RESEARCHERID
THOMSON REUTERS

[Saravanan* 4(5): May, 2017] ISSN 2349-4506
Impact Factor: 2.785

Global Journal of Engineering Science and Research Management

INVESTIGATION ON STRUCTURAL STABILITY OF CMSX-4 AND RENE 77 MADE SHOWERHEAD COOLING DESIGNED GAS TURBINE GUIDE VANES

Dr. R. Saravanan*, M. Karuppasamy
* Principal & Professor (Mechanical Engineering), Elenki Institute of Engineering and Technology, Patelguda, Hyderabad -502319, TS, India
Associate Professor & Head of the Department of Mechanical Engineering, S.Veerasamy Chettiar College of Engineering and Technology, Puliangudi -627855, Tamil Nadu, India

DOI: 10.5281/zenodo.801263

KEYWORDS: CMSX-4, RENE-77, Guide vane, Gas turbione, Showerhead cooling, structureal Stability.

ABSTRACT
The efficiency and power output of a thermal device is directly proportional to its inlet temperature. Operating at elevated temperature affects the structural stability of its components under load. The gas turbine is a thermal device in which components like fixed and moving blades experience dynamic loading. Apart from elevated temperature, the design of cooling passages, materials which made up of also influential in their structural stability of the blades. In this research the guide vane (Fixed blade) with the showerhead type cooling of gas turbine is considered. The objective of the research is to investigate the influence of the materials like CMSX and RENE 77 in such applications. The design softwares like Pro –E and ANSYS R14 employed to design and FEM analysis respectively.

INTRODUCTION
The extensive applications can be found for gas turbines, some applications are: locomotive, power generation, marine propulsion, aircraft and other industrial prime movers. The higher operating temperature will lead to a higher work output and thermal efficiency in a thermal device like the gas turbine. Such higher operating temperature usually ranging from 1000 to 1500°C [1-3]. Some special applications like aerospace, the higher temperature raised to about 1,727°C [4-6], the compressor pressure ratio also high at about 50 [6]. In Such situations the components of the gas turbine often encounter the thermal damages as well as other damages like melting, corrosion, oxidation and erosion [7], the degradation of local or global structural strengths of blades, vanes and other components and it was estimated that half of the lifespan of the blades gets reduced due to small temperature difference by improper cooling [3,6,9]. The specific damages are: blade trailing-edge cracks [8], buckling and risk of blade failure [11], thermal-fatigue [8,10,11]. Hence the perfect cooling is insisted for avoiding them. Many studies were conducted on optimization of lip thickness to slot height ratio (t/H) in trailing edge cooling of blades and vanes [12 -17] in which Kacker et al. [12,13] considered lip thickness constant to estimate film cooling effectiveness, Taslim et al [14,15] varies slot geometries and blowing ratios. The t/H ratio from 0.5 to 1, decrease the overall film-cooling effectiveness by about 10% [14-16]. The decreases of t/H ratio, increases the film-cooling effectiveness [17-19]. [20] considered a a rectangular divergent channel which consists of serpentine shape with ribs, dimples/protrusions, guide vanes, and pin fins at the tip turning the region for his heat transfer studies. [21] studied the cooling performance at tip surfaces of guide vanes and blades at turning regions and insisted the importance of proper design to obtaining desired effects. [22] recommended installing guide vanes in the tip turning regions most suitable way to improve cooling of tip surfaces. [23] insisted that selection appropriate cooling technique with respect to configuration is must. The authors suggested two pass channels cooling at moving blades. This research work investigates with materials behaviors at elevated temperature for impingement cooling design on gas turbine fixed blade (guide vane). The Pro-E and ANSYS are employed to design and analysis. ANSYS is generally the preferred tool for analyzing structural stability. [24] used CATIA and ANSYS to design and investigate the structural stability of various components of Two-Wheeled Inverted Pendulum. In later [25] investigated the suitability of Kevlar29/epoxy composite for drive shaft. The influence of cooling design such as impingement and shower head type on gas turbine guide vanes which are made up of Nimonic 901[26], RENE 77 [27], CMSX 4 [28] were reported. This research investigates the best choice for this

specific type of fixed blades of the gas turbine. The showerhead type cooling designed guide vane is considered in this investigation. The sample guide vane of gas turbine is shown in Fig.1.

MATERIALS AND METHODS

CMSX 4

It is a single crystal super alloy and gives more stability at elevated temperature. Its significant properties at high temperatures includes impact strength, rupture strength, and fracture toughness. The blades which made up of CMSX-4, exhibited good performances as well as extended life span [29-32]. Hence its physical and mechanical properties were included in this analysis of structural stability of specified cooling designed guide vanes of gas turbine and reduced weight [30].

RENE 77

It is preferred for high temperature applications about 1000^{o}C like aviation, petroleum, gas turbine, space flight, ship, etc. because of its significant properties at elevated temperatures like excellent oxidation resistance, with stand at long term stress, creep properties, reliable in physical and chemical properties, good impact and toughness strengths etc. values of such unique properties were included in the analysis by using ANSYS.

Structural Analysis

The modelling works were carried out Pro/E and analysis works were done at ANSYS 14.5 work bench. The dimensional particulars of the guide vane with impingement cooling design is shown in Figure 2. The 3D meshed model is presented in Figure 3. The structural analysis like stress analysis, strain analysis and displacement analysis were considered. The comparative study of materials involved in manufacture them is focused on this research. The young's modulus 294000 Mpa, material density 0.00000774 kg/mm3, Poisson Ratio 0.3 were considered for CMSX 4 made blades. In case of RENE 77 made blades, the young's modulus 200000 MPa, Poisson Ratio 0.30, material density 0.000077 kg/mm3. In the meshed model made with 186 nodes, and pressure 0.188 N.mm2. The displacement analysis carried at ANSYS 14.5 work bench. The displacement with respect to turbine load was observed and shown them for CMSX 4 made blades in Figure 4 and for RENE 77 made blades in Figure 5. The maximum displacements were observed on the concave side of cooling passage nearby its sharp turning. The stress analysis for the above said blades (Figure 6 for CMSX 4 made blades and Figure 7 for RENE 77 made blades.

Figure 1 Fixed blade (Guide vane)

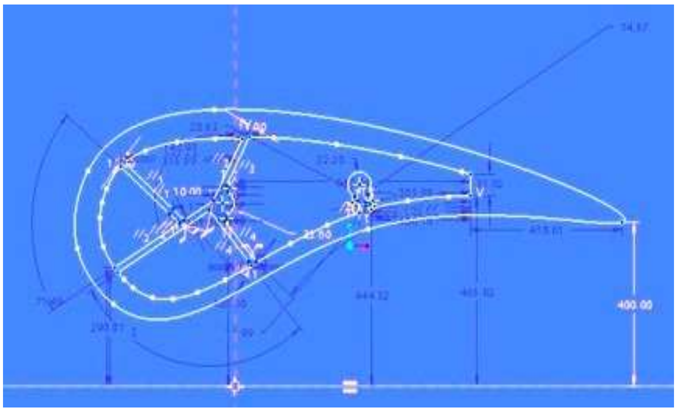

Figure 2 2D Model of Guide vane with Showerhead cooling

ISSN 2349-4506
Impact Factor: 2.785

Global Journal of Engineering Science and Research Management

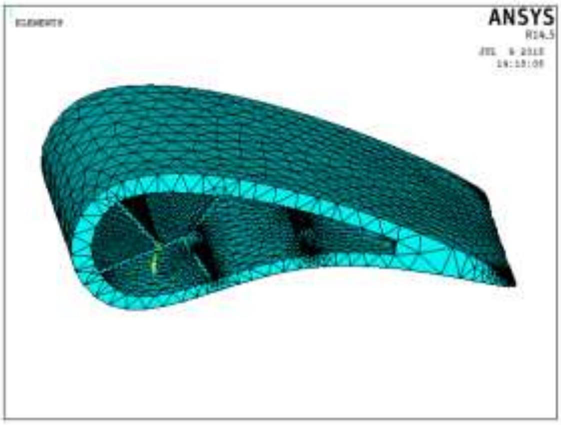

Figure 3 Meshed model of Guide vane

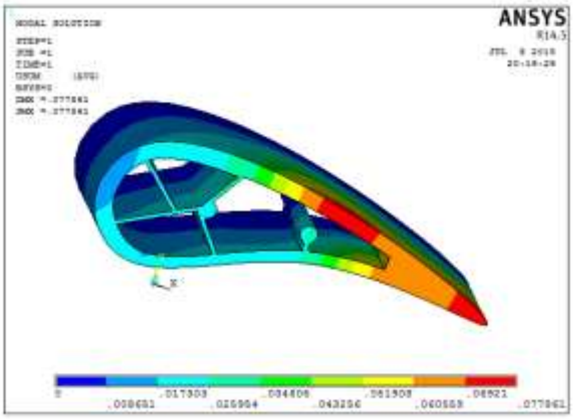

Figure 4. Displacement analysis for CMSX-4 blade

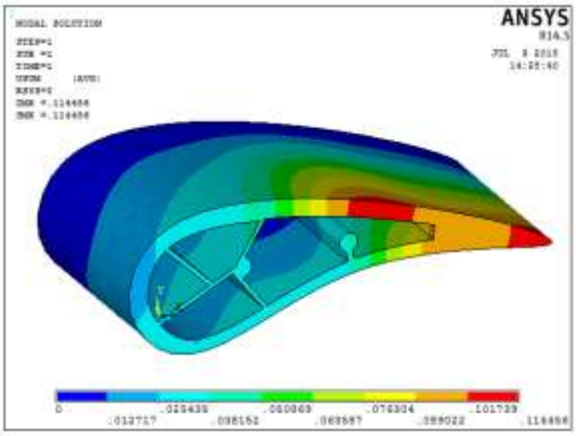

Figure 5. The displacement analysis for RENE-77 blade

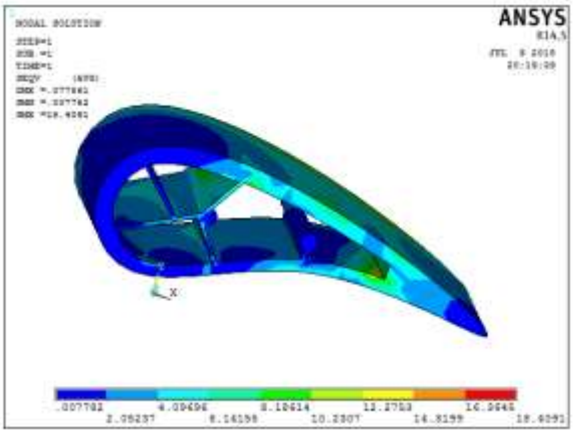

Figure 6. The stress analysis for CMSX 4 blade

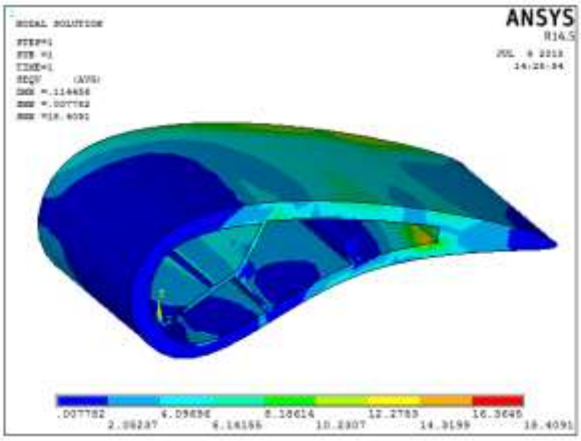

Figure 7. The stress analysis for RENE-77 blade

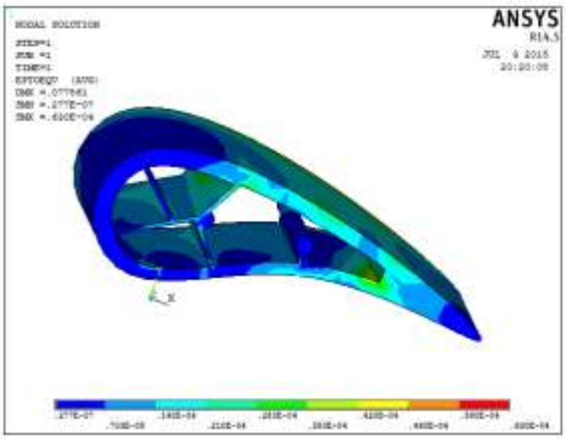

Figure 8. The strain analysis for CMSX-4 blades

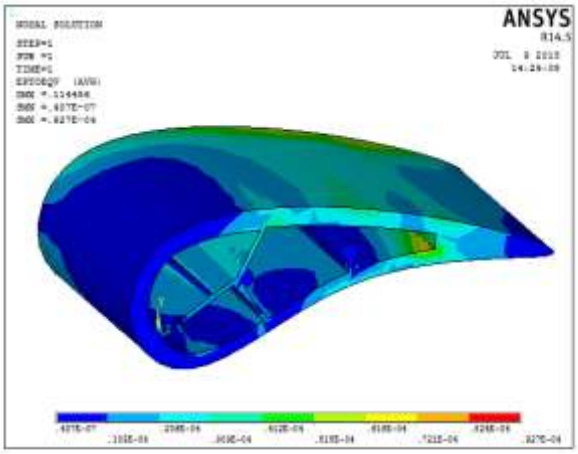

Figure 9. The strain analysis for RENE 77 made blades

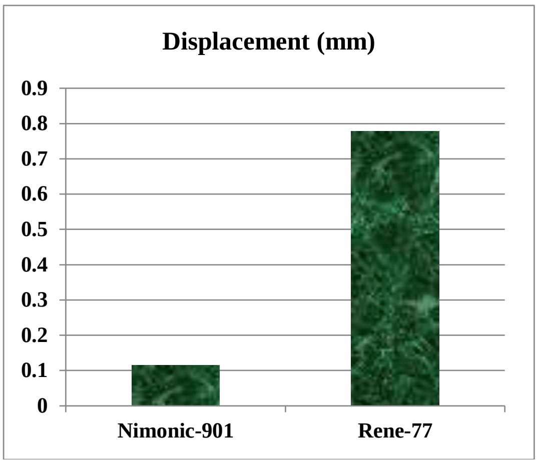

Figure10 Results of Displacement analysis

Table 1. Results of the Structural Analysis

Guide vanes made up of	Displacement (mm)	Stress (N/mm2)	Strain
CMSX-4	0.77861	18.4091	6.30E-05
RENE-77	0.11446	18.4091	9.27E-05

RESULTS AND DISCUSSION

The structural stability of showerhead cooling designed guide vanes of gas turbine was investigated with two different materials such as CMSX 4 and RENE 77. The displacement analysis, stress analysis and the strain analysis were conducted above said materials separately. The results of such analysis were consolidated in the Table 1. The results were compared graphically. The figure 10 is for displacement analysis, the Figure 11 is for the stress analysis and the Figure 12 for strain analysis. According to the outcomes of structural analysis, both materials are structurally stable for the designed profile and cooling design. The RENE 77 made fixed blades are a little more flexible than the CMSX 4 made fixed blades. The more displacements experienced in both concave and convex sides of cooling design towards the tip side. The more stress and strain in found at the sharp turning of cooling design at narrow side. The sharp turning may be avoided for preventing stress concentration and improve the life of the blade.

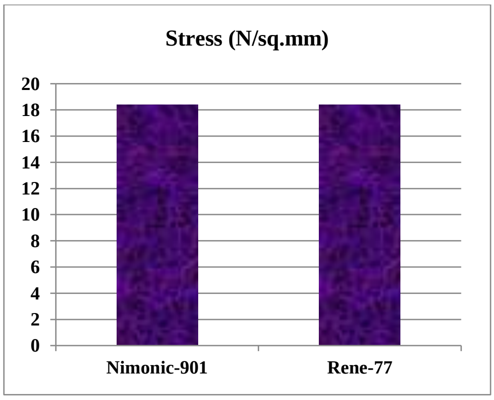

Figure 11 Results of stress analysis

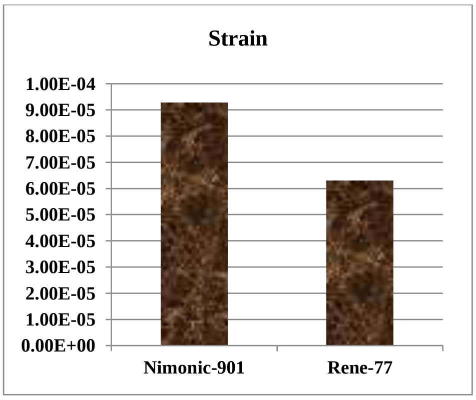

Figure 12 Results of strain analysis

CONCLUSION

The investigation by using prototype is very costly. The information which submit to make prototype must be more reliable. The design softwares are helping to evaluate the alternatives and suggest the most reliable data to meet such requirements. This research investigated the suitability of material to manufacture the gas turbine guide vanes with showerhead type cooling arrangement. The CMSX 4 and RENE 77 are considered for analysis and the results are discussed. The RENE 77 made guide vanes are little more flexible than CMSX 4 made guide vanes and provides equivalent stress bearing capacity. It was suggested that to strengthen the high stress formed portions of the guide vane. The sharp turning especially near the tip of down side of cooling design suffered by more stress. The sharp corners may be avoided in such places.

ACKNOWLEDGEMENTS

The authors acknowledge, the Chairman, Mr.E.Sadasiva Reddy, the Secretary, Mr.E.Dayakar Reddy, The Director Dr.M.Sambasiva Reddy and The Advisor, Dr.G.Ravender Reddy of Ellenki Group of Institutions for their continuous support and encouragement for our research.

REFERENCES

1. J. C. Han and S. Ekkad, “Recent Studies in Turbine Blade Film Cooling”, J. Rotating Machinery, 7(1): 21–40, 2001.
2. J. C. Han, “Recent Studies in Turbine Blade Cooling”, J. Rotating Machinery, vol. 10, no. 6, p. 443–457, 2004.
3. B. Facchini, L.Innocenti, L.Tarchi, “Pedestal and Endwall Contribution in Heat Transfer in Thin Wedge Shaped Trailing Edge”,. ASME. Turbo Expo: Power for Land, Sea, and Air, Volume 3: 101-111, 2004.
4. P. Martin, A. Schulz S.Wittig , “Experimental and Numerical Investigation of Trailing Edge Film Cooling by Circular Coolant Wall Jets Ejected From a Slot With Internal Rib Arrays.” ASME. Turbo Expo: Power for Land, Sea, and Air, Volume 5: Parts A and B :71-79, 2003.
5. P. Martini and A. Schulz, “Experimental and Numerical Investigation of Trailing Edge Film Cooling by Circular Wall Jets Ejected from a Slot with Internal Rib Arrays”, J. Turbomachinery. 126(2): 229– 236, 2004.
6. B.Sunden, G.Xie, “Gas turbine blade tip heat transfer and cooling: a literature survey. Heat Transf Enginering; 31: 527-54, 2010.
7. T. Horbach, A. Schulz and H. -J. Bauer, “Trailing Edge Film Cooling of Gas Turbine Airfoils – External Cooling Performance of Various Internal Pin Fin Configurations,” J. Turbomachinery, 133 94): 041006-1 – 041006-9, 2011.
8. Z. Yang and H. Hu, “An Experimental Investigation on the Trailing-edge Cooling of Turbine Blades,” J. Propulsion and Power Research, 1(1): 36–47, 2012.
9. B.Facchini, F.Simonetti, L.Tarchi, “Experimental Investigation of Turning Flow Effects on Innovative Trailing Edge Cooling Configurations With Enlarged Pedestals and Square or Semicircular Ribs”, ASME. Turbo Expo: Power for Land, Sea, and Air, Heat Transfer, Parts A and B:795-806, 2009.
10. J. Choi, S. Mhetras, J. -C. Han, S. Lau and R. Rudolph, “Film Cooling and Heat Transfer on Two Cutback Trailing Edge Model with Internal Performance Blockages”, J. Heat Transfer, 130(1): 012201-012213, 2008.
11. L. Brundage, M. W. Plesniak, P. B. Lawless and S. Ramadhyani, “Experimental Investigation of Airfoil Trailing Edge Heat Transfer and Aerodynamic Losses”, J. Experimental Thermal and Fluid Science, 31(3): 249–260, 2007.
12. S. C. Kacker and J. Whitelaw, “The Effect of Slot Height and Slot-Turbulence Intensity on the Effectiveness of the Uniform Density, Two Dimensional Wall Jet”. J. Heat Transfer, 90(4): 469–475, 1968.
13. S. C. Kacker and J. H. Whitelaw, “An Experimental Investigation of Slot Lip Thickness on Impervious Wall Effectiveness of the Uniform Density, Two-Dimensional Wall Jet”, J. Heat and Mass Transfer, 12(9): 1196–1201,1969.
14. N. E. Taslim, S. D. Spring and B. P. Mehlmann, (1990) “An Experimental Investigation of Film Cooling Effectiveness for Slot Various Exit Geometries”, Journal of Thermophysics and Heat Transfer, 6(2): 302-307.

15. N. E. Taslim, S. D. Spring and B. P. Mehlmann, (1992), "Experimental Investigation of Film Cooling Effectiveness for Slot of Various Exit Geometries", J. Thermophysics and Heat Transfer, 6(2): 302–307.
16. F. J. Cunha and M. K. Chyu, (2006), "Trailing-Edge Cooling for Gas Turbines", J. Propulsion and Power, 22 (2): 286–300.
17. R. J. Goldstein, (1971), "Film Cooling", J. Advance Heat Transfer, 7: 321–379.
18. S. Sivasegaram and J. Whitelaw, (1969), "Film Cooling Slots: The Importance of Lip Thickness and Injection Angle", J. Mechanical Engineering Science, 11(1): 22–27.
19. W. Burns and J. Stollery, "The Influence of Foreign Gas Injection and Slot Geometry on Film Cooling Effectiveness", J. Heat and Mass Transfer, 12,(8): 935–951,1969.
20. MS Lee, SS.Jeong, SW.Ahn, JC.Han, "Effects of angled ribs on turbulent heat transfer and friction factors in a rectangular divergent channel", Int J Therm Sci.84: 1-8, 2014.
21. Xie Gongnan, Zhang Weihong, Sund_en Bengt, "Computational analysis of the influences of guide ribs/vanes on enhanced heat transfer of a turbine blade tip-wall", Int J Therm Sci. 51: 184-194, 2012.
22. Lei Jiang, Li SJ, Han JC, Zhang L, Moon HK, "Effect of a turning vane on heat transfer in rotating multipass rectangular smooth channel", J Thermophys Heat Transf. 28(3): 417-427, 2014.
23. Wang Chenglong, Wang Lei, Sund_en Bengt, "Heat transfer and pressure drop in a smooth and ribbed turn region of a two-pass channel", Appl Therm Eng. 85: 225-233, 2015.
24. R. Saravanan, R. Pugazhenthi, P. Vivek and M. Santhanam, "Design and Simulation of a Two-Wheeled Inverted Pendulum - a Balanced, Easy Moving Vehicle for the Material Handling", American-Eurasian Journal of Scientific Research. 11(3): 189-198, 2016.
25. R. Saravanan, P Vivek, T Vinod Kumar, "Is Kevlar29/Epoxy Composite an Alternate for Drive Shaft?", Journal of Advances in Mechanical Engineering and Science, 2(3): 1-13, 2016.
26. Dr.R.Saravanan and G.Vinoth Reddy, "Structural Investigation on Nemonic-901 Made Gas Turbine Guide Vanes" Global Journal of Engineering Science and Research Management, 4(4), pp-89-94, 2017.
27. Dr.R.Saravanan and G.Vinoth Reddy, "Structural Investigation on Cooling Design influences in Rene-77 made Gas Turbine Guide Vanes " International Journal of Advanced Scientific Technologies, Engineering and Management Sciences, 3(5), pp.7-11, 2017.
28. Dr.R.Saravanan and G.Vinoth Reddy, "Investigation On Influence of Cooling Design In Structural Stability Of CMSX-4 Made Gas Turbine Guide Vanes" International Journal of Science and Research, 6(4), pp. 2522-2526, 2017.
29. J.Lapin, T.Pelachová, M.Gebura, "The effect of creep exposure on microstructure stability and tensile properties of single crystal nickel based superalloy CMSX-4" Kovove Materials, 50(6), pp.379-386, 2012.
30. A.Ma, D. Dye, R.C. Reed, "A model for the creep deformation 150ehavior of single-crystal superalloy CMSX-4", Acta Mater., 56 (8), pp.1657-1670, 2008.
31. J.Lapin, M.Gebura, T.Pelachová, M.Nazmy, "Coarsening kinetics of cuboidal gamma prime precipitates in single crystal nickel base superalloy CMSX-4", Kovove Materials, 46(6), pp.313-322, 2008.
32. Juraj Lapin , Tatiana Pelachová , Oto Bajana, "The Effect of Microstructure on Mechanical Properties of Single Crystal CMSX-4 Superalloy, Proceedings of Metal 2013, 15–17, 5, Brno, Czech Republic, EU. 2013.