MECHANIKA
TEORETYCZNA
I STOSOWANA
2/3, 21 (1983)

ENGINEERING APPLICATIONS OF PLANE AND GENERALIZED ISODYNE PHOTOELASTICITY

JERZY T. PINDERA,

Department of Civil Engineering
University of Waterloo
Waterloo, Ontario, Canada N2L 3G1

BOGDAN R. KRASNOWSKI

Department of Civil Engineering
University of Waterloo
and
Institute of Aircraft Technology and Applied Mechanics
Warsaw Technical University, Warsaw, Poland

Summary

Basic Concepts of Isodyne Photoelasticity

A new family of characteristic lines of plane stress fields has been introduced on the basis of Airy Stress Function and denoted as "Elastic Isodynes".

Isodynes are loci of points related to first derivatives of Airy Stress Function at which the total normal forces, acting on the corresponding sections, are constant. Being a derivative of a two-variable function, each isodyne field is related to a concrete direction called the "Characteristic Direction".

Isodynes directly yield values of the normal and shear stress components in chosen directions; — no additional relationships are needed. Basic analytical relations and characteristic features of the isodyne field are given in [3].

By using a measurement system called Isodyne Polariscope[1], the theory of which is presented in several papers [1-4], it is possible to obtain fields of photoelastic isodynes directly related to the elastic isodynes. The photoelastic isodynes can only be obtained when the consequences following from the Rayleigh Model of Scattering are strictly observed and the corresponding transfer function is optimized: — e.g., the observation angles must be close to 90°, the azimuthal angles must be close to 0° or 180°, and the optical paths must be the same for all scattering points.

For three-dimensional stress states, the photoelastic isodynes are related to so-called generalized elastic isodynes. Such states occur in contact and stress concentration problems

[1] Patent pending.

when the plane equilibrium equations are not valid — in such cases the isodyne photoelasticity yields data on the third normal stress components.

The overall transfer function of the isodyne polariscope has been designed to satisfy requirements following from the theory of the elastic and photoelastic isodynes, including the generalized isodynes. This function has been taken as the major component of the physical and mathematical models of the isodyne polariscope. When the design conditions are satisfied, the isodyne polariscope can be treated as a zero-order, time-invariant instrument.

Applications

Within the framework of the theoretical conditions and constraints the isodyne polariscope can be readily and inexpensively applied to determine and/or analyze various classes of important engineering problems. Some typical engineering applications are:

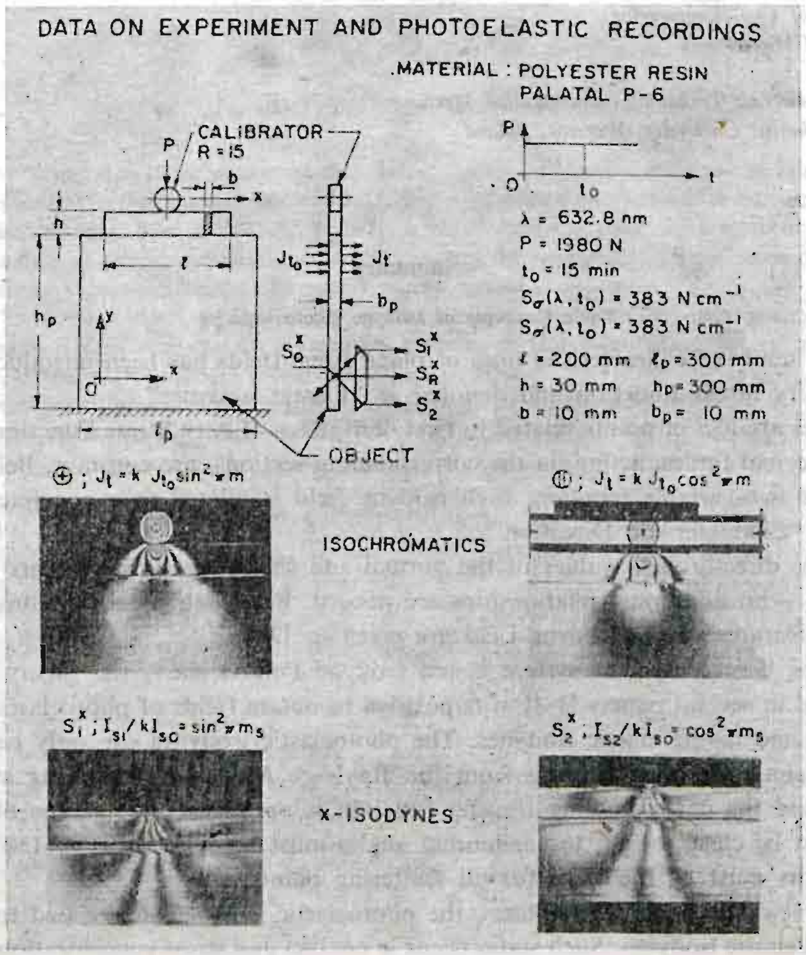

Fig. 1a A sample of analysis of a contact problem: a beam on a square plate. Set of complementary photoelastic data: transmission isochromatics and two complementary families of isodynes.

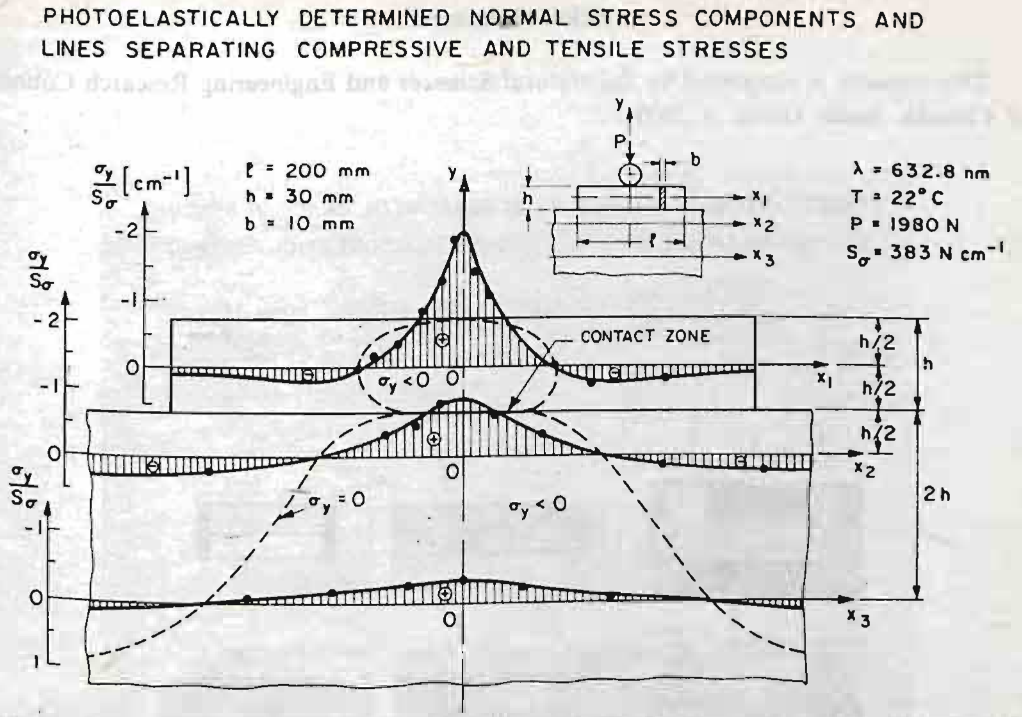

Fig. 1b A beam on a square plate. Evaluated relations: distribution of normal stress components along the beam axis and in two parallel cross-sections of plate; geometric loci of points in beam and plate where the normal stress component is equal to zero.

— verification of applicability of particular solutions of the theory of elasticity: analytical, numerical and hybrid evaluations;
— stress states in plane and three-dimensional contact problems;
— crack tip mechanics problems: fracture criteria including discussion of the concept of stress intensity factor;
— three-dimensional stress states in components of composite structures, including structures with internal cracks;
— thermal stresses: transient and stationary.

Examples of applications are given in Figures 1 - 6.

Conclusions

It has been demonstrated that the Isodyne Photoelasticity opens new horizons in experimental stress analysis, inaccessible to methods of classical transmission photoelasticity. However, because of the high sensitivity and resolution of isodyne photoelasticity methods, it is necessary to develop and apply stronger theoretical foundations of the interaction between the actual state of deformation and propagation of radiation; e.g., it is necessary to check in every concrete case of stress analysis whether the relations of plane elasticity are applicable.

Acknowledgement

This research is supported by the Natural Sciences and Engineering Research Council of Canada, under Grant A 2939.

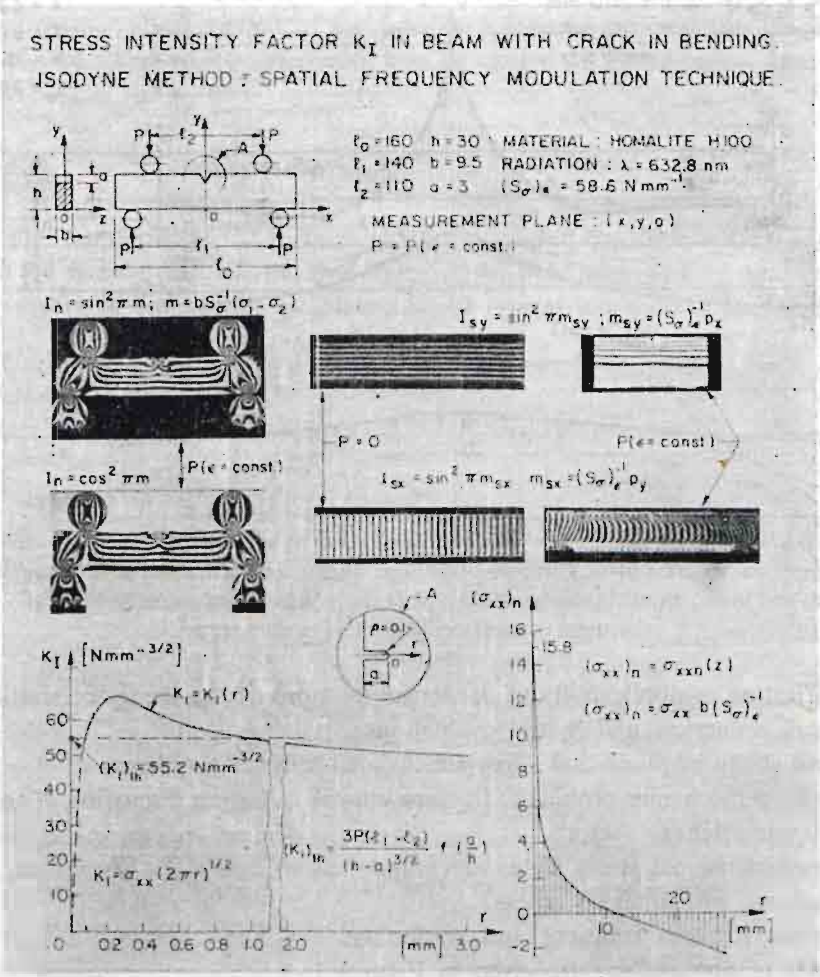

Fig. 2 Determination of stress intensity factor K_1 in a beam with a crack, in bending, using the isodyne frequency modulation technique.

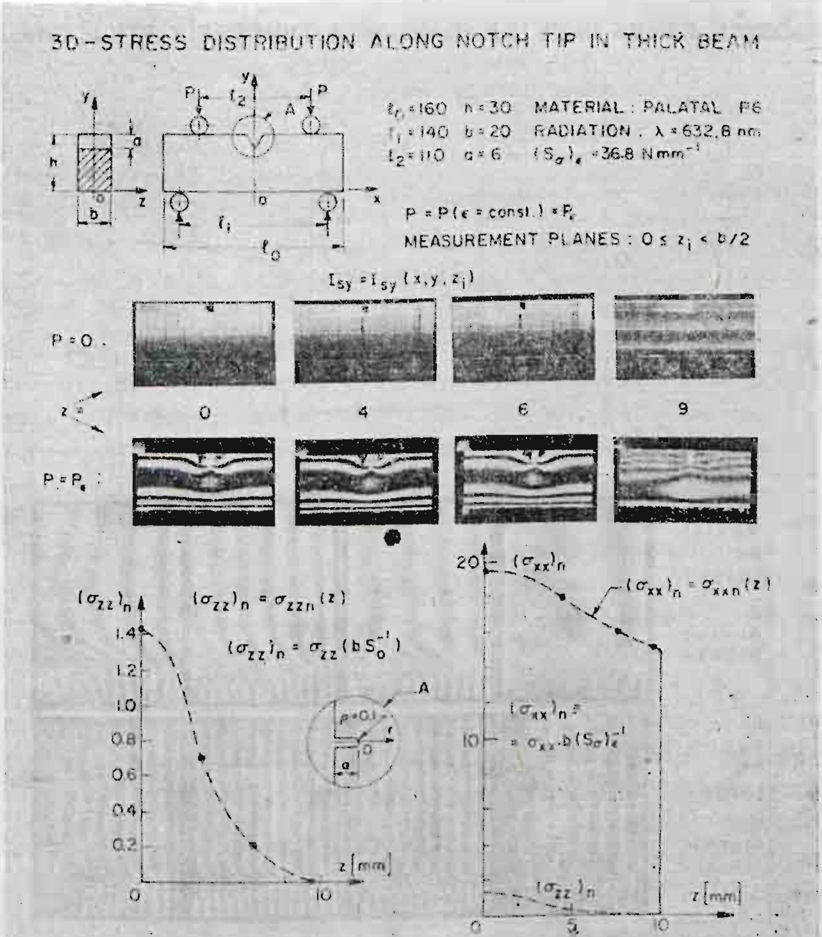

Fig. 3 Stress distribution at the notch tip in a beam in pure bending, along the beam thickness.

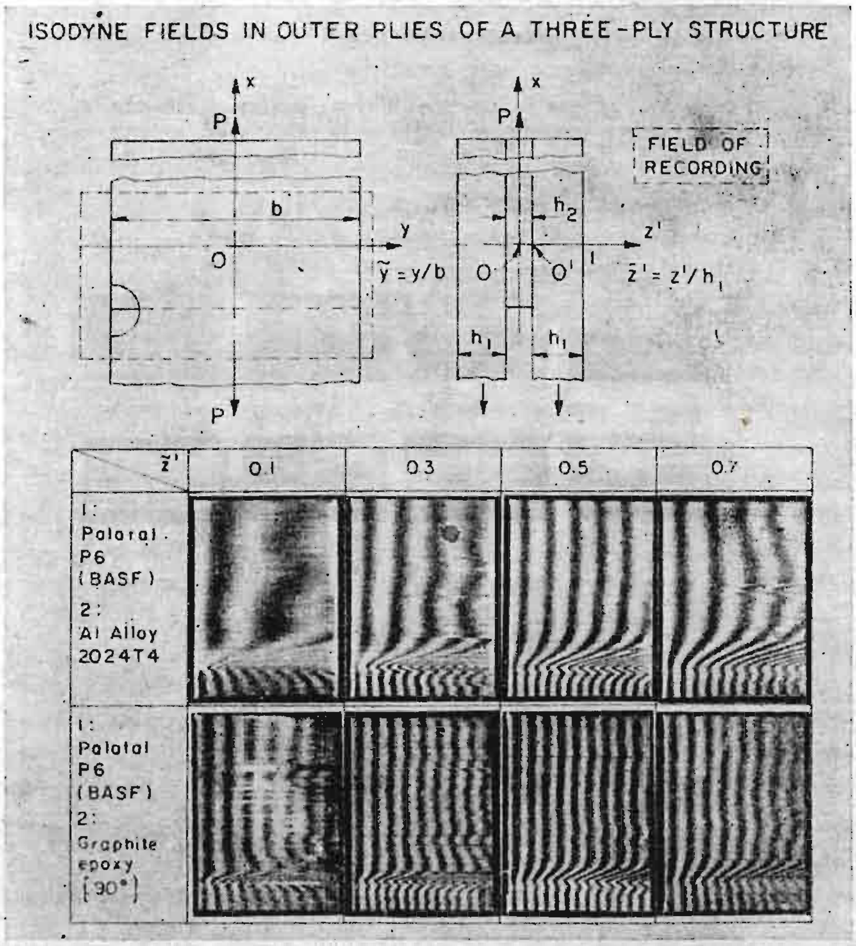

Fig. 4a Determination of interlaminar stresses in a composite structure: Isodyne fields in outer plies of a three-ply structure, at various distances from the interface.

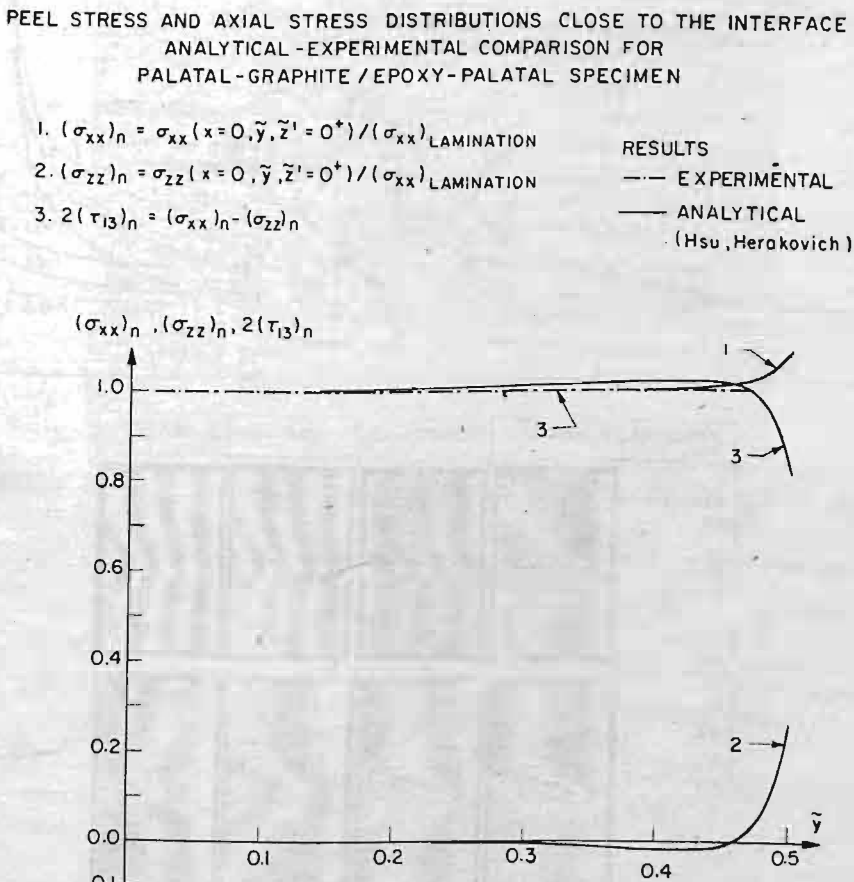

Fig. 4b Comparison of experimental and analytical results for stress distribution close to the interface.

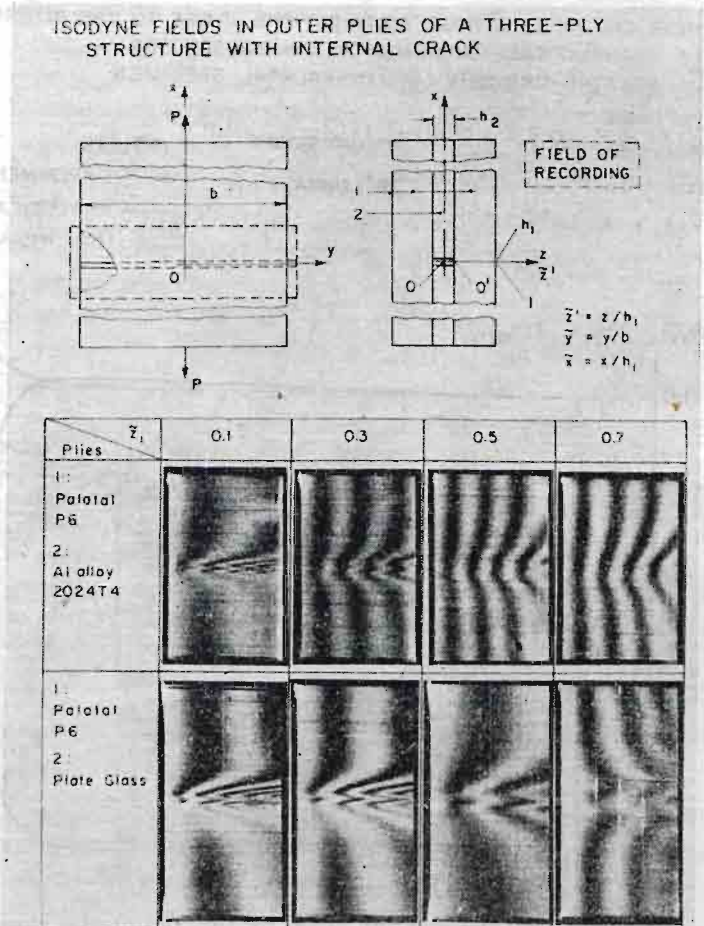

Fig. 5a Determination of stress distribution in a three-ply composite structure with internal crack. Scheme of a system and isodyne fields.

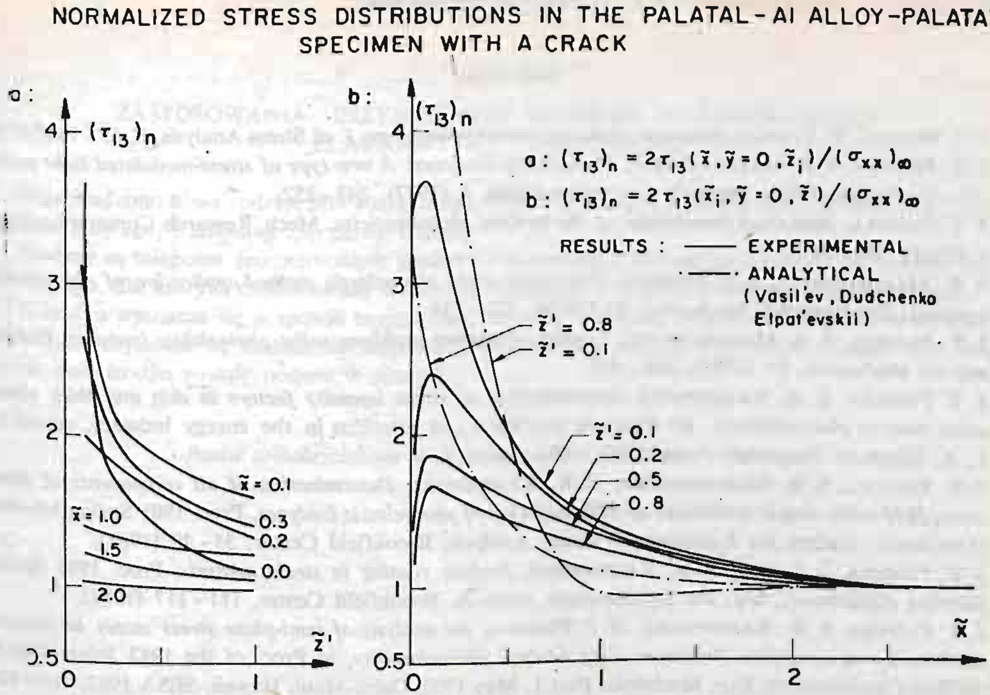

Fig. 5b Comparison of experimental and analytical results.

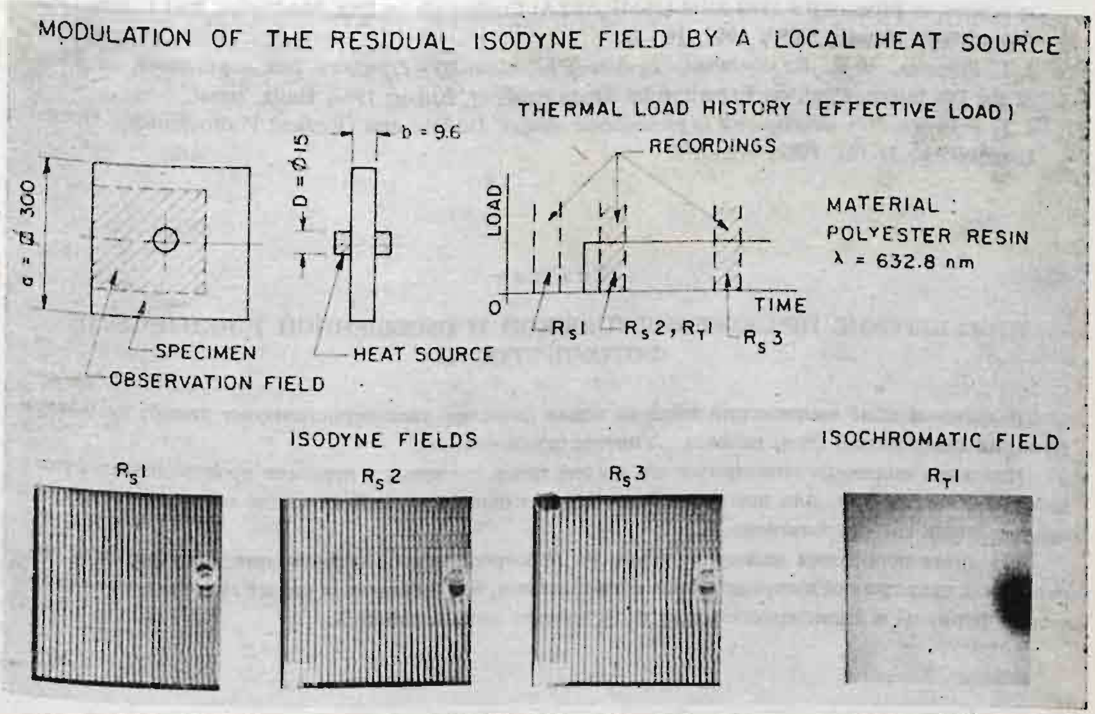

Fig. 6 Sample of application of isodyne photoelasticity to determination of components of thermally induced stresses, using the isodyne spatial frequency modulation technique.

References

1. J. T. PINDERA, P. STRAKA, *Response of the integrated polariscope*, J. of Stress Analysis, 8, 65 - 76 (1973).
2. J. T. PINDERA, S. B. MAZURKIEWICZ, *Photoelastic Isodynes: A new type of stress-modulated light intensity distribution*, Mech. Resarch Communications, 4 (1977), 247 - 252.
3. J. T. PINDERA, *Analytical foundations of the isodyne photoleasticity*, Mech. Research Communications, 8 (1981), 391 - 397.
4. S. B. MAZURKIEWICZ, J. T. PINDERA, *Integrated plane photoelastic method-application of photoelastic isodynes*, Experimental Mechanics, 19 (1979), 225 - 234.
5. J. T. PINDERA, S. B. MAZURKIEWICZ, *Studies of contact problems using photoelastic isodynes*, Experimental Mechanics, 21 (1981), 448 - 455.
6. J. T. PINDERA, B. R. KRASNOWSKI, *Determination of stress intensity factors in thin and thick plates using isodyne photoelasticity, in*: Fracture problems and solutions in the energy industry, edited by L. A. Simpson, Pergamon Press, 1982, 147 - 156.
7. J. T. PINDERA, S. B. MAZURKIEWICZ, B. R. KRASNOWSKI, *Determination of all components of plane stress field using simple techniques of differentiation of photoelastic isodynes*, Proc. 1981 Spring Meeting (Dearborn), Society for Experimental Stress Analysis, Brookfield Center, 35 - 40 (1981).
8. J. T. PINDERA, S. S. ISSA, B. R. KRASNOWSKI, *Isodyne coating in strain analysis*, Proc. 1981 Spring Meeting (Dearborn), Soc. for Experimental Analysis, Brookfield Center, 111 - 117 (1981).
9. J. T. PINDERA, B. R. KRASNOWSKI, M. J. PINDERA, *An analysis of semi-plane stress states in fracture mechanics and composite structures using isodyne photoelasticity*, in Proc. of the 1982 Joint (JSME/ /SESA) Conference on Exp. Mechanics Part 1, May 1982, Oahu-Maui, Hawaii, SESA 1982, 417 - 421.
10. J. T. PINDERA, B. R. KRASNOWSKI, M.-J. PINDERA, *Determination of interface stresses in composite structures*, in Proc. of the 1982 Joint (JSME/SESA) Conference on Exp. Mechanics, Part 1, May 1982, Oahu-Maui, Hawaii, SESA 1982, 18 - 22,
11. J. T. PINDERA, B. R. KRASNOWSKI, *Isodyne Photoelasticity - Principles and applications*, in Proc. of the 7th Intern. Conf. on Experimental Stress Analysis, August 1982, Haifa, Israel,
12. J. T. PINDERA, *New development in photoelastic studies*: Isodyne and Gradient Photoelasticity, Optical Engineering, 21 (4), 1982, 672 - 678.

Резюме

ИНЖЕНЕРСКИЕ ПРИЛОЖЕНИЯ ПЛОСКОЙ И ОБОБЩЕННОЙ ИЗОДЫНОВОЙ ФОТОУПРУГОСТИ

В плоском поле напряжений введена новая фамилия характеристических линий, на основе функции напряжений Эри, названа „Упругие изодыны".

Изодыны являются геометрическим местом точок связаных с первыми производными функции напряжений Эри, для которых общие нормальные силы, действующие в определенных сечениях являются постоянными.

Изодины позволяют непосредственно на непосредственное определение нормальных и касательных напряжений в определенных направлениях, без добавочных связей. Основные аналитические формулы и характеристические поля изодын даны в работе 3.

Streszczenie

ZASTOSOWANIA INŻYNIERSKIE PŁASKIEJ I UOGÓLNIONEJ ELASTOOPTYKI IZODYNOWEJ

Wprowadzono nową rodzinę linii charakterystycznych w płaskim polu naprężeń, w oparciu o funkcję naprężeń Airy'ego, i nazwaną ,,sprężyste izodyny".

Izodyny są miejscem geometrycznym punktów związanych z pierwszymi pochodnymi funkcji naprężeń Airy'ego, dla których całkowite siły normalne, działające w odpowiednich przekrojach są stałe.

Z izodyn wyznacza się w sposób bezpośredni normalne i styczne składowe naprężenia w wybranych kierunkach, zbyteczne są dodatkowe zależności. Podstawowe związki analityczne i cechy charakterystyczne pola izodyn zostały podane w pracy [3].

Praca została złożona w Redakcji dnia 15 kwietnia 1983 roku
