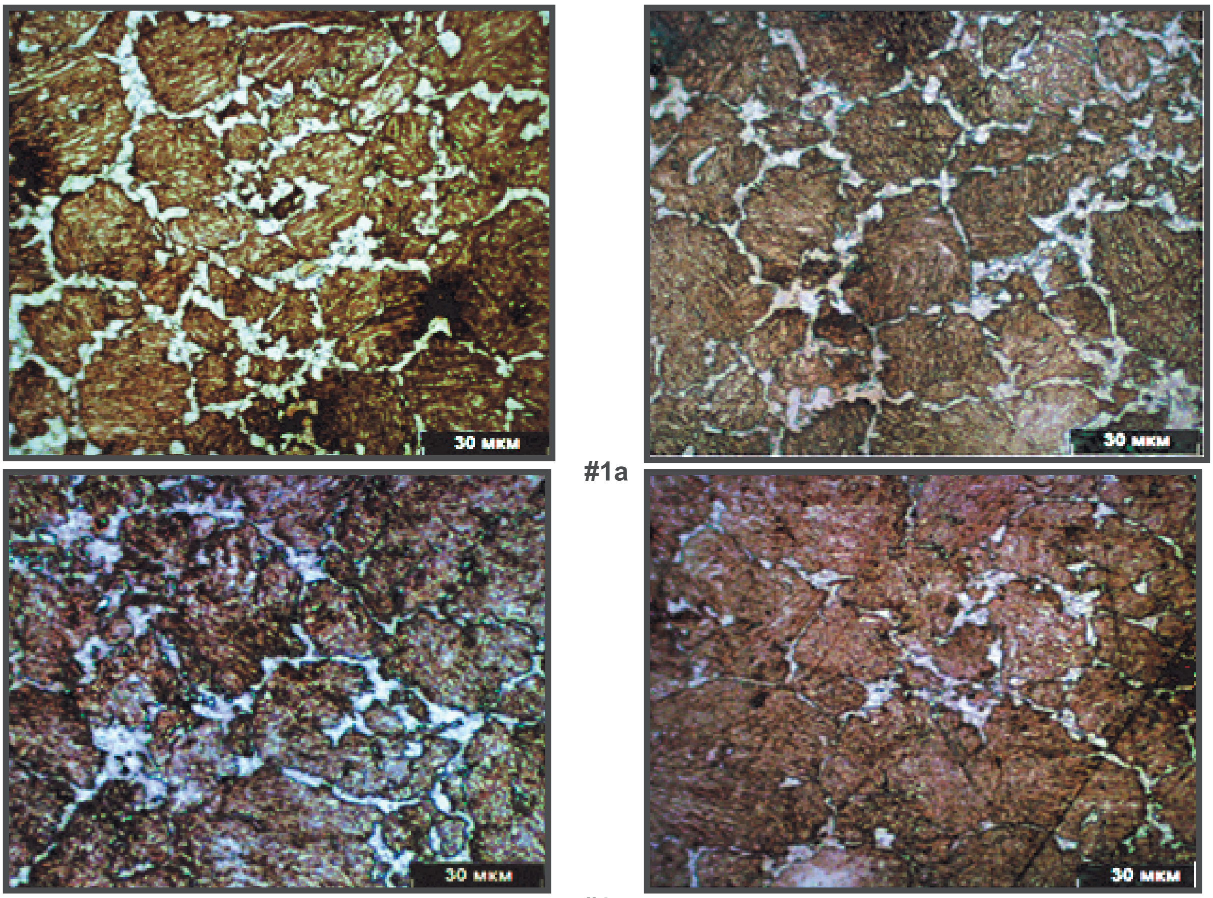
4. MICROSTRUCTURE DISCUSSION

Processed samples were cut for microstructure analysis. Retained austenite was defined with the help of XRD analysis. Retained austenite volume fraction is shown in **Table 3**.

Table 3 Retained austenite volume fraction depends on treating schedule

	PT	Partition time	Retained austenite volume fraction		PT	Partition time	Retained austenite volume fraction
#Shedule	°C	min	%	#Shedule	°C	min	%
1a	350	1	6.12	2a	350	1	9.40
1b	350	2	5.52	2b	350	2	7.90
1c	400	1	5.30	2c	400	1	7.48
1d	400	2	6.16	2d	400	2	12.22

Polished and etched with 2 % Nital micros were viewed by optical microscope Carl Zeiss. Received microstructures are shown in **Fig. 4**.



#1a #1b

#1c #1d

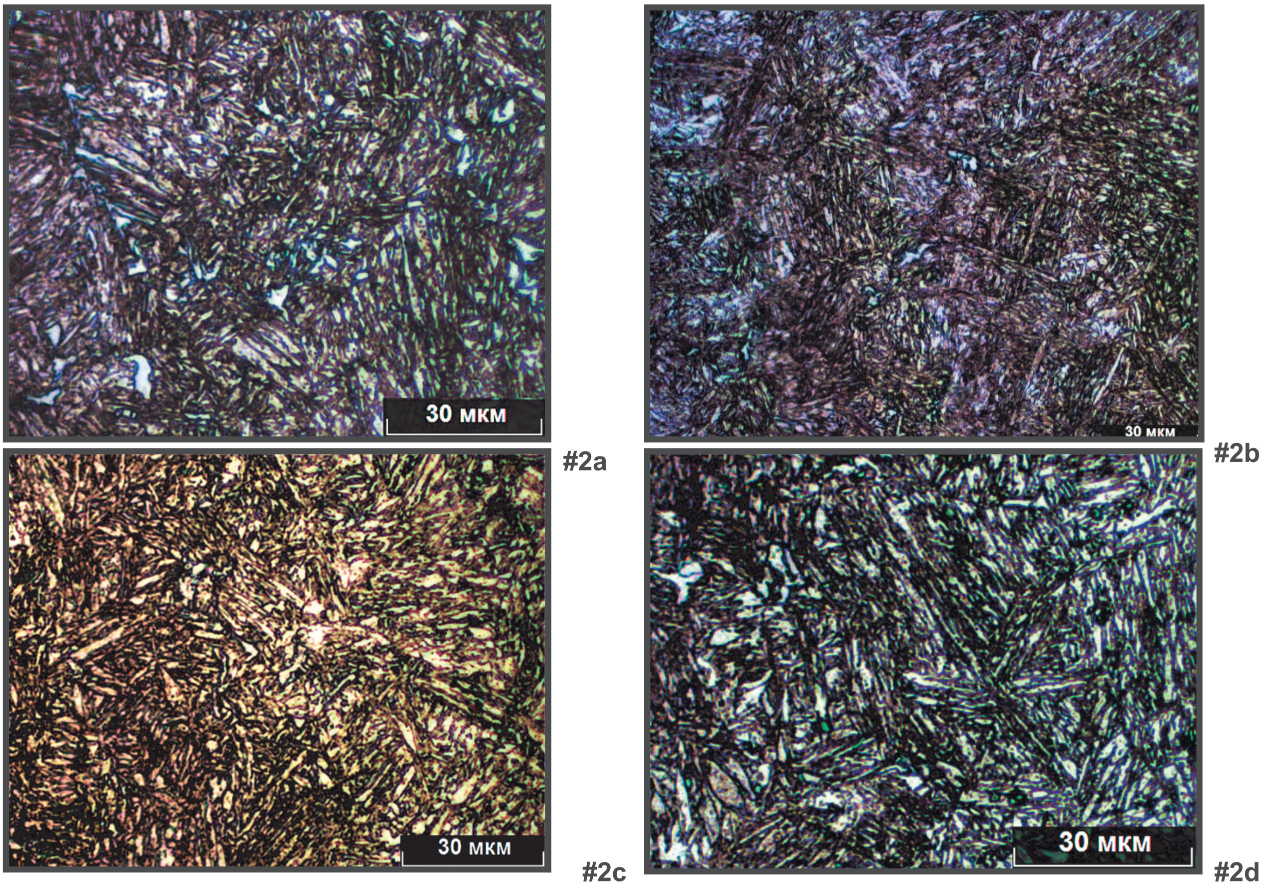


Fig. 4 Light optical micrographs after Gleeble-3800 tests

Samples treated according to schedule #1 have microstructure consists of about 15 % ferrite, formed on initial austenite grains boundaries, and martensite-bainite mixture. Samples treated according to schedules #2a-2d have martensinte-bainite mixture.

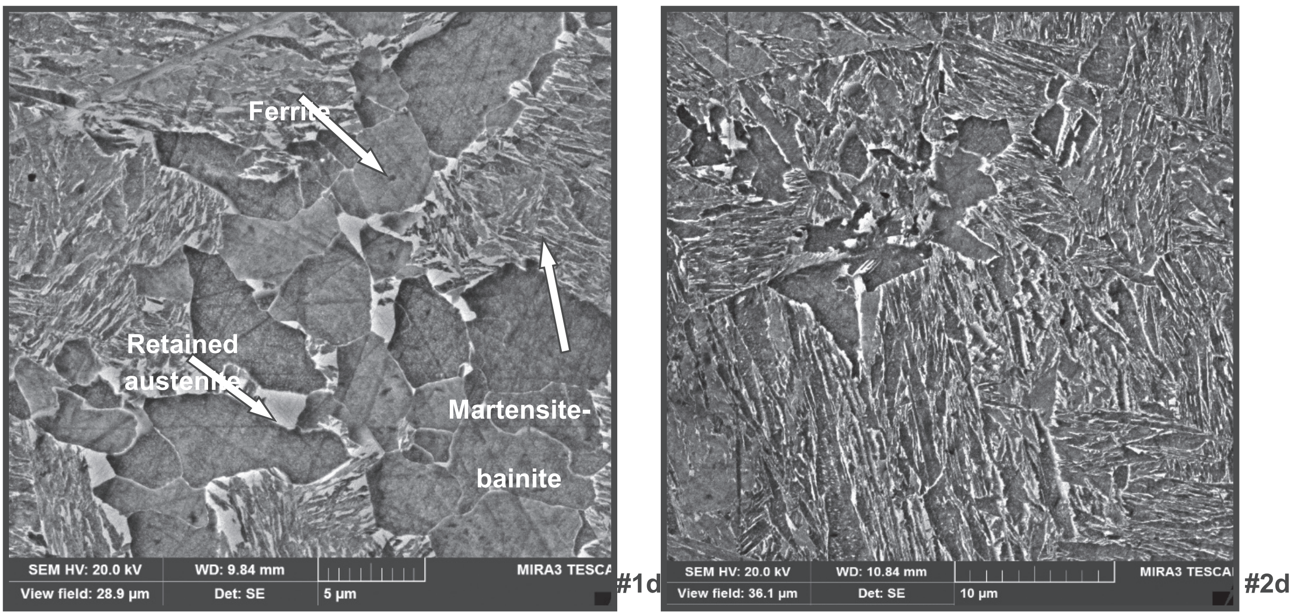


Fig. 5 SEM images of etched specimens after Gleeble-3800 tests

Samples with maximum retained austenite volume fraction, i.e. #1c, #2d, were also viewed by SEM (scanning electron microscope) Tescan Mira 3. SEM images are shown in **Fig. 5**. Retained austenite is observed in sample #1d located as a separated islands on martensite-bainite-ferrite boundaries compare to sample #2a-2d. Hence according to XRD analysis and SEM images it could be summarized that retained austenite in samples treated by schedule #2a-2d forms as fine fraction inside the bainite-martensite mixture.

After physical simulation samples with maximum retained austenite volume fraction were tested for mechanical properties by Zwick-Roell equipment. Strain-stress curves are shown in **Fig. 6**.

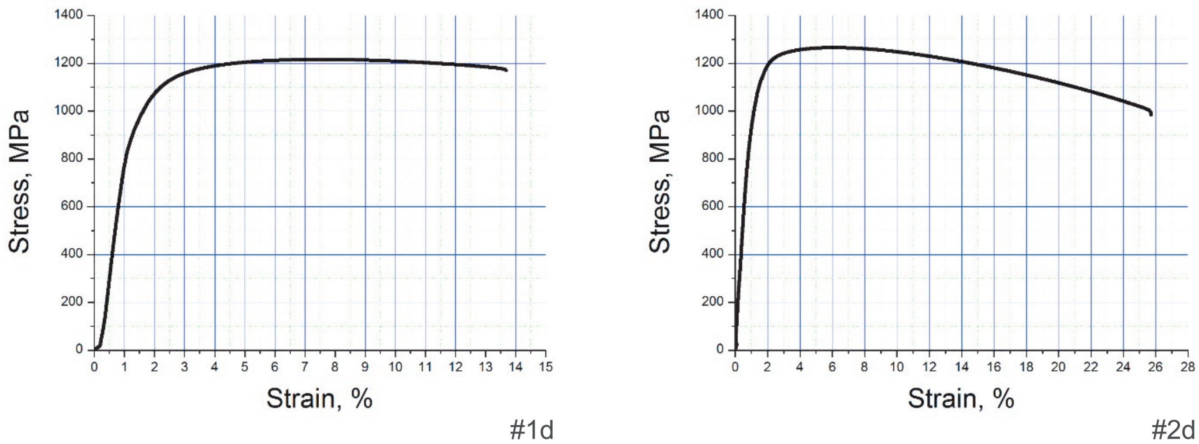


Fig. 6 Strain-Stress curves for samples #1d, #2d

Samples #1d and #2d have the same level of ultimate tensile strength 1219 MPa (#1d) compared to 1270 MPa (#2d). It should be noticed that elongation of sample #2d almost in two times greater then elongation of sample #1d: 12.6 % and 27.7 % respectively. It could be associated with more uniform retained austenite distribution in sample #2d.

5. SUMMARY

Q&P-microstructures by physical simulation on Gleeble-3800 using tension-compression technique were received. Retained austenite microstructure formation behavior was discussed. Mechanical properties of processed samples were obtained and associated with retained austenite microstructure formation behavior: more uniform distribution leads to significant elongation increasing.

REFERENCES

[1] J.G. SPEER, D.K MATLOCK, B.E. DECOOMAN, J.G. SCHROTH. Carbon partitioning into austenite after martensite transformation. *Acta Mater.,* 51, 9, 2003, 2611-2622.

[2] G.A. THOMAS, J.G. SPEER AND D.K. MATLOCK. Quenched and Partitioned Microstructures Produced via Gleeble Simulations of Hot-Strip Mill Cooling Practices. *Metall. Mater. Trans., A42*, 12, 2011, 3652-3659.

[3] S.F. SOKOLOV. Steel microstructure and strain resistance during hot plastic deformation research and simulation. *Ph.D. Thesis*. St-Petersburg 2013, 216 p.

[4] N.G. KOLBASNIKOV, A.I. RUDSKOY, A.A. NEMTINOV, V.A. LUNEV, D.S. SAVIN, A.A. NAUMOV. Adaptation of computer program HOT STRIP MILL MODEL (HSMM) in rolling manufacturing for structure and mechanical properties of rolling metal prediction. *Sci. Tech. J. SPbSPU #3*, St. Petersburg, 2007, 38-47.

[5] ANTON A. NAUMOV, YURIY A. BEZOBRAZOV, NICOLAY G. KOLBASNIKOV, EVGENII V. CHERNIKOV. Novel Physical Simulation Technique Development for Multistage Metal Plastic Deformation Processing. *Mater. Sci.Forum*, 762, 7, 2013, 62-69.