Dynamic Systems Inc.

The Gleeble® NEWSLETTER

Summer 1994

Bulletin Board

Welcome to the Summer 1994 edition of the Gleeble newsletter. You may notice that this edition has more than the usual number of recent Gleeble papers listed. Quite honestly, there are so many new publications involving studies using Gleeble systems that we are falling behind on listing the abstracts. So here is our attempt to "catch up" a bit. In addition, we have a complete and up-to-date listing of more than 300 of the latest papers in our Bibliography. If you would like a copy of the Bibliography, please call or fax us directly, and we would be glad to send it to you.

Recently, we received several inquiries concerning the methods and feasibility of studying aluminum in the solid-liquid state using very small compressive or tensile stresses. The Gleeble, with its directional solidification capability, is a useful tool for this type of work. We have done some aluminum melting at DSI, and we are interested in hearing from other researchers who are working in this area. If this is of interest to you, and you wish to discuss the topic further, please contact Dr. Hugo Ferguson at DSI.

It's Your Turn. This column is intended to be a forum for Gleeble System users throughout the world. Information, replies, comments, or correspondence may be addressed to David Ferguson at Dynamic Systems, Inc., or faxed to us at 518-283-3160.

Gleeble Application Profiles:

The Gleeble at the University of Oulu, Finland

The production of thermomechanically processed, high-strength, low-alloy steel plates commenced in Finland in 1991 after the installation of the accelerated cooling facility at Rautaruukki Oy hot rolling mill at Raahe. Plates with the yield strength up to 500 MPa are being produced by accelerated cooling for ultimate application in ice-breakers.

To aid research and development work related to these steels, the first Gleeble in Finland was purchased and installed at the University of Oulu, Materials Engineering Laboratory in April, 1991. This new machine allowed us to investigate new areas in metallurgy, and we eagerly began studies on the physical simulation of hot working. The work was financially supported by the Finnish steel companies, Rautaruukki Oy, Outokumpu Polarit Oy and Imatra Steel Oy Ab, as well as the Technology Development Centre (TEKES). The Academy of Finland, The Foundation of Outokumpu Oy and University of Oulu have also funded this research. Furthermore, the Gleeble offered a new technique for research in welding metallurgy, which had already been studied for a number of years at the laboratory.

During the past three years, the Gleeble 1500 has been utilized in several projects, supervised by Professor Pentti Karjalainen, in close cooperation with the steel industry. These include:

- the effect of chemical composition on transformation of austenite and mechanical properties of TMCP steel plates
- austenite transformation in hot rolled steel strip during accelerated cooling
- the behaviour of Ti in rough rolling of high strength sheets

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The Gleeble staff at the University of Oulu, Materials Engineering Laboratory, includes (left to right) Ulla Orava, Petteri Steen, operator Martti Korhonen, professor Pentti Karjalainen, and visiting professor Zuze Xu from the Central Iron and Steel Research Institute, Beijing, P.R. China.

Recent Gleeble Papers

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The Development of a Thermomechanical Weld HAZ Simulation Test for the Evaluation of Stress-Relief Cracking Susceptibility

by J.P. Balaguer and E.F. Nippes

The stress-relief cracking susceptibility of an age-hardening HSLA steel and the effects of mechanical constraint in the weld HAZ, were investigated. Stress-relief cracking tests were performed on simulated weld heat-affected zones (HAZ) of HY-80, a quench-and-tempered steel, and HSLA-100, an experimental age-hardening copper-containing steel, at temperatures of 575 and 625°C (1067 and 1157°F) and stress levels of 274 to 550 MPa (40 to 80 ksi). Measurements of flow stress in the coarse-grained HAZ of HSLA-100 indicated that a substantial increase in flow stress occurs during the transformation of unstable austenite to lower-temperature microconstituents. A reasonable fraction (~30%) of the room-temperature yield strength is attained only after approximately 50% of the microstructural transformation is complete. Based on these data, a more realistic thermomechanical (vs. thermal only) simulation test was developed to model the effect of residual stresses and thermal transients on the stress-relief cracking susceptibility of HSLA steels. The imposition of mechanical constraint on the cooling portion of the weld thermal cycle resulted in a slight increase in HAZ hardness and stress-relief cracking susceptibility of the HSLA steel. Failure of the HSLA steel occurred by a low-ductility intergranular mode of fracture.

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Weld Fusion Zone Simulation in Aluminum Alloy 2090

by C.C. Chen and W.A. Baeslack, III

The Gleeble 1500 system has been utilized to generate simulated weld fusion zones in aluminum-lithium alloy 2090. Using both program-controlled and free cooling, cooling rates during solidification ranging from 10 to 165°C/s were achieved. The relationship between secondary dendrite arm spacing and cooling rate was determined to be: SDAS = 20.8CR – 0.25. Hot ductility testing on cooling from peak temperatures above the liquidus was also performed. Fractographic analysis of the hot ductility test specimens showed the extent of solid-solid dendrite bridging during solidification to increase with decreased temperatures in the brittle temperature range.

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Ferrite Grain Coarsening in Aluminum Killed Steels During Simulated Hot Strip Rolling Practice

by H. Kobayashi

A simulation experiment employing a Gleeble 1500 unit has been conducted to investigate the occurrence of ferrite grain coarsening encountered in aluminum killed hot-rolled strip. Hot-rolling practices were reproduced on the equipment using 70% compression strain at various levels of temperature, followed by annealing in a furnace to simulate the slow cooling in coiling practice. The austenite to ferrite transformation temperatures of various steels with the hot-deformation have been determined as a function of their carbon equivalent. The transformation temperatures were verified to establish the minimum finishing temperature required to prevent coarse grains in hot-rolled strips, as a result of their microstructural analysis. It was recognized, however, that in some cases these temperatures were too high to be achieved in actual hot-rolling practice. The experiment demonstrated that the grain coarsening takes place during self-annealing after the coiling operation, instead of during the hot-rolling operation. Hot-rolling with a low finishing temperature will produce a high potential to cause coarse grains. The coarse grains in question were categorized as the secondary recrystallization of steel where only a few grains preferentially grow at the expense of a large number of small grains during the annealing. The size of small grains decreased with decreasing hot-deformation temperature, resulting in the great driving force for the growth of coarse grains. Therefore, the fraction of coarse grains increased with decreasing hot-deformation temperature. The growth of coarse grains was significantly reduced with decreasing annealing temperature, resulting in the practical elimination of coarse grains in the steel. As a result, it is recognized that the coarse grains were prevented by the proper combination of hot-deformation and annealing temperature. A diagram has been developed for various levels of carbon equivalent steels from this simulation experiment to indicate the critical conditions in terms of finishing and coiling temperature which prevent the occurrence of coarse grains. The diagram was examined using the microstructures obtained from actual hot-rolled strip. It is concluded that the coarse grains will be prevented by controlling the finishing and the coiling temperature based on the individual carbon equivalent of the steel.

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Research on the Microfusion Mechanism and its Effects on Welding the Fused Bond Zone of Medium-Carbon Low-Alloy Steel by Using a Gleeble 1500

by J. Niu, Z. Zhang, W. Li, F. Zhao, and J. Zhai

Using the Gleeble 1500, research on the microfusion mechanism and its effects on weld fusion bond zone of medium-carbon low-alloy steel has been carried out. The result shows that to simulate different thermal cycles and to enlarge the bond region of the weld heated-affected zone (HAZ) by using the Gleeble 1500 are convenient methods to study thermal plasticity and its relationship to toughness and cold cracking in the HAZ. The microfusion region of the HAZ was caused by low-melting point phase non-metallic inclusions and carbides formed by elements such as P, S, Si, Cr and Mo. The microfusion reduces the toughness of the HAZ greatly and finally leads to cold cracking.

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Structure Inheritance in HAZ of Multilayer Welding and its Effect on HAZ Properties

by Z. Li, Z. Zhang, J. Liu, and M. Xie

By means of the Gleeble test technique, studies have been carried out on structural inheritance in the HAZ of a multilayer welding of low alloy high strength steel, 12Ni3CrMoV. and its effect on the properties of the HAZ. The results show that there is evidence of structural inheritance in the HAZ, which is characterized by narrow strip-shaped grain boundaries and inherited coarse grains. Because of the influence of intragranular phase transformation, a recrystallizing process occurs in austenite grains as well as in the small grains at the boundaries when the temperature is high enough. It has been found that the inherited structure greatly decreases the toughness of the HAZ. This is due to the restoration of coarse grains, however there is no boundary weakening. In addition, the authors investigated the mechanism and regularity of the inherited structure in the HAZ of multilayer welding, and considering the mechanism of phase transformation, suggestions have been put forward to restrain the inheritance, and hence improve the properties of the HAZ.

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Microstructure and Mechanical Properties of Carbon/Carbon Composites at High Temperature

by Zhao Feng, Wang Diamliang, J.C. Han, and S.Y. Du

The characteristics of tensile mechanical properties for 3D pierced fabric carbon/carbon composites were investigated by using the rapid resistive self-heating technique. The test results showed that the tensile properties at 1600°C ~3000°C were different from that at lower temperature. The fracture strength increased with the crement of test temperature up to 2400°C, and then droped with temperature, but the loss in strength to 3000°C was relatively small, and the higher the test temperature was, the more the failure strain increased. The fracture mechanism was analyzed by SEM fractography. The fracture surface of composites at high temperature was more smooth than that at low temperature.

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Physical Simulation of Hot Compression of Si-Mn Steel

by Z. Wang, S. Yu, G. Chui, and Y. Wang

The purpose of the present investigation is to simulate the hot compression process of Si-Mn steel. Single-stage and four-stage compression tests have been conducted. The compressions were carried out at temperatures of 1150, 1000, 900 and 800°C and at strain rates of 0.005, 0.01 and 0.2 s^{-1}. The maximum true strain for each stage compression was 0.6. The true stress-time strain curves show that the form of these curves varied with variation in the compression parameters. The peak strain (ε_p) was related to the compression temperatures (t) and the strain rates ($\dot{\varepsilon}$). When $\dot{\varepsilon}$ = 0.005 or 0.001 s^{-1}, $\varepsilon_p < 0.02$ and when $\dot{\varepsilon}$ = 0.2 s^{-1}, ε_p = 0.2–0.4. The peak stress (σ_M) also was influenced by the t and $\dot{\varepsilon}$. With increasing the Zener-Hollomon parameter (z), the peak stress increased. When $\varepsilon < \varepsilon_p$, the variation in the true stress of the test steel during single-stage compression was expressed by the relation $\sigma = A\varepsilon^n\dot{\varepsilon}^m e^{k/T}$. When four-stage compression was carried out, at the interrupted times (τ), the tested steel was softened. When t = 1150–1000°C, $\dot{\varepsilon}$ = 0.2 s^{-1} and τ = 4 s, the softening index was a maximum, and when t = 900–800°C, ε= 0.005 s^{-1} and τ = 2 s, it was a minimum. During four-stage compression, the true stresses of each stage were expressed by the relation $\sigma = A(\varepsilon + \Delta\varepsilon)^n\dot{\varepsilon}^m e^{k/T}$. The microstructures of the test steel varied relevantly during compression.

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A Study of Reheat Cracking in Low Alloy Steels and its Testing Method

by Z. Li, Z. Dai, L. Hu, and M. Xia

This paper investigates the constant-load heating-up rupture test for an unnotched specimen containing a simulated HAZ structure produced using the Gleeble. The reheat cracking susceptibility of three low alloy steels was evaluated by means of this test and a comparison between this method and the others was made. The relationship between the stress level and second-phase precipitation is also considered.

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Simulation of the Thermomechanical Treatment of High-Grade Pipeline Steels Using the Gleeble 1500

by B. Buchmayr, R. Kleemaier, M. Witwer, and H. Cerjak

Thermomechanical treatment (TMT) simulations using a Gleeble 1500 were performed on experimental steel grades similar to API X70 and X80 in order to optimize the processing route and chemical composition to attain high strength combined with high toughness and improved weldability. Austenitizing treatments, and single and multistage rolling simulations were made to characterize the flow stresses and the resulting microstructures during initial rolling. For reasons of comparison, some screening tests were conducted using a servohydraulic hot flat compression machine.

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Correlation Between Solidification Cycle Hot-Tension and Transvarestraint Tests

by Z. Sun and H.Y. Han

Solidification cracks can be a serious defect when welding many alloys. Various methods for the evaluation of the solidification crack susceptibility of weld metal have been developed, among which the Varestraint and the Transvarestraint tests are widely used. A simulation technique has been used to estimate the hot crack susceptibility of the heat-affected zone (HAZ) in many cases, but evaluation of the solidification crack susceptibility of weld metals has not been used as extensively as for the HAZ, due to difficulties in simulating the heating and cooling of weld metals. The evaluations of the solidification crack susceptibility of weld metals using an induction heating simulator have been reported by Sopher *et al* and Cordea *et al*. The object of this study was to use a resistance heating Gleeble-1500 simulator to examine the solidification cycle hot-tension test and its application in the evaluation of the solidification crack susceptibility of weld metals. The Transvarestraint test was employed to confirm the accuracy of the simulation results.

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Heat-Affected Zone Thermal Cycles in Inconel 718

by R.J. Bowers and E.F. Nippes

Computerized regression analysis assists in tabulating the thermal cycles for gas tungsten arc welding (GTAW) of 1-cm Inconel 718 plate. Thermal cycles adjacent to autogeneous welds in 1-cm (0.39 in) IN718 plate were obtained using a computer data-acquisition system. Data from gas tungsten arc welds (GTAW) of various energy inputs were regression analyzed and tabulated for various times and distances from the weld centerline. The observation of grain-boundary precipitates in simulated and actual weld microstructures was used as a method of thermal-cycle verification. Application of the thermal-cycle data to the simulation of a fracture-toughness specimen was investigated. Thermal gradients across the specimen and high cooling rates were limiting factors in the microstructural simulation of the large cross-sectional-area specimen.

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Gleeble Simulation of Stainless Steel Weld Metals

by Z. Sun and H.Y. Han

In this paper, simulations of both austenitic and austenitic-ferritic stainless steel weld metals using a Gleeble-1500 machine are reported. The investigation was intended to exploit the suitability of such a simulation for weld metals, and consequently its utilization in evaluating the tendency towards solidification cracking. For comparison, the Transvarestraint test was used to verify the reliability of the simulation test. The results show that the simulation test is reliable in terms of illustrating an element's effect on the hot ductility and identifying the influence of a particular low melting eutectic on the solidification crack susceptibility. The simulation test is advantageous in terms of saving testing materials and being easy in identifying specific low melting constitution from the samples. The simulation test is found to be an effective way in evaluating the solidification crack susceptibility.

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Investigations on the HAZ-Behavior of Fine-Grained Structural Steels and Heat Resistant Steels

by B. Buchmayr, M. Abdou, H. Cerjak, H.P. Fauland, and H. Kammerstetter

A Gleeble simulation technique was applied to study the metallurgical processes in the heat-affected zone during welding and their effects on the mechanical properties in the case of fine-grained structural steels and heat resistant CrMoV-steels. The influences of welding parameters and PWHT on the transformation, toughness and stress relief cracking behavior were considered. Finally, the microstructural changes in the HAZ were described using a metallurgical based model.

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The Effect of Welding Thermo-Straining on Reheat Cracking Susceptibility

by L. Hu, J. Liu, Z. Li, and Z. Zhang

In this study, two low-alloy steels, 12NiCrMoV and WT-62CF, were used for Gleeble testing. A short-time creep test was done to assess the reheat cracking tendency. In the test, different thermal strains were app;lied during the thermal simulation. The results show that, for the different test temperatures and creep stresses, the creep fracture time and ductility decrease with an increase in thermo-straining. From micro-observation, it has been found that the thermo-straining promoted precipitation of carbides which was the internal cause of rising reheat-creacking susceptibility. Furthermore, the paper also discusses the basis of applying stresses and the assessing criterion for the short-time creep test. It is considered that, comparing with fracture time, creep ductility can better represent reheat cracking susceptibility of materials.

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The Effect of Thermal Prestrain on the Fracture Toughness of HAZ of WT-62CF Low Alloy High Strength Steel

by J. Xiong, Q. Lan, and A. Wang

In this paper, the Gleeble 1500 was used to simulate the thermal cycle and thermal strain in two temperature ranges of the HAZ of WT-62CF steel. The effect of thermal prestrain on the fracture toughness of the simulated HAZ was studied. The cause of the variation in fracture toughness was analyzed and discussed with respect to metallurgical microstructure and characteristics.

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An Investigation on the Performance of HIP Test on Gleeble 1500

by H. Guo and J.-J. Chêne

HIP is a process heating and pressing a material with an aid of compressed gas and it is used in sintering of powder, defect healing of casting, and diffusion bonding, etc. The process allows to produce a material with isotropic properties which result from the even distribution of the alloying elements, freedom of porosity and fine structure. The isotropic properties lead the material to have the better performance than the conventional material of the same chemical compositions. HIP, however, is a very complicated process, and the cost of HIP is quite high. This is why the interest is developed to reproduce the HIP process of powder consolidation on Gleeble 1500. The aim of this work is to investigate the possibility of operating HIP process on Gleeble 1500. The special emphasis is placed on exploring the reproduction of the HIPing environment of homogeneous temperature and isostatic pressure on Gleeble machine. An attempt has been done to perform the powder consolidation by HIP on a Gleeble 1500 machine. Different size samples of sintered Fe-based Cr-Co powder have been made. The results of the experiment are discussed by examining the microstructure and measuring hardness of the sintered powder material.

The Gleeble at the University of Oulu, Finland

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- thermomechanical processing of the 17%Cr ferritic stainless steels
- hot forgability of maraging steels
- the effect of hot charging on hot ductility of microalloyed medium-carbon steels
- constitutive equations and softening in austenitic stainless steels
- hot ductility of duplex stainless steels
- effect of chemical composition and manufacturing route on impact toughness of HAZ in TMCP steels
- impact toughness of electrogas welded and simulated HAZ's of TMCP steels
- impact toughness in the HAZ of new 12%Cr-type ferritic stainless steels.

For example, we have been able to develop a high number of CCT diagrams for commercial HSLA steels as well as new experimental steels. These diagrams will be used for controlled manufacturing or for welding of these steels.

Precise data concerning temperatures and kinetics of austenite transformation and exothermic heat generation is also required in order to achieve uniform properties for high strength formable steel sheets. The thermal and mechanical capabilities of the Gleeble are very important for the simulation, which is presently needed to rebuild a new, more versatile accelerated cooling system for the sheet rolling line.

For the 17%Cr ferritic stainless steels, a new thermomechanical rolling schedule has been developed on the basis of Gleeble simulations, in which more homogeneous austenite distribution could be achieved, which, in turn, results in more uniform distribution of martensite and carbides after cooling so that the microstructure of the sheet is suitable to be annealed in a continuous annealing line.

Recently, generation of data (the constitutive equations) required for FEM calculations of residual stresses in rolling, originating from nonhomogeneous temperature distribution, aimed to improve flatness control of plates has started in a joint project. Even more data for modelling will be needed in the European Concerted Action on modelling in materials science and processing materials (COST 512) in which the integrated simulation of multipass hot rolling will be investigated by Swedish, Italian, Spanish, Norwegian and Finnish researchers.

The applicability of the Gleeble for solving different tasks in hot rolling have been assessed. Comparison of Gleeble results with hot torsion (tests at McGill University) and plane strain compression (tests at the University of Sheffield) have been carried out. The tests have shown, for instance, that the "no-recrystallization temperature" can be determined by multiple compression, although torsion testing is more convenient. Recently, a lot of attention has been paid to use the Gleeble to monitor the kinetics of softening and precipitation in hot-deformed austenite. A new, simple technique, the stress relaxation, has been found to be very effective for these purposes.

As shown in the figure, softening is revealed by a rapid stress relaxation stage in the stress vs log time curves after predeformation, and the effects of temperature, strain, strain rate and chemical composition can be effectively studied. The onset of precipitation causes a termination of stress relaxation so that a stress plateau will appear as seen in the figure. The Gleeble has proved to be suitable for the relaxation tests, although the longitudinal temperature gradient in specimens is a drawback. Thus the Gleeble and the stress relaxation technique form a very efficient tool for investigating these phenomena during hot working.

We are also interested in high energy welding methods, such as electro gas welding, at the Finnish shipyards. For a sufficient impact toughness and to prevent an excess softening in the HAZ of the weldments, the chemical composition of the base metal must be carefully tailored. The Gleeble is a very effective tool to simulate the coarse grained HAZ so that the properties can be tested more reliably than in the real welds. The Gleeble is also used constantly by students in their welding metallurgy exercise works, in which they first time become familiar with numerous, unique properties of this machine.

Based on our first three years experience, I believe we will use the Gleeble even more in the future to simulate hot-working and welding of steels.

—Pentti Karjalainen

Softening revealed by the stress relaxation on the Gleeble.

Precipitation revealed by a plateau in stress relaxation curve.

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Welding of Martensitic to Austenitic Stainless Steels

by H.Y. Han and Z. Sun

Studies have been carried out to examine the weldability of dissimilar steel joints between martensitic and austenitic stainless steels—F6NM (0CrI3Ni4Mo) and AISI 347, respectively. Weld simulation of the martensitic steel was performed to investigate the influence of weld thermal cycles and post-weld heat treatment (PWHT) on the microstructure and mechanical properties of the heat-affected zone (HAZ) using a Gleeble-1500 thermal simulator. The implant method was used to examine the tendency for cold cracking of martensitic steel. Hot crack susceptibility of the multi-pass dissimilar steel joints was examined using a rigid restraint test. The simulation results indicated that the toughness of the HAZ did not change significantly after the weld thermal cycles. PWHT improved the toughness. The implant test results showed that welds made with nickel-based filler have no tendency for cold cracking, whereas welds made with martensitic or ferritic filler show such a tendency. A welding procedure was developed for producing welds which are not susceptible to hot cracking, according to the rigid restraint test results. Joints made with the proposed welding procedure exhibit satisfactory properties.

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Hot Ductility of Simulated Stainless-Steel Weld Metals

by Z. Sun and H.Y. Han

Simulation of stainless-steel weld metals was performed using a Gleeble-1500 thermomechanical simulator. Two classes of materials were investigated, including both fully austenitic and austenitic-ferritic stainless steels. The niobium content varied within each class. The simulation comprised heating to melting point, melting for a short time, and cooling to a number of temperatures, at which point the samples were fractured under a tensile load. The hot ductility, in terms of reduction of area, was measured. Metallographic examinations were performed using both optical and electron microscopy. The hot ductilities of the austenitic-ferritic weld metals investigated were superior to those of fully austenitic weld metals of corresponding niobium content. The beneficial effects of ferrite were found to decrease with increasing niobium content. The effect of niobium on hot ductility was detrimental, i.e., an increase in niobium content resulted in a decrease in hot ductility which was attributed to the formation of $(FeCrNi)_2Nb$-y, a low melting eutectic, along the austenitic grain boundaries. The criterion of hot ductility by simulation of the weld metals was also found to be reliable for evaluating susceptibility to solidification cracking.

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