

# Physical Appearance Evaluation of Automotive Seat Structure with J-SEATdesigner

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## 1 Introduction

Seat styling is one of the important factors for automotive interior design. Automotive OEM company specifies 3D design to the seat supplier or their seat design section and the seat supplier designs 2d pattern to achieve desired 3D design as possible. design of the pattern from 3D seat design requires a lot of experience, in many company, limited number of specialist can design the pattern based on their experience. These companies strongly desire the simulation system to design the pattern from 3D seat design.

We had released J-SEATdesigner v2.0, in last June, which has basic features to set up seat manufacturing process like sewing/hooking/covering with LS-DYNA. v2.0 provides residual stress evaluation on seat fabric from sewing process simulation in LS-DYNA but the process simulation is not enough to evaluate physical appearance because of simplification of fabric 2d pattern. To evaluate physical appearance in LS-DYNA, the feature of J-SEATdesigner has been improved based on collaboration work with Japanese seat supplier.

In this paper, new features for advanced sewing set-up in J-SEATdesigner will be introduced and new quantitative evaluation of wrinkle on manufactured seat surface will be shown. As I mentioned above, manufactured seat surface is one of the important factors for interior design, this means that it is important how the user feel the wrinkle on seat surface. This feeling is highly depending on fabric texture and color which cannot be considered in manufacturing process simulation. To resolve this issue, the sensory evaluation based on computer graphics technology is implemented in J-SEATdesigner. This sensory evaluation will also be introduced.

## 2 Introduction of J-SEATdesigner

### 2.1 System concept

The main objective of J-SEATdesigner is to provide high accuracy results of seat related simulations for all engineers without special effort and knowledge. This means that the engineer who has no information about crash regulations can run sled simulation and have high accuracy results for JNCAP, Euro-NCAP, US-NCAP, etc. To achieve this objective we need a framework that can cover following requirements:

- Easy setting and user-friendly GUI
- Management system for models
- Include information for seat design related regulation and assessment
- Easy to improve models for high accuracy results
- ID free system

Primer, developed by Arup, is one of most powerful pre-processors for LS-DYNA. Primer has several features for automotive application like dummy/seat positioning, seatbelt fitting and seat foam deformation with and without using simulation. However operation of these special features is not easy for the entry-level user because of the need to understand these features and set several parameters to get proper results. To efficiently use these features the user requires a new graphical interface as few input parameters as possible. We developed J-SEATdesigner as a seat design system in Primer to meet this requirement.

J-SEATdesigner consists of four systems as below:

- Graphical user interface
- Database management system for models and related information
- Automatic assembly system
- Seat modelling system

In the current version (ver. 2.0) we focused on making the framework for an automatic sled model assembling system and first features for the seat modelling. In the next section several useful features in ver2.0 are introduced.

## 2.2 Main features in automatic assembly system

### 2.2.1 5 steps setup for setup for automatic assembling

J-SEATdesigner provide special gui to setup sled model for LS-DYNA. The database in J-SEATdesigner has information which is dummy type, boundary condition and control/output setting, according to basic crash assesment and regulation. Only 5 steps setup showw in Fig.1 is required to create input deck for sled analysis.The steps are:

1. Select regulation/assessment & test condition registered in DB.
2. Read seat & vehicle models from DB.
3. Define node pairs for connection between models.
4. Select contact pairs which user wants to create.
5. Set flags for positioning, seating and seatbelt refitting



Fig.1: 5 steps setup for sled analysis

### 2.2.2 Automatic dummy and seat positioning

To perform dummy and seat positioning, the user only has to activate flag for positioning and input seat back angle and seat cushion position for the seat, and torso angle for the dummy. Based on the information in the database, J-SEATdesigner automatically identifies where positions of hands, heels and toes should be in the assembled model. Fig.2 shows example of positioning with same dummy and different vehicle body (BIW) model. As shown in Fig.2, the dummy's feet are on the pedals in both cases, however the dummy's hands are located on the steering wheel in Fig.2.a and kept at the initial position in Fig.2.b. This is because the BIW model in Fig.2.a has target points on steering wheel for hands but the BIW in Fig.2.b has no target points for hands. If the refitting button is activated, after dummy and seat positioning the seatbelt is refit to the new position. Fig.3 shows several refitting results. Fig.3.a shows seat belt refitting of a loose seat belt that occurred after seat positioning. Fig.3.b shows refitting in the case of a penetrating seat belt that occurred after dummy positioning.

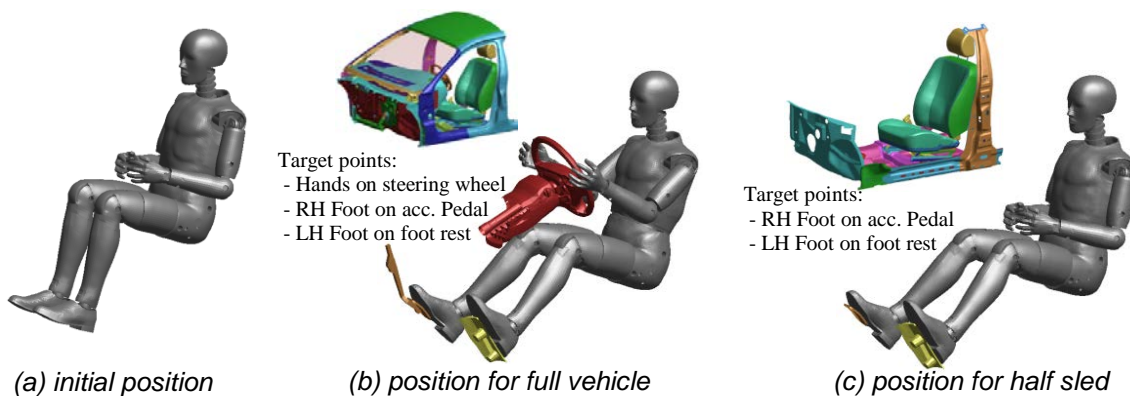


Fig.2: Dummy positioning with different BIW model

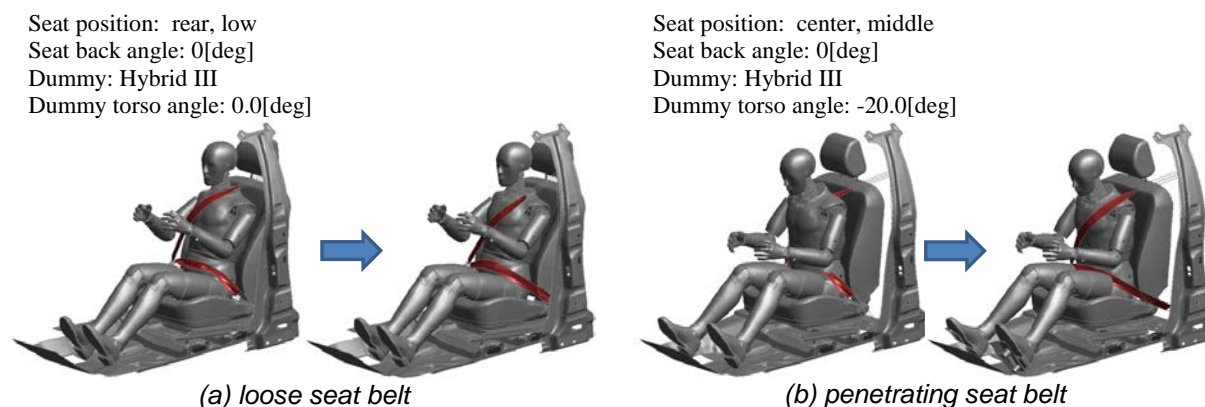


Fig.3: Seatbelt refitting results for different seat/dummy position

### 2.2.3 Importing seating simulation results

J-SEATdesigner provides two types of seating simulation method. The first we call a kinematic based method. "Kinematic" means to calculate the deformed geometry of seat foam without stress calculation. In this method, coordinates of internal nodes of seat foam are interpolated from surface nodes positions which are prescribed by contact between dummy surface and seat foam. Thus some internal node coordinates may not be realistic. The second is an LS-DYNA based method. Here the deformed geometry is the result of a seating simulation with LS-DYNA and material properties in seat model are fully considered. J-SEATdesigner can create input deck for seating simulation with rigidified dummy model. After the seating simulation the deformed geometry is registered in the database and can be imported during the automatic assembly process. Thus the user does not re-execute the seating simulation if it has already been done before. J-SEATdesigner uses **\*INITIAL\_FOAM\_REFERENCE\_GEOMETRY** to set initial stresses of seat foam in the sled simulation. Some examples of imported seat deformation are shown in Fig.4. In these examples the seating simulations have been done in advance so user can select either seat deformation without any calculation.

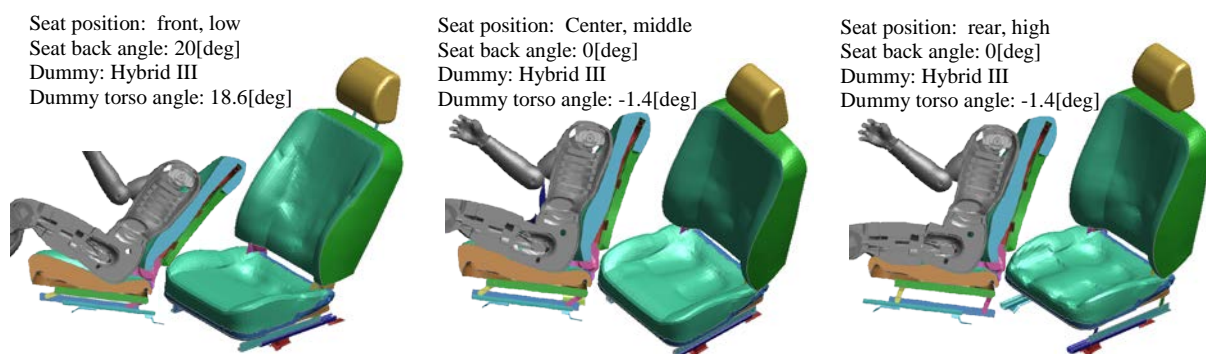


Fig.4: Imported seat foam geometries for several seat/dummy positions

## 2.3 Fabric material parameter identification

Several types of fabric and leather are used for seat cover. Typical fabric material has anisotropic and non-linear property under tensile loading and shear loading. Because of their woven architecture, some fabrics show over 0.5 in macroscopic Poisson's ratio. This means that it is not easy to measure fabric material properties. KES (Kawabata evaluation system) is testing system to measure the mechanical properties of fabrics. KES is composed of four different machines on which following six tests can be performed.

- Tensile and shear test (loading/ unloading)
- Pure bending test
- Compression test though the thickness

- Surface test (surface friction and roughness)

In addition to above, the bias extension test is commonly used to measure shear property of woven material and the self-cantilever test is also used for bending stiffness evaluation.

**MAT\_FABRIC** is used for fabric modeling in LS-DYNA. This material cannot be used to calculate bending stiffness because this material is implemented for membrane shell element, but recent extension of this material model (**FORM=-14**) can accept not only additional elastic modules as coating layer to calculate bending stiffness but nonlinear curve input for tensile loading, unloading and shear. To use this material model for seat covering simulation, we provide a tool to identify material parameters from some tests. Required tests to identify fabric material parameters are below:

- For tensile stiffness: Load and unload test in warp and weft direction
- For shear stiffness: Simple shear test or bias extension test
- For bending stiffness: Pure bending test or self-cantilever test

Fig.5 shows test results and material validation results for leather materials. For tensile and shear properties, Identified material model shows good agreement with test data. However, due to the elastic input for coating layer, this material model cannot represent anisotropic bending behaviour.

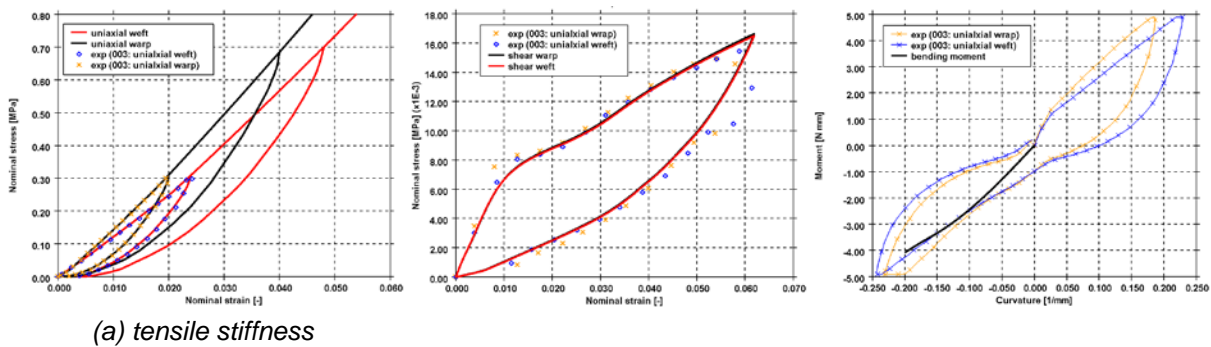


Fig.5: Validation of measured material (leather)

## 2.4 Simple sewing setup

To modeling sewing process, J-SEATdesigner provides features to manage sewing process and create discrete elements to connect node pair on fabric edge. Each discrete element has initial stress that makes its length zero during each process time and the initial stress has changed gradually to avoid instability in covering simulation. To create discrete elements to stitch sewing edge pairs, following 4 steps are required.

6. Pick start node on master sewing line
7. Pick end node on master sewing line
8. Pick start node on slave sewing line
9. Pick node that indicates sewing direction on slave sewing line

And then, J-SEATdesigner automatically find end node on slave sewing line and create discrete elements between nodes on master line and slave line (see Fig.6). In this setup, number of node on master line and slave line should be same. This limitation means user needs to change element size of fabric to change sewing pitch. Fig.7 shows process management panel and some snapshots corresponding to the process in this panel. In this panel, user can see time line of each process, change start/end time for each process and crate groups to manage multiple processes.

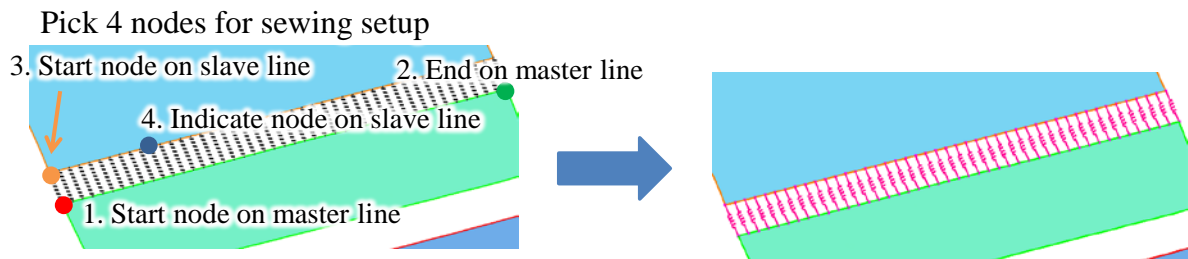


Fig.6: Operation to create discrete element to stitch sewing line pair.

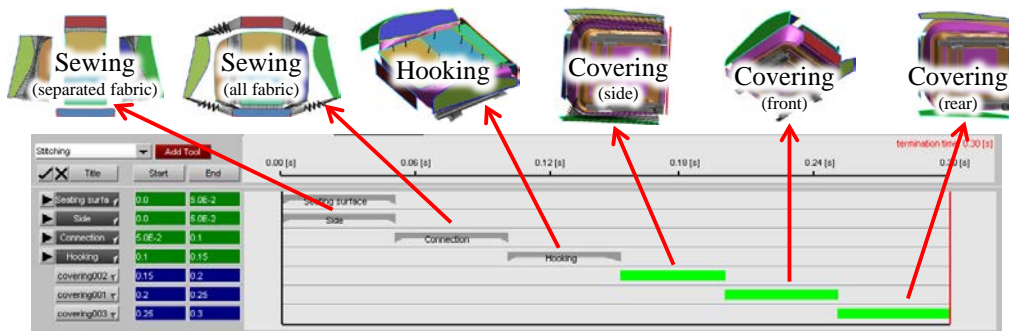


Fig.7: Sewing process management panel

### 3 Physical appearance evaluation

#### 3.1 Requirements for appearance evaluation

Manufactured seat surface is one of the important components of interior design. This means that it is important how the consumer feels appearance of manufactured seat structure. Most important defect of manufactured seat structure for interior design is wrinkle and distortion of texture pattern on fabric. These defects are caused by geometry of fabric 2d pattern, fabric material properties, manufacturing process and manufacturing irregularities. As shown in section 2.4, sewing setup feature (so call simple sewing setup) in previous version is one of good approached to consider residual stress coming from manufacturing process but is not enough to evaluate physical appearance. In simple sewing setup, we neglect effect of edge stiffness of bending hem, sewing pitch change and pulling certain sewing line to connect insert wire on seat foam.

#### 3.2 Enhancement of sewing process setup

##### 3.2.1 Sewing pitch change

Enhanced sewing process setup feature has been implemented in Latest J-SEATdesigner to evaluate physical appearance. Latest version supports independent sewing line from fabric mesh. In previous version, sewing lines should shares nodes with nodes on fabric edges. This limitation makes sewing pitch unchangeable with same fabric mesh size. Thanks to the independence of sewing line, sewing pitch change is easy applied even though fabric mesh size has not been changed. And discrete elements can be created properly between fabrics even mesh size of these fabrics is different.

##### 3.2.2 Hem consideration

Previous version uses outline of fabric as sewing line. This is easiest way to find sewing line from 2D fabric pattern but actual 2D pattern for seat surface is considering hem width. To support hem width in 2D fabric pattern, new feature to find sewing line from actual fabric outline has been implemented. Fig.8 shows how this feature works. Actual 2D pattern has some notches to align fabrics in sewing process. The notch whose size is smaller than setting value is neglected in this feature. To create discrete elements to stitch sewing line pairs, user selects sewing lines created by the new feature instead of nodes. Fig.9 shows deformation during sewing process. As you can see in Fig.9, J-SEATdesigner automatically find hem area and sewing line and then apply loading on nodes of the areas to bend hem inside. This loading makes sewing process stable in LS-DYNA.

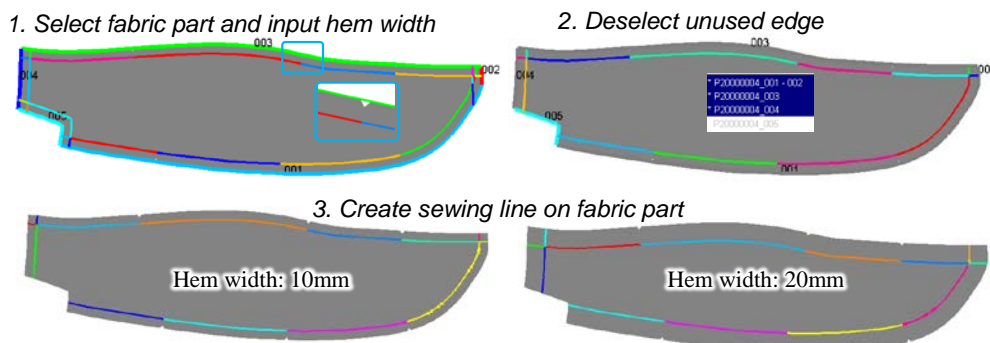


Fig.8: Create sewing line from actual fabric geometry

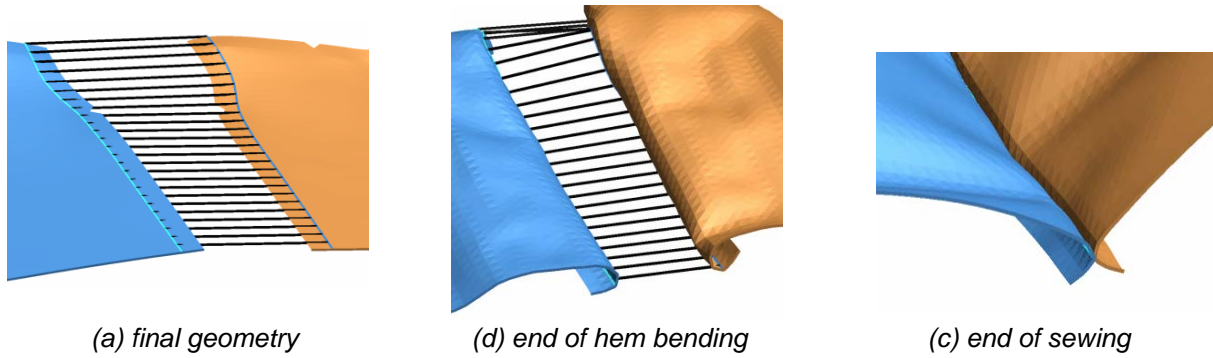


Fig.9: Sewing process with considering hem width

### 3.3 Approach for wrinkle detection

#### 3.3.1 Stress/strain based approach

Quantitative evaluation based on the simulation results is commonly used in metal forming. FLD and curvature is used for wrinkle evaluation in metal forming. In this paper, we use the curvature of each fabric element defined by

$$C = \left( \frac{\varepsilon_{top} - \varepsilon_{bottom}}{T} \right) \quad (1)$$

, where  $\varepsilon_{top}$  and  $\varepsilon_{bottom}$  is minor principal strain on top and bottom surface of each element and T is thickness of element. We have defined wrinkle index based on the curvature as below.

$$W_1 = \frac{C_{elem}}{C_{threshold}} \quad (2)$$

Where,  $C_{threshold}$  is maximum curvature on which user is focusing to evaluate the result. Another wrinkle index with negative value of first wrinkle index equation (2) is also defined by

$$W_2 = -\min[W_1, 0] \quad (3)$$

Fig.10 shows final deformation and contour of both wrinkle indexes in covering simulation. The contour of first wrinkle index ( $W_1$ ) based on positive and negative curvature indicates incorrect area as 1.0 because a seat original design has some convex area. On the other hand, second wrinkle index ( $W_2$ ) based on negative value of first wrinkle index indicates proper wrinkle area by removing convex area of original design.

Unlike metal forming, manufactured seat surface consists of several fabric parts. Thus, the wrinkle of seat surface is caused by not only balance of in-plane stress but difference of length between stitching lines. It is important to distinguish what causes the wrinkle to improve 2d pattern. To distinguish wrinkle caused by unbalance of in-plane stress, we have introduced in-plane stretch ratio defined by:

$$R_{stretch} = \begin{cases} 0, & \text{if } \varepsilon_{major} \leq 0 \\ 1 - \min \left[ \left| \frac{\varepsilon_{major}}{\varepsilon_{minor}} \right|, \left| \frac{\varepsilon_{minor}}{\varepsilon_{major}} \right| \right], & \text{if } \varepsilon_{major} > 0 \end{cases} \quad (4)$$

where,  $\varepsilon_{major}$  and  $\varepsilon_{minor}$  is major and minor principal strain at midplane surface. If the balance of in-plane stress is fine ( $\varepsilon_{major} \cong \varepsilon_{minor}$ ), this stretch ratio becomes 0.0 and the ratio closes to 1.0 in case of major principal strain is larger than minor principal strain (unbalance case). By multiplying this ratio and second wrinkle index ( $W_2$ ), the wrinkle index at stretch area can be defined as

$$W_{stretch} = W_2 R_{stretch} \quad (5)$$

and the index at compression area defined as below:

$$W_{compression} = W_2 (1 - R_{stretch}) \quad (6)$$

Distinguished distributions of second wrinkle index in Fig.10c are shown in Fig.11. These distributions indicate that critical wrinkle area cannot be removed by making length of sewing lines equal and modification of cushion foam geometry to improve balance of inplane stress is required.

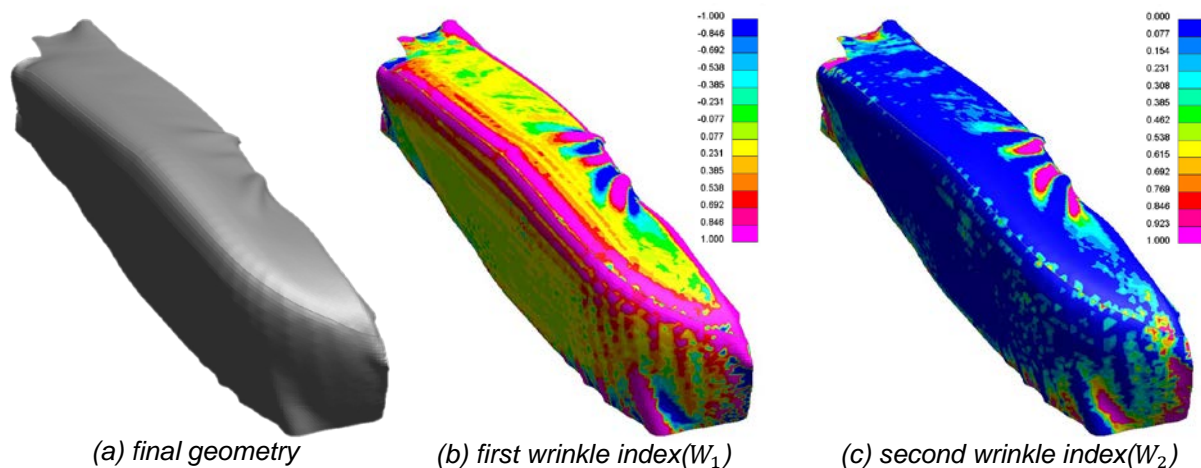


Fig.10: Deference between first and second wrinkle index

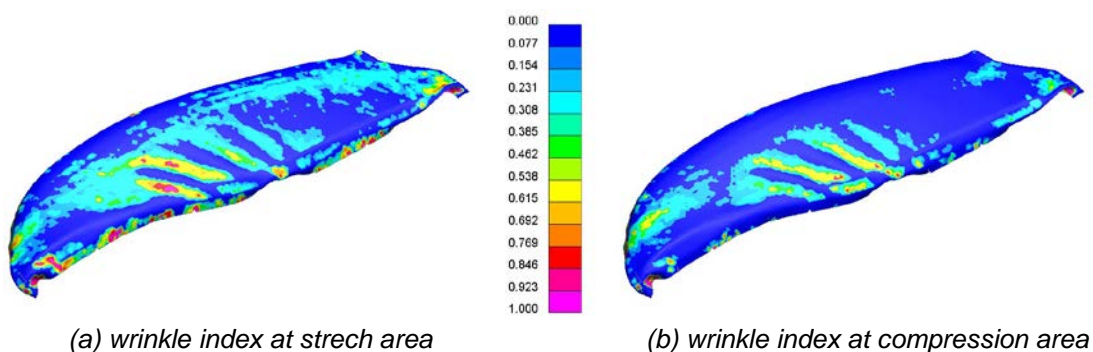


Fig.11: Second wrinkle index ( $W_2$ ) at stretch and compression area

### 3.3.2 Sensory based approach

The evaluation of human feeling for wrinkle is important for seat design. From covering simulation result in LS-DYNA, postprocessor (e.g. LS-PREPOST, Oasys D3plot and so on) shows the geometry and deformation during covering process in 3 dimensional space. However the feeling is highly depending on fabric texture and color which cannot be considered in sewing process simulation. To resolve this issue, the sensory evaluation based on computer graphics technology is implemented in J-SEATdesigner. Realistic graphics rendered by this feature helps users to evaluate feeling of seat design by in virtual environment.

General CAE postprocessors have been implemented based on flat shading and smooth shading. In these shadings, element color is calculated from base color, normal vector of element and lighting direction. These shadings are quite fast shading algorithm but the shading result is not realistic. User can change color of each materials and light direction but cannot change material texture to evaluate human feeling for seat fabric texture. Phong shading which is implemented in almost all computer graphics software provides more realistic result based on advanced reflection model. Phong shading reflection model consists from reflection of ambient light, diffuse reflection and specular reflection. Flexibility of this reflection model makes the shading result more realistic but improper parameters cause unrealistic result. Parameters of the reflection model should be adapted to describe real world texture based on computer graphics artists' knowledge. This means that it requires some know-how to determine the parameters of the reflection model and it is difficult for CAE engineer to use the model. Physically based rendering has been proposed to reduce requirement of CG artists' know-how by preserving energy conservation as below:

$$\text{Diffuse} + \text{Relreflection} + \text{Refraction} \leq \text{Incoming light} \quad (7)$$

Physically based rendering has three parameters to describe realistic results. These parameters are albedo, metalness and roughness. Albedo is base color from which light reflection has been removed. Metalness defines the material is like metal or not and the parameter is closed to 1.0, the material is becoming to metallic material. Roughness is parameter to control microgeometry of the surface. As this parameter becomes larger, the surface is rougher and the strength of diffuse reflection is stronger. Fig.12 shows effect of roughness and metalness on material texture under same light source condition. As shown in Fig.12, larger roughness makes high-lighted area wider. And the reflection power is concentrated to high-light area as metalness is close to 1.0. Some rendering results with different parameters are shown in Fig.13. These results are quite realistic even though these geometries are same and rendering parameters are three as mentioned in above.

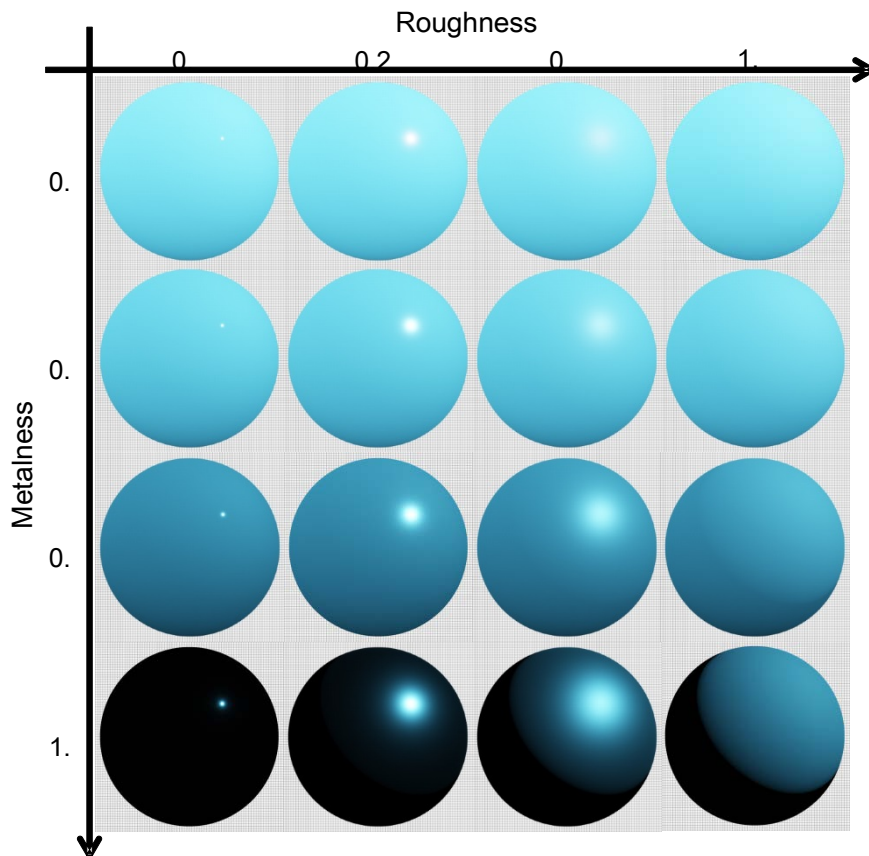


Fig.12: Effect of roughness and metalness on rendering result

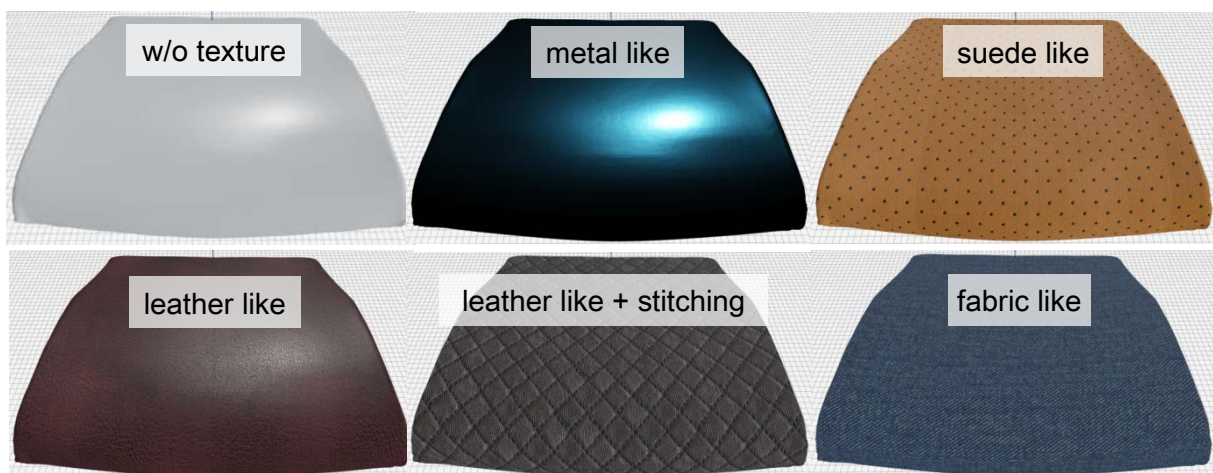


Fig.13: Rendering results of same geometry with several textures



#### 4 Case study

Sewing process simulation with / without hem width in 2d pattern has been done. Fig.14 shows 2d pattern and initial geometry for sewing simulation with hem. Blue line is outline of 2d pattern with hem width and red line is outline of 2d pattern without hem in Fig.14a. Process simulation results are shown in Fig.15. As shown in Fig.15, each process (sewing/ hooking/ covering) has been done with/ without hem. And some small difference between “with hem” and “without hem” can be observed at sewing lines because of stiffness of edge difference between “with hem” and “without hem”. Fig.16 shows wrinkle index distribution for “without hem (Fig.16a)” and “with hem (Fig.16b)”. It may be difficult to find some difference between “with hem” and “without hem” in Fig.15, but it is easy to find the difference of wrinkle index as you can see in Fig.16. Fig.16c shows distinguished distribution of wrinkle index at stretch and compression area. As you can see in Fig.16c, wrinkles are mainly caused by unbalance of in-plane stress and the improvement of hooking process is required to make balance of in-plane stress. Rendering results with geometry of “with hem” are shown in Fig.17 and zFig.18. The condition of lighting power (solar irradiance and bulb brightness) in Fig.17 is same but the positions of bulb light are different. As you can see in Fig.17, the light position is important to detect the wrinkle in rendering results. In Fig.18, there are three rendering results with "black leather like", "bright leather like" and "suede like" texture but with same light power and same light position. These results indicate that shiny darker material emphasize wrinkle and rough and bright material makes wrinkle unremarkable.

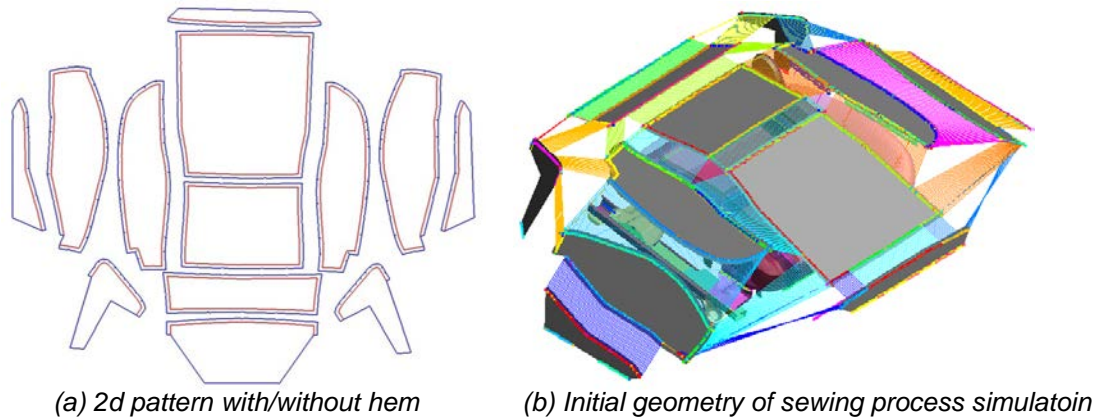


Fig.14: 2d pattern with/without hem and initial geometry for sewing process simulation.

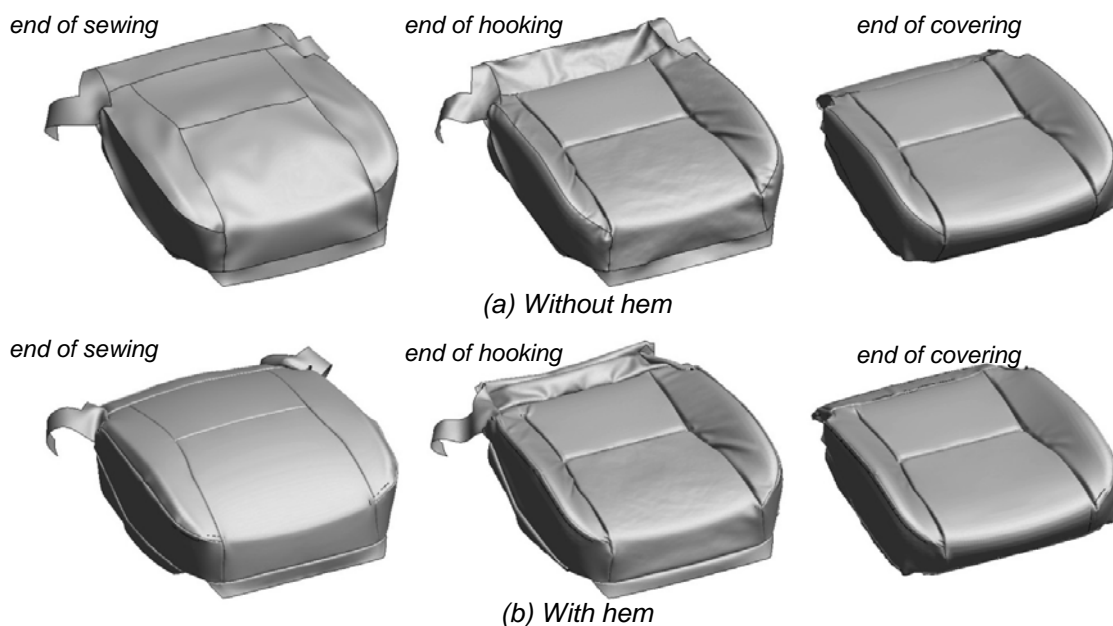


Fig.15: Sewing process simulation results

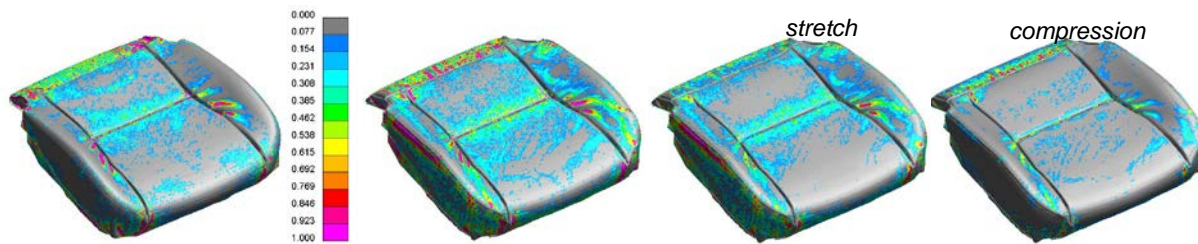


Fig.16: Counter of wrinkle index ( $W_2$ ).



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Fig.17: Rendering results under different light positions.

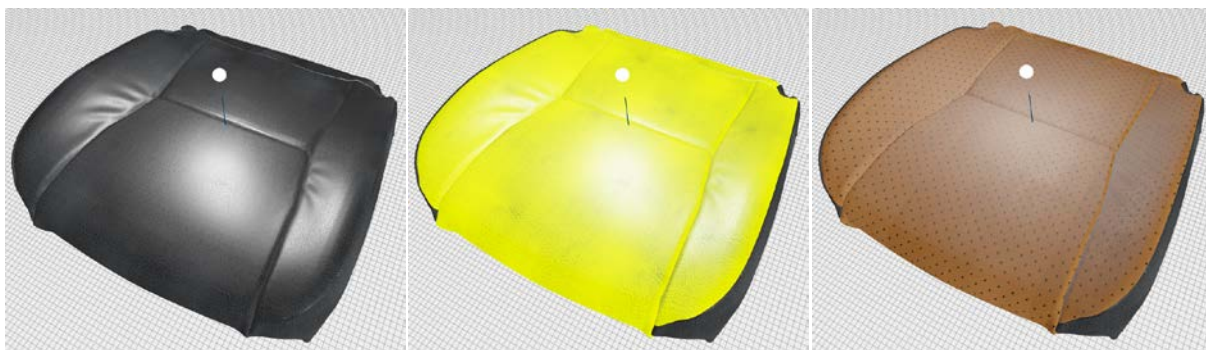


Fig.18: Rendering results with different textures.

## 5 Conclusion

New features for physical appearance evaluation have been implemented in J-SEATdesigner and stress/strain based approach and sensory based approach with physically based rendering has been shown in this paper. Wrinkle indexes proposed in this paper are useful to emphasize the wrinkle area and to identify what does cause the wrinkle. Physically based rendering brings more realistic graphics to the engineer who does not have expertise of computer graphics. These features can help the engineer to setup complex sewing process and evaluate wrinkles based on not only stress/strain state but human feelings. Update of the latest version is dedicated to evaluating wrinkles with considering textures of fabric material. We are developing more useful features which makes 2d pattern design easier. One feature is automatically improved 2d pattern to remove wrinkles.

By using J-SEATdesigner, all users can obtain our know-how for automotive crash simulation and sewing process simulation without any effort and spending time. We hope that J-SEATdesigner helps engineers who need seat related simulation to have useful simulation result in LS-DYNA.